BALANCESCAPES:
AN INVESIGATION INTO THE EFFECTIVENESS OF SITE-SCALE WATER HARVESTING IN ST. LOUIS, MISSOURI

by

WESLEY ADAM HAID

B.S., Missouri State University, 2007

A REPORT

submitted in partial fulfillment of the requirements for the degree

MASTER OF LANDSCAPE ARCHITECTURE

Department of Landscape Architecture and Regional & Community Planning
College of Architecture, Planning & Design

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Approved by:

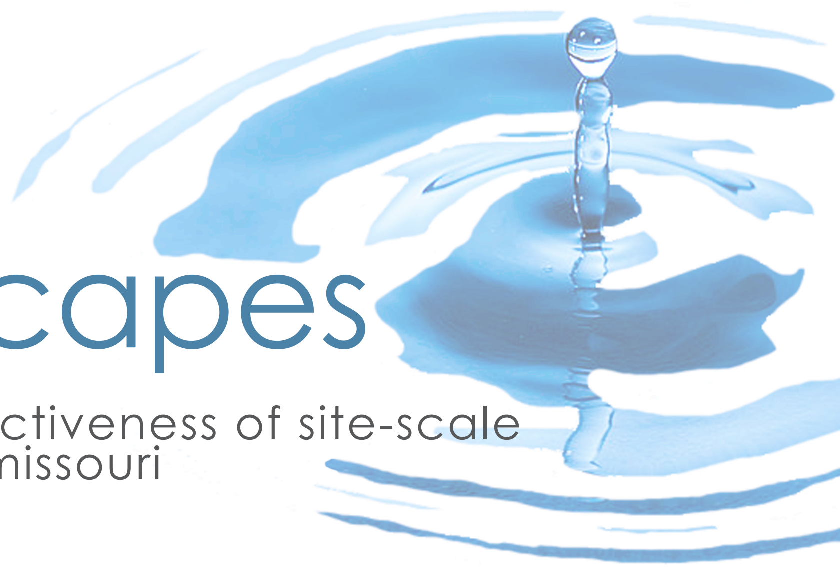
Major Professor
Howard Hahn

Abstract

Outdoor landscape irrigation is a prodigious consumer of potable water and accounts for more than 50% of urban water use in the United States. It is therefore imperative to reserve potable water for essential uses. The variability of recent drought trends coupled with the prediction of more intense, less frequent storms and rising water costs suggest the need to recycle as much free water as possible to meet non-essential irrigation demands. But is it possible to harvest enough water on-site to meet landscape water requirements with little to no reliance on municipal water? If not, how can design professionals adjust planting plans to bring the landscape water demand into equilibrium with potential supply while still meeting aesthetic objectives?

This report uses predictive performance-based modeling to answer these questions. The author chose three study sites in St. Louis, Missouri to determine if the water demand of the existing landscapes can be supplied by collecting enough rainfall runoff and air conditioning condensate. Site selection depended on site size, differing harshness of localized environmental conditions, and ability to collect and generate large quantities of runoff and condensate water. Methods included a literature review, site inventory/analyses, estimation of plant water requirements using evapotranspiration data, estimation of rainfall runoff from various surfaces, and estimation of air conditioning condensate using thermodynamic equations.

Findings show that landscape water needs for two of the three sites can be potentially met by on-site water sources with little to no reliance on municipal water. This was due to limited landscape areas compared to larger paved areas, the building footprint, and large quantities of air conditioning condensate produced during the hottest months. Under existing conditions, the third site was out of water balance. Consequently, the author undertook a planting re-design to convert low priority turf expanses to a naturalistic meadow requiring less water. Additionally, the author performed a return on investment analysis for both retrofit conditions and new construction. Overall, this research demonstrates that site-scale water harvesting for landscape irrigation purposes is a viable option to curtail reliance on municipal water supplies in the Midwest and similar climates.



balancescapes

an investigation into the effectiveness of site-scale water harvesting in st. louis, missouri

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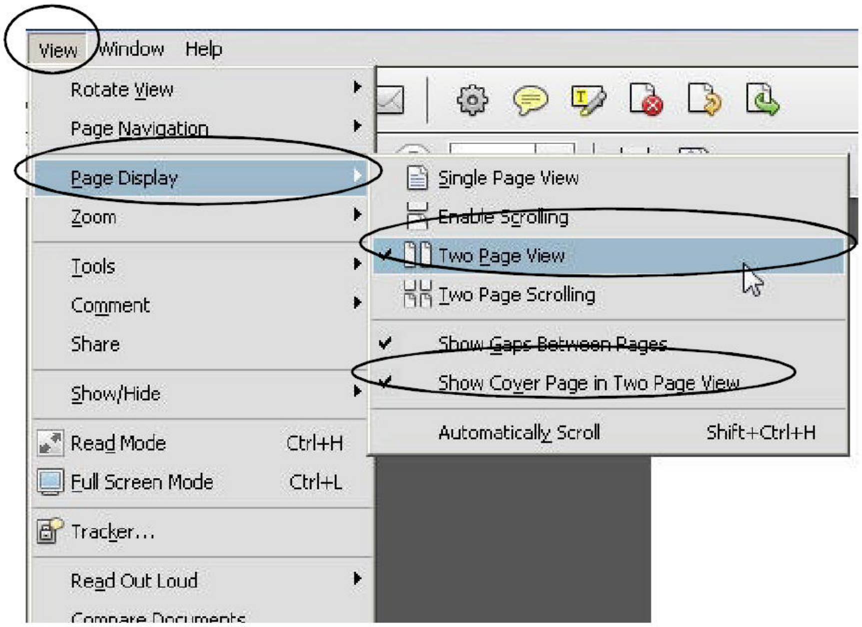

BalanceScapes:
An investigation into the Effectiveness of Site Scale Water Harvesting in St. Louis, Missouri

A report submitted in partial fulfillment of the requirements for the degree:
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Department of Landscape Architecture and Regional & Community Planning
College of Architecture, Planning & Design
Kansas State University

Master's Project Committee:
Howard Hahn, Associate Professor, Department of LARCP
Lee Skabelund, Associate Professor, Department of LARCP
Dr. Cathie Lavis, Associate Professor, Department of Horticulture, Forestry, & Recreation Resources

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Kansas State University

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Kansas State University

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chapter I:
introduction

I INTRODUCTION

Driving Forces and Dilemma

Water is our most essential resource. Without it, we cannot survive. Without it, our landscapes cannot survive. When our most essential resource has limited availability, we must limit our usage. Recent drought trends in the Midwestern United States show that no region is immune (Figures 1.1 - 1.3). The annual fluctuation of areas impacted by drought make it difficult to estimate when a region will need to limit its water consumption. The United States Environmental Protection Agency (EPA) predicts that future heavy rainfall events in the Midwest are likely to become more intense. Between heavy downpours, however, there will likely be longer periods without precipitation. Intense, infrequent storm events, coupled with predictions of increased evaporation during warmer summer months, will likely increase the amount of water shortages and probability of drought in the region (EPA 2013).

In times of severe drought, restrictions are put on non-essential water uses in an effort to minimize demand as the water supply decreases. Outdoor landscape irrigation is the most common non-essential use in the United States, making up more than an estimated 50% of urban potable water use (Bauer, Coopersmith, and Davis 2011). Potable water is typically used to meet these non-essential demands because it is readily available, despite the fact that non-potable harvested stormwater would suffice. When potable water is used in non-essential situations, chemicals, energy and money are effectively wasted in treating and distributing the water (Jones and Hunt 2010). Water restrictions do not impede plant materials within a landscape; their need for water exists no matter what the supply is. Reliance on potable water from a municipal source for irrigation in a time of drought not only substantially strains infrastructure, but also depletes the water supply available for other uses.

As drought occurrences are predicted to increase, so too has the cost of water throughout the country (Figure 1.4). Water rates in St. Louis rose approximately 68% from 2002-2012, a substantial increase that is dwarfed when compared to other regions of the country (McCoy 2012). The situations above suggest the need to collect runoff from intense rain events for non-essential landscape uses during sporadic periods without precipitation in order to reduce dependency on municipal potable water supplies. Harvesting and recycling this “free water” is a common, and recently mandated, practice in the Southern and Southwestern portions of the United States. However, minimal literature currently exists on the effectiveness of a comprehensive water harvesting and reuse system in the Midwest. A comprehensive water harvesting system consists of the capture and reuse of water from surface

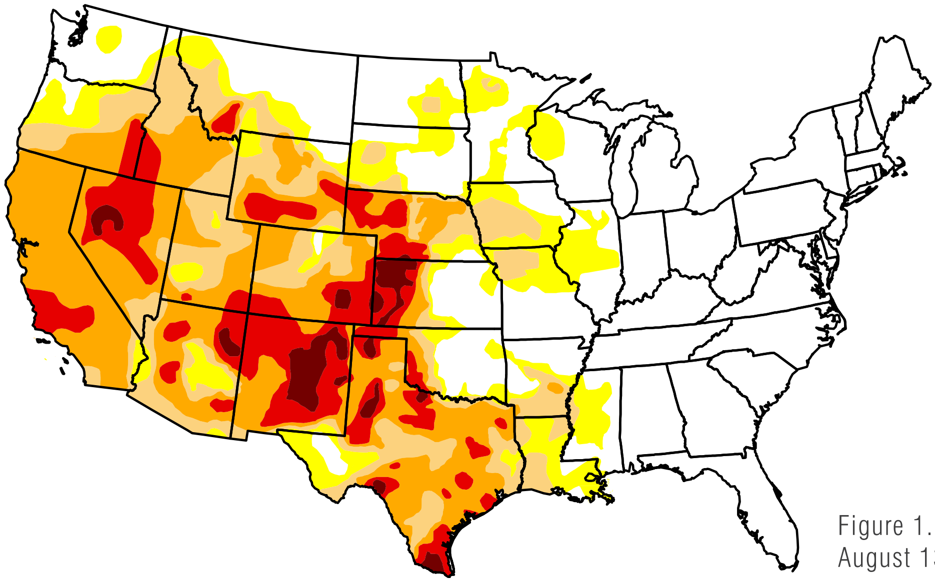


Figure 1.1 United States Drought Monitor August 13, 2013. Author Michael Brewer

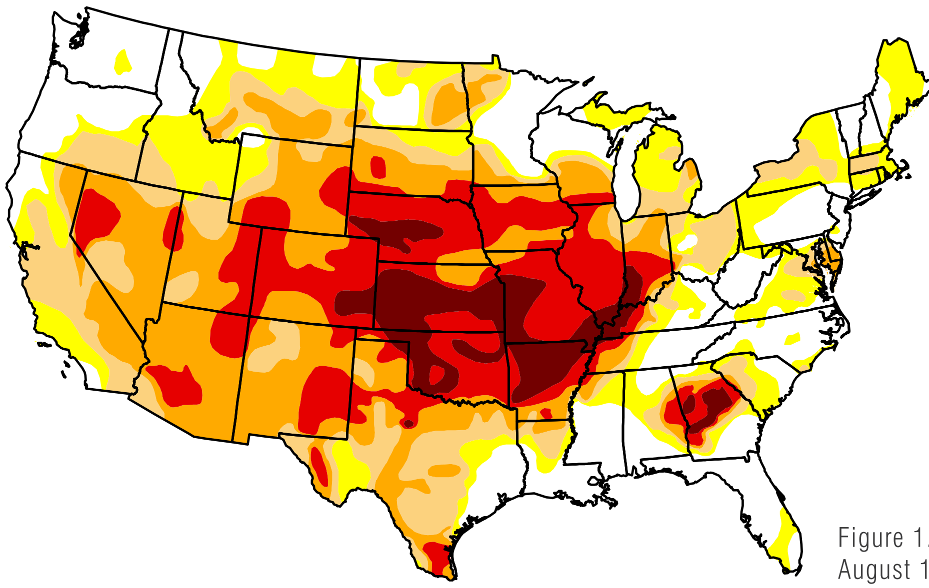


Figure 1.2 United States Drought Monitor August 14, 2012. Author Michael Brewer.

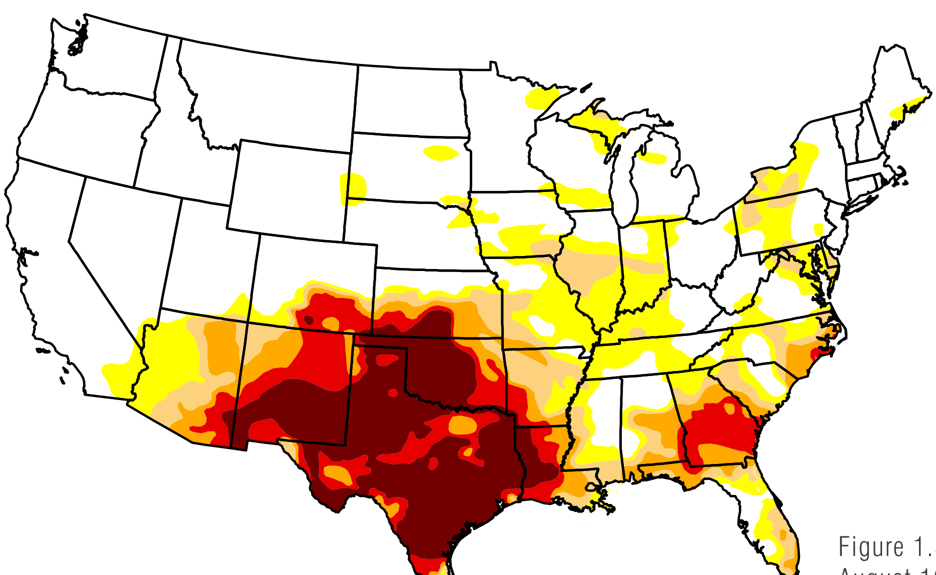


Figure 1.3 United States Drought Monitor August 16, 2011. Author Laura Edwards.

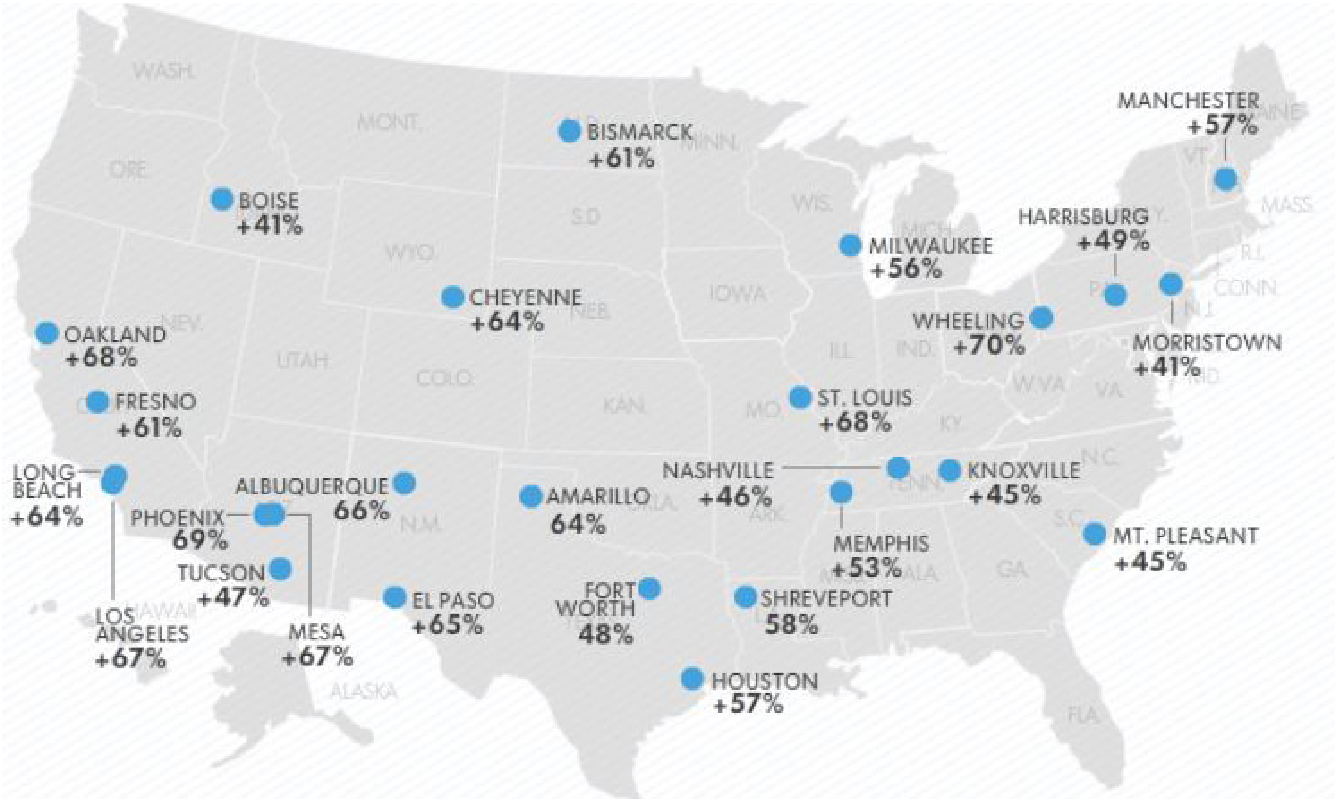


Figure 1.4 Increase in water costs from 2000 - 2012.
Authors: Kevin A. Kepple, Denny Gainer, Joan Murphey, Dough Carroll, Kevin McCoy, Oliver St. John, and Tom McGarrit, USA TODAY.

and rooftop runoff, as well as condensate from air conditioning units. This leads to the questions to be addressed in this Master's Project and Report (MP+R): *Is it possible to harvest enough water on a site to meet the current water demand of an existing site-scale landscape in St. Louis, Missouri? If so, how do we do it? If not, what adjustments need to be made to the landscape design to better balance the water demand with the supply of harvested water?*

Thesis

St. Louis has notoriously hot and humid summers coupled with average precipitation over 30 inches per year. Sites within the city have an incredible opportunity to collect and reuse the abundance of water generated through air conditioning condensation and stormwater runoff based on regional climatic trends. While there is a finite quantity of water on earth, the closest thing that we as designers and problem solvers can come to creating water is to take advantage of recycled or "harvested" resources that are largely untapped. Reusing harvested water to meet all of a site's landscape irrigation demands can potentially eliminate the need to pay for potable water and curtail the negative environmental impacts associated with urban stormwater runoff.

Relevance to Landscape Architecture

Water is essential to the field of landscape architecture. Literature that is currently available on the effectiveness of water harvesting in the Midwest is minimal. Recent publications describe general system components, benefits versus risks, and broad design considerations for "do-it-yourselfers." While these sources provide a well-rounded base of knowledge on the subject, they still do not provide sufficient numerical data regarding a water harvesting system's effectiveness in the region or the potential return on investment. This MP+R uses predictive modeling and some past actual performance-based metrics to enable practitioners to estimate a site's potential for water harvesting. The techniques and methods used to produce the metrics presented in the following chapters can be adapted by anyone in the design professions for almost any site in the world to determine the existing balance of potential water supply and landscape demand.

Project Intent

The predictive performance-based models used in this project are techniques extracted from literature written by leaders in the fields of thermodynamics and water harvesting. The techniques are used to estimate the irrigation demand of a site's landscape and potential supply of water available to harvest and reuse for irrigation. Results from the estimation calculations will show how much imbalance currently exists between a site's potential supply and demand. The severity of the imbalance will determine the extent of design interventions needed to retrofit the existing landscape design in order to improve the equilibrium between the amount of water needed by plants and the "free water" available on-site. The end result will be an adjusted landscape that pulls all of its irrigation needs from on-site harvested water, thus having zero-dependency on a municipal potable water supply.

Three sites in the St. Louis area have been chosen to conduct this study. Potential water supply and landscape demand estimations will be run for each site. The results from the application of prediction models will determine which site has the greatest imbalance of irrigation needs versus potential water supply. The site with the greatest imbalance will be chosen for the design intervention portion of the project.

Non-potable water for landscape irrigation is the primary focus for the water harvesting methods in this study. The predictive modeling estimations for potential water supply will be limited to surface runoff from impervious surfaces, such as parking lots, sidewalks, and rooftops. Surface runoff from vegetated areas will not be used for water harvesting due to inefficiencies at producing significant quantities of runoff for collection, as well as health issues related to brownfield sites. Potential water supply contributions produced from air conditioning condensate from buildings within each site's boundaries will also be estimated.

Given the nature of predictive modeling, exact quantities of water cannot be determined from the estimation methods used in this study. Similarly, no post-modeling actual measurements will be collected due to time constraints associated with the study. All predictive measurements are based on recent trends of regional climatic data and methods that have been deemed acceptable through publication in peer reviewed journals and recommendations by professional consultants who were contacted. Once validated by post-construction measurements and results, metrics that are within an acceptable range of actual system performance expectations can be used for planning water harvesting systems. For actual water harvesting system implementation, a professional should be contacted to conduct a significantly more detailed site analysis than what is feasible in the time-frame of this project.

Location of Sites

Each site is located within the city of St. Louis, Missouri, and range from 7-15 acres in size. The sites have been systematically chosen based on their site-scale size, differing harshness of settings, ability to collect and generate large quantities of water, and confinement to clearly delineated physical boundaries. The St. Louis region was chosen based on Lawrence, Perry, and Alsen's (2012) study which identified cities throughout the country with the most potential to produce large amounts of water from air conditioning condensate. Guz (2005) and Lawrence, Perry, and Dempsey (2010a) were used to identify specific types of buildings that have the potential to produce the greatest amounts of water from condensate collection. The authors suggest targeting buildings which require constant conditioning of the air during the cooling season, such as large scale laboratory and technological centers, office buildings, and public destinations that have a great amount of human activity throughout the day. These types of buildings produce the greatest amount of condensate because of their high activity and need

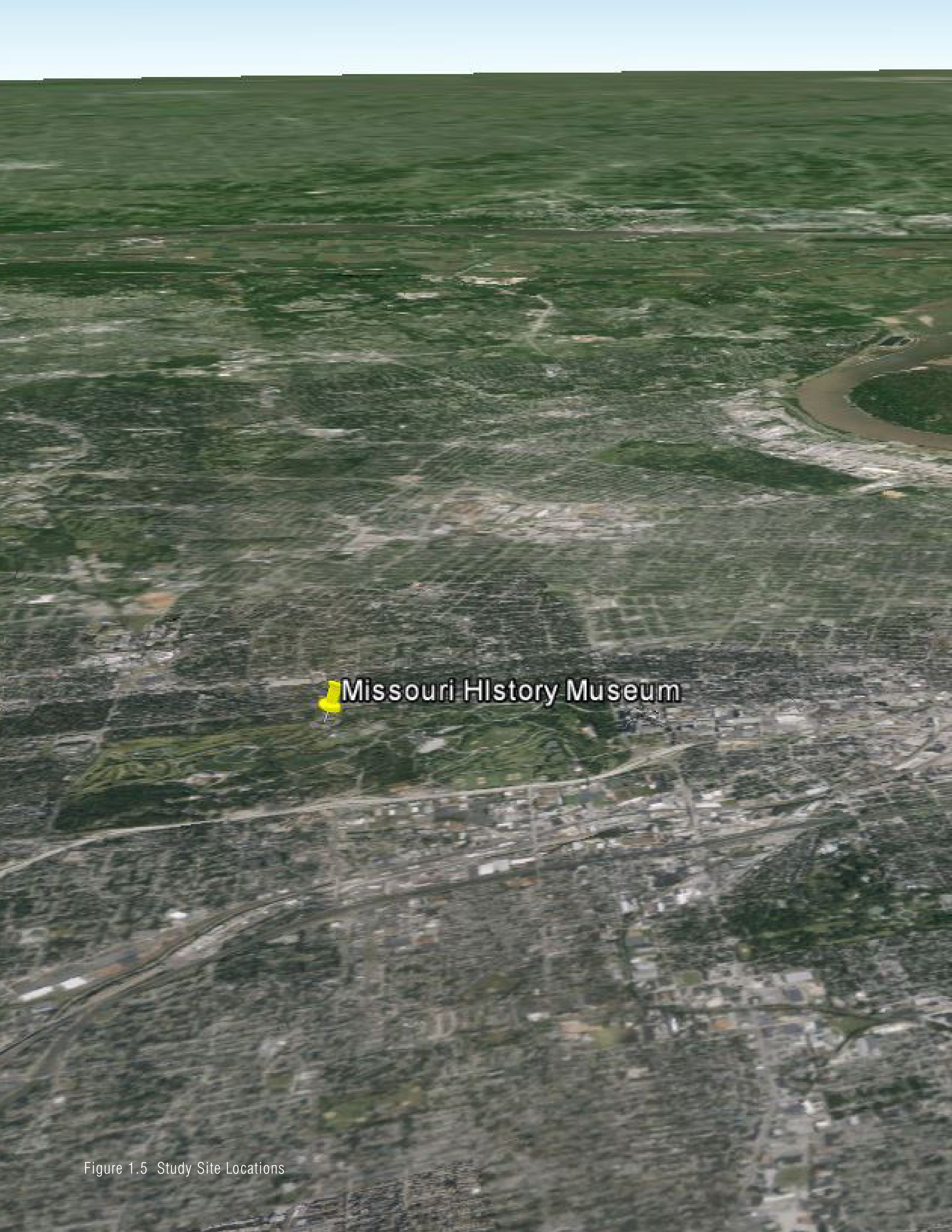
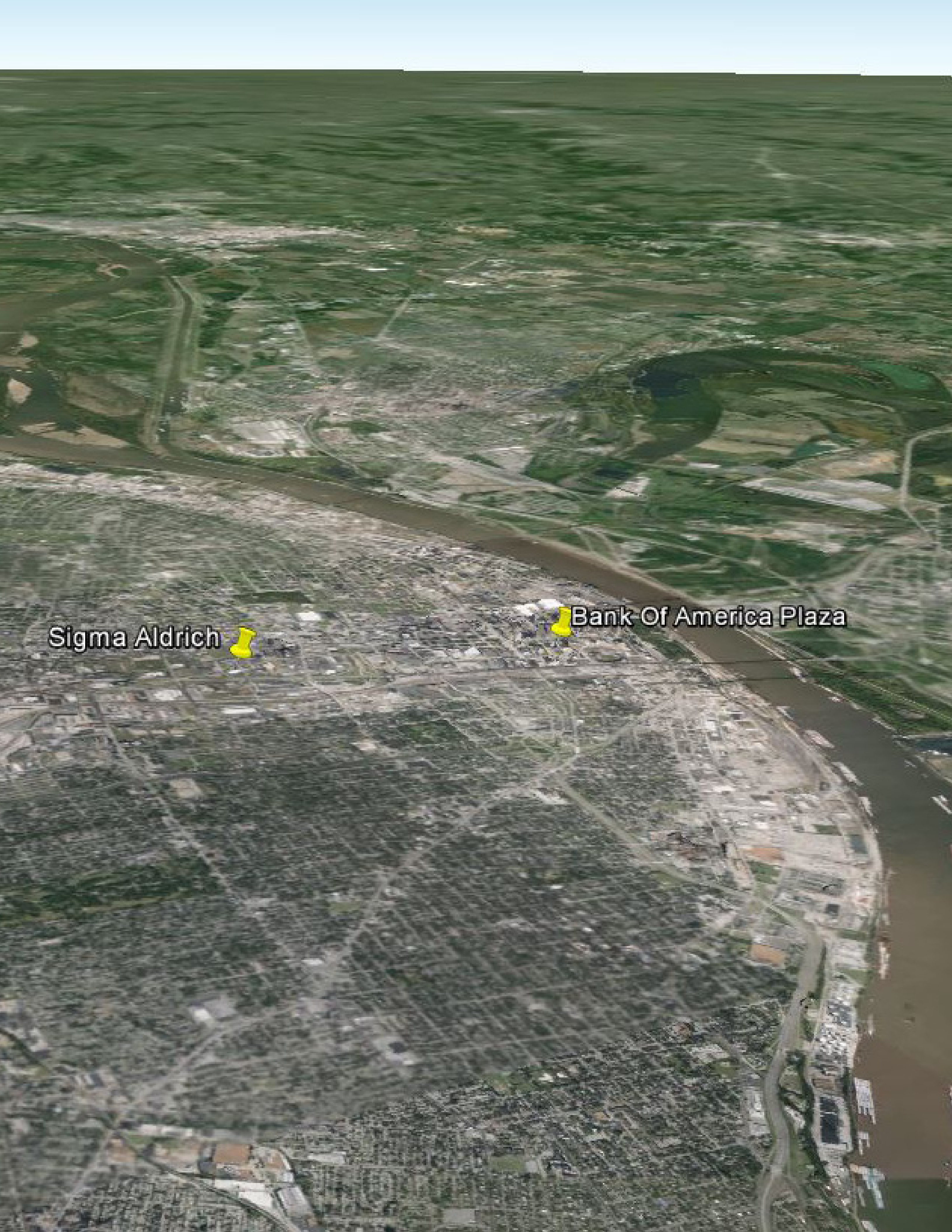


Figure 1.5 Study Site Locations


Sigma Aldrich
Bank Of America Plaza

for conditioned air 24 hours per day. Eight initial sites were chosen and then narrowed down based on their surrounding landscape. Three different types of final sites were selected based on their surrounding context and ratio of existing landscape to building footprints. This typology of sites is intended to provide baseline data regarding the existing landscape water demand versus potential supply per site. For example:

> Site A is a dense urban setting with 50% of the site occupied by a building and 50% occupied by existing landscape. After applying relevant potential supply and landscape demand estimations, it is found that this type of site has a complete balance of landscape water demand and potential supply. Site B, however, is a low density park setting where 10% of the site is buildings and 90% is landscape. After estimations, it is found that the landscape demands eight times more water than can be potentially harvested and reused for irrigation.

Site 1 is the Missouri History Museum in Forest Park. This large building is open to the public and requires large amounts of intense air conditioning during the cooling season, resulting in a large potential to collect condensate for reuse in the landscape. The surrounding landscape consists of mostly turf and ornamental plantings in a low-density park setting. Since there are no physical boundaries to the site, a theoretical boundary has been determined (Figure 1.6).

Site 2 is the Sigma Aldrich Campus in St. Louis, Missouri, located at the corner of Laclede Avenue and Ewing Street near St. Louis University. Sigma Aldrich is a life science and high technology corporation which specializes in biochemical manufacturing, pharmaceutical development, research, and laboratory testing activities. The landscape consists of mostly turf which requires irrigation during the summer months. Ornamental plantings make up minority of the landscape design. The site is approximately 15 acres confined to a single block (Figure 1.7).

Site 3 is the Bank of America Plaza and surrounding landscape in downtown St. Louis. This highly dense, urban setting has a balanced ratio of building footprint to landscape plantings. The study site is confined to two city blocks dissected by various four-lane streets. The Bank of America building is a 31-story, 750,000 square foot office building located in the northern half of the study site. The landscape in the northern half of the site consists of turf and mature native deciduous trees. The southern half of the study site consists of a multi-use building and surrounding landscape consisting of turf and a mix of young deciduous and evergreen trees (Figure 1.8)

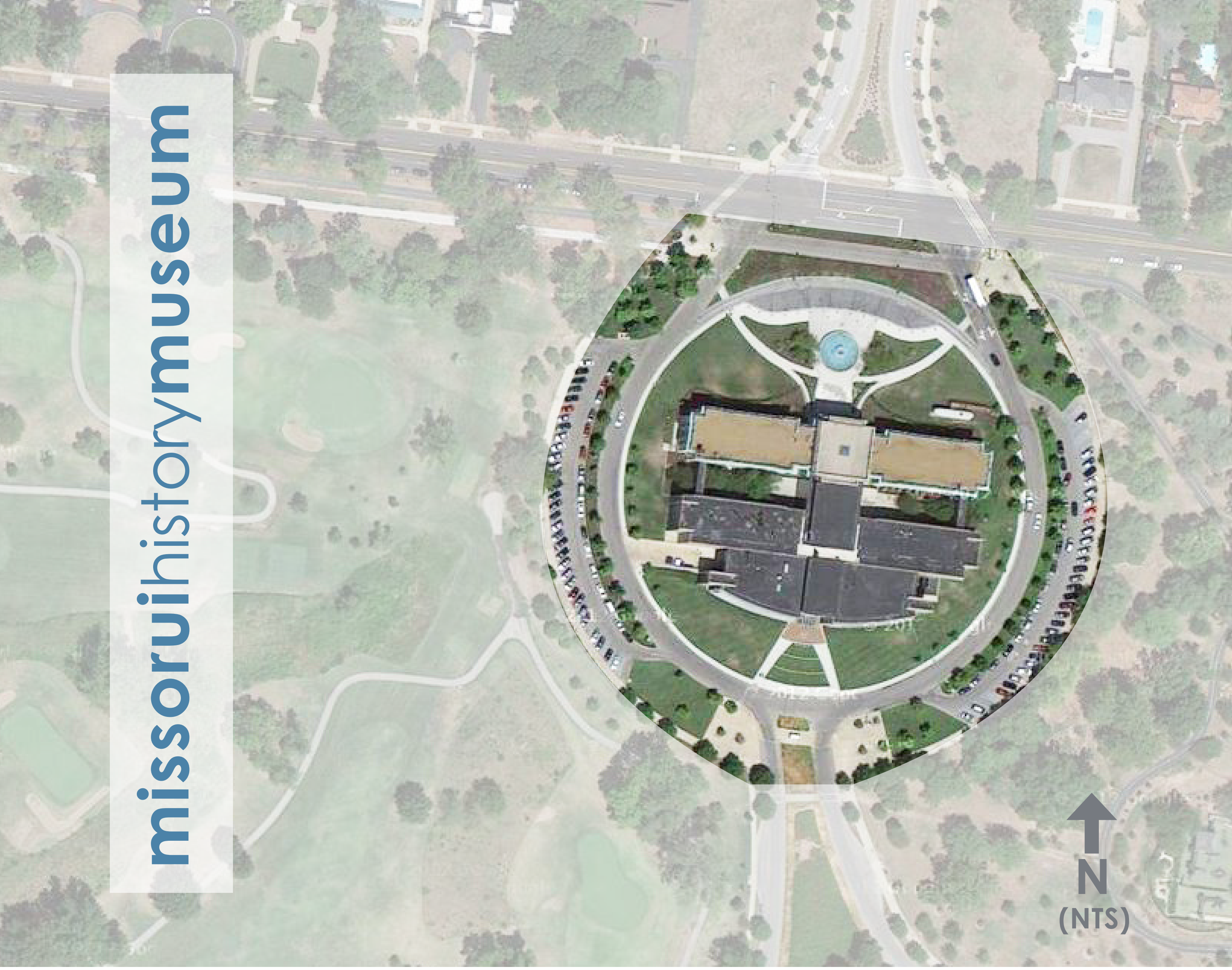


Figure 1.6 Site 1: Missouri History Museum

siteinformation

- 7.3 acres
- 129,000 ft^2 museum
- Park setting
- Open to the public

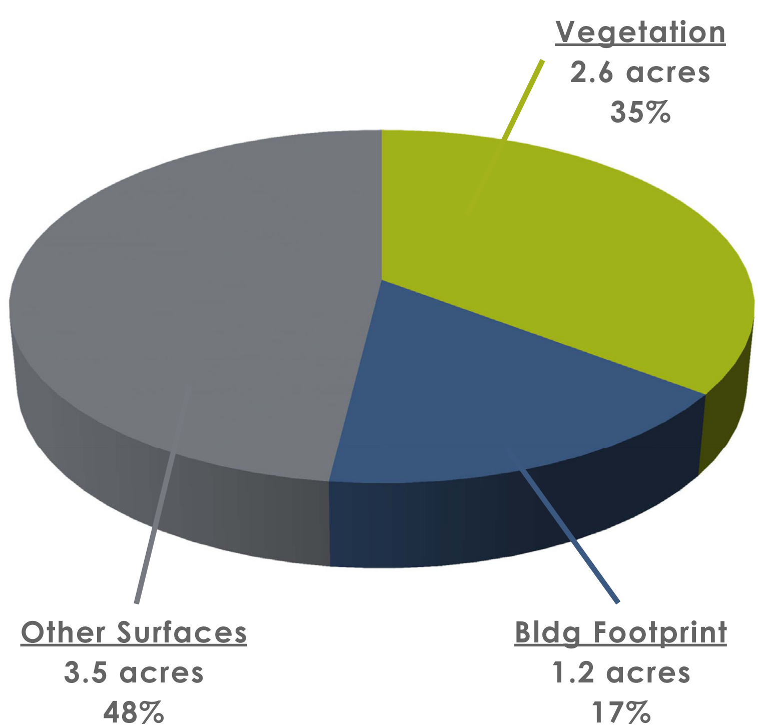


Figure 1.7 Site 2: Sigma Aldrich Corporation

siteinformation

- 15.3 acres
- 138,000 ft² laboratory building
- Research/office activities
- Urban setting
- Private campus

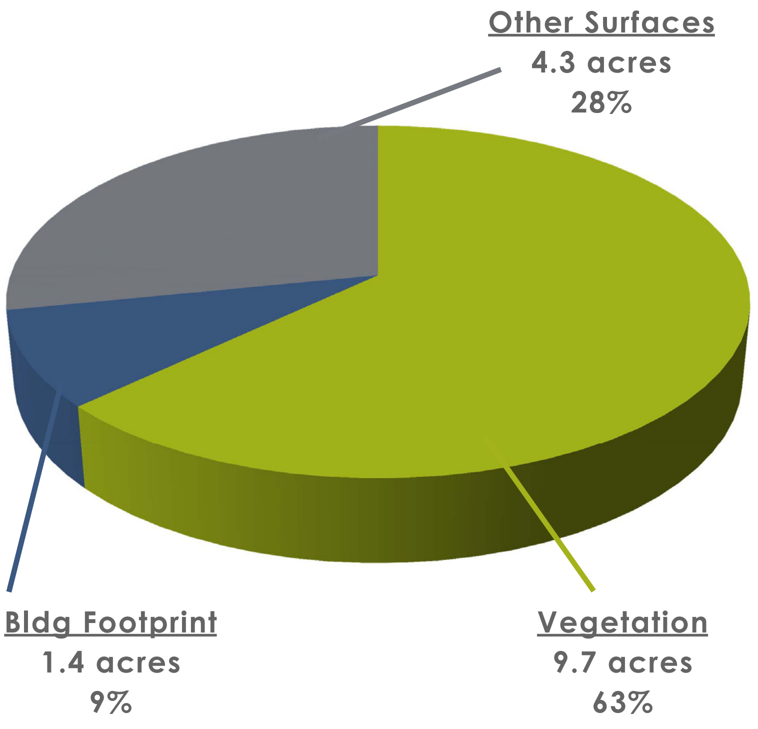
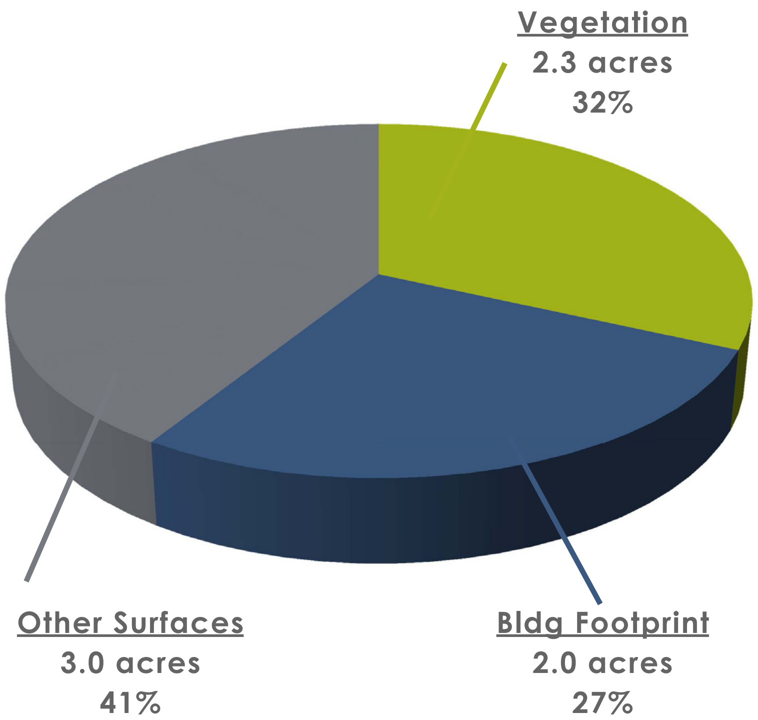


Figure 1.8 Site 3: Bank of America Plaza



siteinformation

- **7.3 acres**
- **750,000 ft² office building**
- **384' tall / 31 stories**
- **Dense urban setting**

chapter II:
background

II BACKGROUND

What is Water Harvesting?

To effectively construct or retrofit a site with a comprehensive water harvesting system, a base of knowledge on the subject must first be established. The following chapter discusses historic practices, current trends, and recent literature on the topic of site-scale water harvesting and reuse systems in the landscape. For the purposes of this MP+R, site-scale water harvesting refers to the practice of collecting, storing, and reusing water generated from stormwater runoff and air conditioning condensation for landscape irrigation. Stormwater runoff is water that leaves a catchment area as surface flow during and after a storm event. Air conditioning condensate refers to the water that is generated as condensation on an air conditioning unit's cooling coils as the result of the difference in the absolute humidity, or water vapor, level of the air entering and leaving the unit. Together, stormwater runoff and air conditioning condensate are the sources that make up the supply of water can be potentially harvested and reused for landscape irrigation purposes.

Historic Water Harvesting and Current Policies

Harvesting rainwater for reuse is not a new phenomenon. In the 9th century BC, King Mesha of Moab won a war on the quest for land east of Jordan due in large part to water collection reservoirs. The reused water allowed him and his army to stay hydrated through the devastating droughts of the time (Kinkade-Levario 2007). In the 6th century AD, Caesar Constantine built enormous 80,000 meter^3 rainwater collection cisterns in Istanbul (Kafin and Van Ooyen 2008).

More recently, numerous cities in the southern United States have adopted legislation mandating water harvesting at residential and commercial scales. The City of San Antonio now requires all newly constructed buildings with air conditioning systems to have an air conditioning condensate collection line for future utilization as process water or landscape irrigation water (City of San Antonio 2009). As of June 1, 2010, the City of Tucson, Arizona requires 50% of a commercial property's landscape irrigation must be supplied from rainwater (Kloss 2008). Santé Fe County, New Mexico requires rainwater harvesting systems on all new residential and commercial structures over 2,500 ft^2 (Krishna 2005).

Figure 2.1 Modern Water Harvesting System Storage Container. (Image Source: Flickr user Bob Muller 2007)

Figure 2.2 Ancient Portuguese Underground Cistern in El Jadida, Morocco. (Image Source: Axel Rouvin 2007)

Literature Review

As mentioned previously, much of the current literature concerning water harvesting covers reuse system components, benefits and risks, general design considerations, recent projects, and predictive methods. However, the current available literature is primarily derived from practitioners and educators based in the southern, southwestern, and southeastern United States. This section of the MP+R analyzes relevant literature's applicability to the midwestern United States. Subtopics identified from recent literature include: "Free water" sources and associated benefits and risks, water harvesting system components and design considerations, and methods for estimating landscape irrigation demand and potential water supply.

"Free Water" Sources

Briggs, Socha and Terrey (2009) identified potential sources for site-scale water harvesting in their National ASLA presentation. Bauer, Coopersmith, and Davis (2011) supplemented a similar list of potential sources in their 2011 San Diego National ASLA presentation with even more site-scale sources of water that have the potential to be harvested and reused. While both lists are not all inclusive, they provide a comprehensive overview of sources to be identified during the site analysis phase (Table 2.1 Potential Sources of Free Water).

Benefits versus Risks

The Texas Manual on Rainwater Harvesting (Krishna 2005), the *Virginia Rainwater Harvesting Manual* (Cabell Brand Center 2009), and the EPA's *Municipal Handbook: Rainwater Harvesting Policies* (Kloss 2008) all provide comprehensive lists of rainwater harvesting benefits and risks. These three publications advocate for the implementation of rainwater harvesting systems for associated environmental and economic benefits. The sources also present associated risks with harvesting systems to supplement their collective advocation for the best interest of the public's general welfare. Graffam, Holmes, and Kinkade (2010) present similar environmental benefits in their 2010 National ASLA Conference presentation, as do Farahbakhsh, Despins, and Leidle (2009) in their investigation, "Developing Capacity for Large-Scale Rainwater Harvesting in Canada" (Table 2.2 Benefits and Risks of Site-Scale Water Harvesting)

Potential Sources of Free Water

Briggs, Socha, and Terrey (2009)	*Bauer, Coopersmith, and Davis (2011)*
Stormwater	Rooftop rainwater
HVAC condensate	Surface stormwater
Grey water	Grey water (showers, sinks, washers)
Re-claimed water	Cooling condensate
Reverse osmosis water	Steam Condensate
Well blow-off	Groundwater ejectors
Process water	Cooling tower "blow-down'
	Process Wastewater

Table 2.1 Potential Sources of Free Water

Benefits and Risks of Site-Scale Water Harvesting

Benefit	Source
• Protect water resources • Reduce stormwater runoff and pollution • Reduce water/sewer bills • Demonstrate sustainability • Obtain LEED credits	Graffam, Holmes, and Kinkade (2010)
• Water is free; the only cost is collection and use • The end use is typically close to the source; eliminates costly distribution system • Provides water source when centralized source is not available • Reduces runoff volume, lessening impact on erosion downstream • Prevents pollutants collected from runoff from entering receiving waters	Krishna (2005)
• Relieve pressure on existing infrastructure • Potentially delays need for future infrastructure expansion	Farahbakhsh, Despins, and Leidl (2009)
• Reduces peak summer demands • Reusing harvested water for irrigation requires little treatment • Reduces downstream erosion	Kloss (2008)
• Reduces dependency on expensive conveyance system • Reduces pollutants entering receiving waters; protecting native flora and fauna • Helps eliminate the need for infrastructure expansion • Decreases need for larger stormwater facilities • Savings on water bills	Cabell Brand Center (2009)

Risk	Source
• Existence of pollutants in harvested stormwater • Course material blocking or damaging system • Algal bloom in harvesting tank • Accidental ingestion of contaminated water • Environmental damage to plants and soil due to contaminated water	Graffam, Holmes, Kinkade (2010)
• Existence of particulate matter • High costs associated with water harvesting	Krishna (2005)

Table 2.2 Benefits and Risks of Site-Scale Water Harvesting

System Components

Krishna (2005), Cabell Brand Center (2009), and Kinkade-Levario (2007) provide comparable and thorough lists of typical rainwater harvesting system components in their respective publications. While the specific components will inevitably vary with the nuances of a given project, their lists introduce primary components including: catchment area, conveyance, filtration, storage, treatment, and delivery. Each manual states that more detailed components should be addressed by a professional when designing a system (Figure 2.4).

General Design Considerations

Three general considerations must be addressed when designing a water harvesting system: capture, storage, and reuse. Graffam, Holmes, and Kinkade (2010) illustrate these three overarching considerations in their 2010 presentation with effective diagrams. Jones, Hunt, and Wright (2009) delve deeper into reuse consideration in their article, "Rainwater Harvesting Solutions in the Humid Southeast USA." The authors explain that knowledge of anticipated water use is imperative to ensure that an appropriately sized cistern is used to gain the most economic and environmental benefits (Jones, Hunt, and Wright 2009). Kinkade and Bock (2011) addressed similar issues in their 2011 ASLA presentation, except with more of an emphasis on water balance considerations. In their case, the supply (annual rainfall amount, seasonal rainfall patterns, size of catchment area, hydrologic properties of the catchment areas, and potential losses) and demand (intended end-use, estimated irrigation demand, seasonal and annual use) are always influencing each other. The goal is to design for the perfect balance between the two.

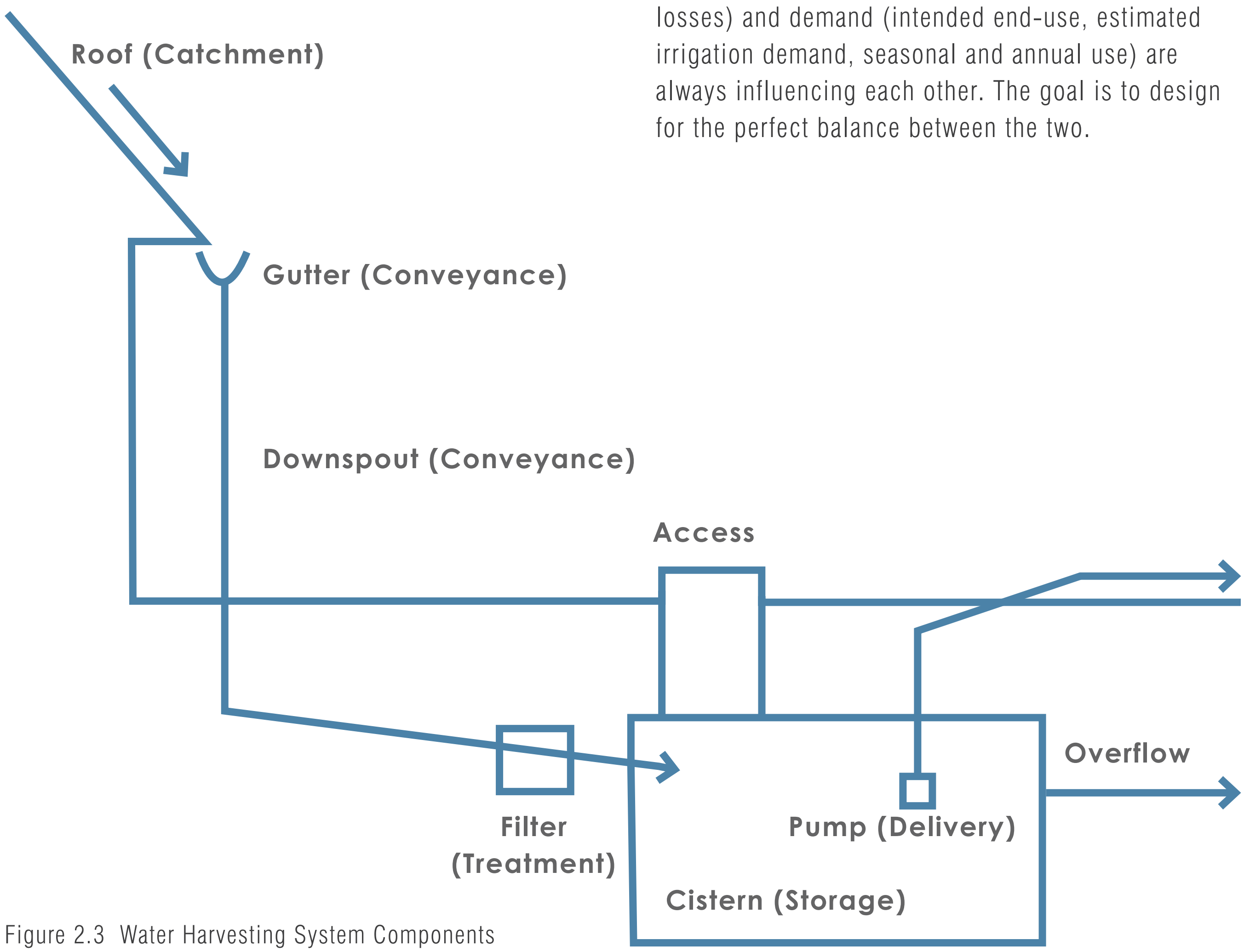


Figure 2.3 Water Harvesting System Components

The effectiveness of rainwater harvesting systems primarily revolve around the system components and design considerations. Another water harvesting collection method, air conditioning condensate, is becoming increasingly effective in producing significant amounts of free water as current technologies continue to improve. Lawrence, Perry, and Dempsey (2010a) in their ASHRAE Journal article, "Capturing Condensate by Retrofitting AHUs," explain how air conditioning condensate collection systems work, as well as what types of buildings have the greatest potential to produce significant amounts of water to capture and reuse. The authors build upon suggestions made by Guz (2005) regarding a building's potential to produce effective amounts of condensate for reuse in the landscape. Recommendations have also been made regarding regional hot-spots for potential air conditioning condensate collection. Lawrence, Perry, and Alsen (2012) utilized economic, climatic, and environmental impact studies to suggest which cities throughout the country have the greatest potential to produce effective amounts of air conditioning condensate. St. Louis, Missouri is categorized as a first tier city, characterized as being "...an obvious locality for requiring, or at least strongly considering, the application of condensate collection systems." (Lawrence, Perry, and Alsen 2012).

Estimating Landscape Water Demand

Landscape water demand must be known, or estimated, before determining how much supply should be collected. Blaney and Criddell's (1962) publication, "Determining Consumptive Use and Irrigation Water Requirements," presents a means for estimating landscape demand. The authors' formula multiplies the region's evapotranspiration rate (ET_o) by the crop coefficient (K_c–the amount of water needed for a crop's *optimum* growth or yield). The product is then multiplied by landscape area (A) and then by a multiplier to get the plant water requirement (PWR). *The Virginia Rainwater Harvesting Manual* (Cabell Brand Center 2009) suggests using the same formula as Blaney and Criddell, with an additional step of subtracting the amount of effective rainfall in a given period (which is water that can be used by the plant without the need for supplemental irrigation).

Waterfall (2004) and Pittenger (2012) suggest using the same formula with a minor adjustment. They use a plant factor (P_f) instead of the crop coefficient (K_c). The plant factor determines the amount of water required by the plant for *acceptable* growth and level of intended appearance, as opposed to the amount of water needed for *optimum* growth. Kinkade and Bock (2011) also suggest using the plant factor instead of the crop coefficient. Kinkade and Bock's estimations also take into account the efficiency of the irrigation system (IE) and the controller efficiency (CE).

The Irrigation Association (2005) and Calkins (2012) suggest using a hybrid of all of the above methods for estimating the consumptive demands of a landscape. The thorough formula multiplies the ET_o by the P_f . However, both sources suggest further adjustments to the P_f to more accurately reflect the dynamic aspects of plant species, microclimates, and density of planting. This adjustment to the P_f is known as the landscape coefficient (K_L). Estimated monthly effective rainfall (R_e – rain usable by plants) is then subtracted from the product of the ET_o and K_L to give you the net plant water requirement (PWR_{net})

The methods for estimating demand presented in this section all assume that the plants in the landscape form a uniform, nearly continuous canopy and are using water in direct proportion to the rate of the ET_o. The University of California (2013) questions the ability of the estimation formulas to accurately reflect the landscape's water requirements by stating that "...mixed plantings of groundcover, shrub, and tree species create variations in the plant canopy and shading that prevent the overall planting from functioning as a single big leaf. Water use of some woody landscape plants does not increase proportionally as ET_o increases throughout the day, especially when site conditions are harsh, such as when trees are planted within paved parking lots."

Estimating Potential Water Supply

The Sustainable Sites Handbook (Calkins 2012) suggests two methods for calculating the amount of surface runoff that can be harvested on-site. The author's "simple method" involves a basic estimation of the size of the catchment area and applying a depth (expected rainfall). The Rational Method is presented as a more thorough and accurate approach that is also recommended by Harris and Dines (1998) in *Time Saver's Standards for Landscape Architecture*.

Krishna (2005), Kinkade and Bock (2011), and Waterfall (2004) all recommend the same formula for estimating the amount of stormwater that can effectively be collected from a rooftop. Their suggestion states that: Potential Supply = Rainfall Depth x Catchment Area x Runoff Coefficient.

Few models have been created for estimating the potential supply of water that can be collected as a result of air conditioning condensate. Lawrence, Perry, and Dempsey (2010b) address this issue in their ASHRAE Transactions publication "Predicting Condensate Collection from HVAC air Handling Units." The authors provide two previous estimation investigations, each of which has their respective universal applicability questioned. Guz (2005) suggests a rule of thumb that 0.1 to 0.3 gallons of condensate per ton of air conditioning can be produced per hour of operation, but this only applies to the San Antonio region of Texas. Painter (2009) developed a prediction model for dedicated outdoor air handling units in which he used the expected difference in humidity ratio on the entering and leaving sides of a cooling coil. He developed the model to predict condensate production in three locations in Texas using annual daily average temperature and humidity data. Lawrence et al. (2010b) propose using a general formula in their article that has been field validated and can be applied anywhere in the country with reasonable assumptions and degree of error.

How to Determine the Size of Storage Container

Kinkade-Levario (2007) suggests using a monthly water budget, or water balance analysis. This method "...describes the amount of rainwater that can be collected in the project catchment area and determines if that amount will meet the user's water demands" (Kinkade-Levario 2007, 36). The budget is meant to provide a supply and demand analysis to determine the size of the storage area. A sample water budget example for Phoenix, Arizona is shown in Table 2.3.

Sample Water Budget Example

Month	Irrigation Requirement for Established Plants	Available Runoff Supply	Runoff Minus Landscape Irrigation Requirement	Excess Runoff to Storage Requirement	Accumulative Storage	Irrigation Requirement from Storage	Irrigation from Municipal Supply
Jan.	41,748	137,339	95,591	95,591	329,377	-	0
Feb.	58,076	132,979	74,903	74,903	404,280	-	0
March	93,828	132,979	39,151	39,151	443,431	-	0
April	131,867	61,040	-70,827	372,604	70,827	-	0
May	162,460	23,979	-138,481	234,123	138,481	-	0
June	179,897	17,440	-162,457	71,666	162,457	-	0
July	172,746	170,039	-2,707	68,959	2,707	-	0
August	153,774	185,298	31,554	31,544	31,554	-	0
Sept.	126,407	143,879	17,472	17,472	49,026	-	0
Oct.	93,828	93,739	-89	48,937	89	-	0
Nov.	54,595	115,539	60,944	60,944	109,881	-	0
Dec.	37,414	161,319	123,905	123,905	233,786	-	0

Table 2.3 Example of a Sample Water Budget, Phoenix, Arizona (Adapted from Kinkade-Levario 2007, 40)

Note: From Kinkade-Levario (2007, 40)
The above rainwater harvesting process was started in August with the summer rains in order to accumulate enough rainwater to fulfill the next summer's irrigation needs. The August quantity of 31,554 gallons begins the water budget / accumulative storage process. Each month as rainwater is harvested the quantity increases; during months that require water for irrigation above what is harvested for that month, the deficit is subtracted from the accumulative storage quantity. The accumulative storage is a running total of water in the cistern. The maximum amount of rainwater stored, 443,431 gallons, occurs in March. The maximum accumulative storage quantity, March in this case, will be the amount used to size the storage system. A cistern or storage facility is sized to hold the maximum accumulative quantity of rainwater plus a little extra as a safety factor or buffer for a non-average rainfall year.

chapter III:
data collection

III Data Collection

Gathering the most accurate and applicable data is critical for conducting the predictive modeling introduced in the previous chapters. Regional climatic trends and existing site conditions contain the variables needed to be input into the landscape irrigation demand estimation models and the potential water supply estimation models. Regional climatic data were gathered from Weather Underground's historic climatic database which uses readings recorded from a weather station located at Lambert International Airport in St. Louis, approximately 15 miles northwest of each of the three study sites. A site inventory and analysis was conducted for each study site to document existing conditions and compile the factors required to run each predictive model.

Regional Climate Data

Estimating Landscape Demand - Precipitation and Evapotranspiration Data.

The most recent average monthly precipitation data from the last 11-years (2003-2013) and average monthly evapotranspiration data from the last 30 years are the most pertinent factors for estimating the irrigation requirements of a landscape. Table 3.1 and Figure 3.1 show monthly rainfall totals (in inches) for the St. Louis area during the main growing season, March 1 – October 31, as well as the 11-year average monthly rainfall for the same period. Table 3.2 and Figure 3.2 show the average number of significant rainfall events for the same period. The number of rainfall events per month are critical in determining how large a water storage structure must be sized in order to accommodate typical dry periods per month. Table 3.3 and Figure 3.3 show the average amount of rainfall per significant rainfall event for the same period. The average amount of rainfall per event was determined by dividing the average total monthly rainfall data (Table 3.1) by the number of significant rainfall events for each month (Table 3.2). Only months during the typical growing season are being used to determine landscape water demand. A majority of the vegetation in each of the three study sites goes into dormancy from November - February when the plants are not active and do not require quantities of water significant enough to necessitate being included in this study.

Month	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Avg. Monthly Rainfall
March	2.79	4.27	1.05	3.07	2.80	8.39	3.04	2.35	4.74	3.33	4.95	3.71
April	4.32	1.92	1.63	1.73	3.18	3.76	4.06	3.01	7.88	7.30	5.67	4.04
May	3.97	9.64	0.78	2.70	4.26	10.84	4.72	4.64	4.16	1.70	7.13	4.96
June	11.21	0.81	5.10	2.26	2.88	1.89	6.42	4.04	9.10	1.97	5.86	4.69
July	2.23	5.15	2.22	1.38	3.11	7.50	4.20	6.69	2.91	0.72	3.35	3.59
August	2.52	3.09	3.87	2.27	1.57	1.59	2.48	3.62	1.04	4.02	1.19	2.48
Sept.	4.26	0.21	5.30	1.28	1.71	9.77	3.16	3.73	3.18	3.03	2.74	3.49
Oct.	2.81	3.02	1.52	3.72	1.97	1.23	12.38	1.06	1.66	2.50	2.35	3.11

Table 3.1 Monthly Growing Season Rainfall Totals (inches) for St. Louis (2003 - 2013). (Source: Weather Underground)

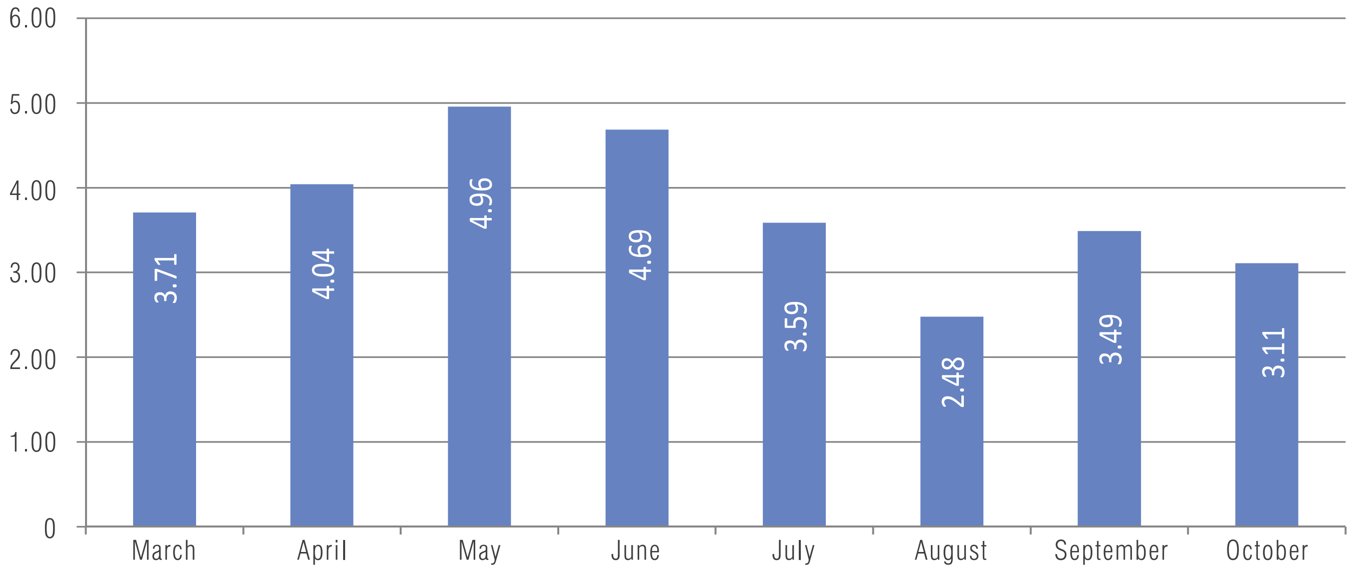


Figure 3.1 Average Monthly Rainfall (inches) for St. Louis (2003 - 2013). (Source: Weather Underground)

Month	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Avg. # of Rainfall Events
March	11	15	5	10	10	12	8	11	11	11	14	10.7
April	12	6	13	10	8	11	14	12	17	11	10	11.3
May	14	14	7	11	12	17	16	15	17	6	14	13.0
June	12	8	6	6	10	11	13	13	12	3	13	9.7
July	5	13	9	7	7	14	8	17	5	5	8	8.9
August	7	11	12	8	8	6	8	6	8	11	4	8.1
Sept.	11	2	8	7	7	7	7	13	8	11	7	8.0
Oct.	10	12	5	7	8	4	15	5	6	10	14	8.7

Table 3.2 Number Significant Rainfall Events (0.1”>) for St. Louis (2003 - 2013). (Source: Weather Underground)

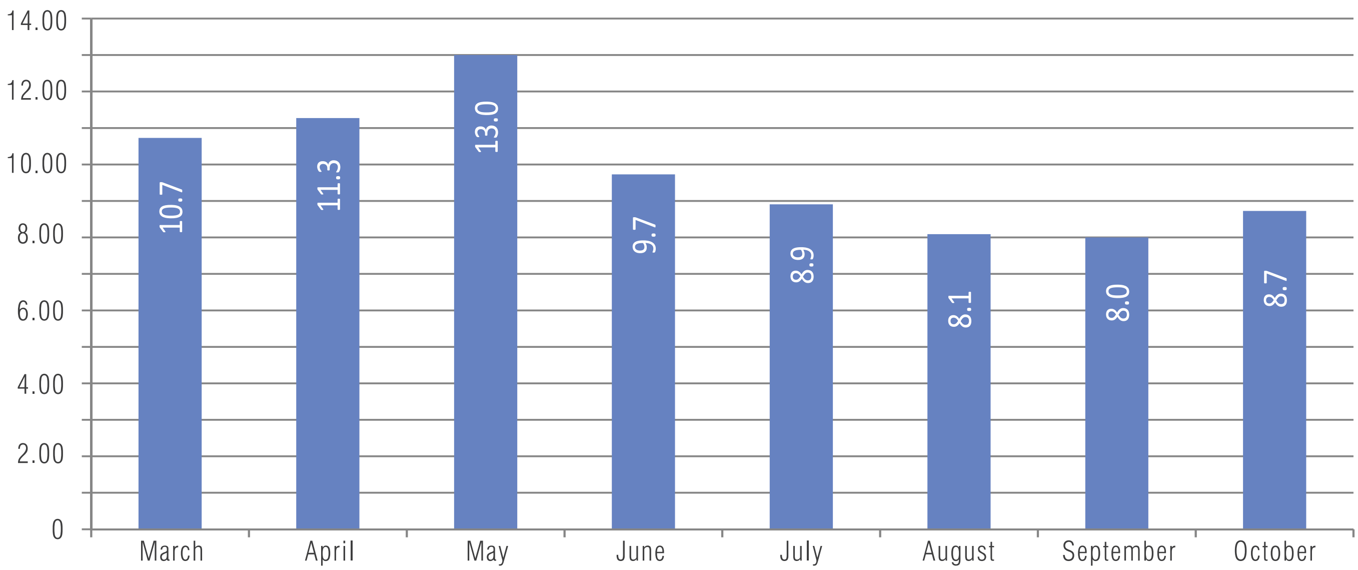


Figure 3.2 Average Number of Significant Rainfall Events (0.1”>) for St. Louis (2003 - 2013). (Source: Weather Underground)

Evapotranspiration (ET) is the total amount of water lost from the soil and plant surfaces (evaporation) and water used by the plants (transpiration). Reference evapotranspiration is evapotranspiration from vegetation having known, defined reference characteristics. The reference evapotranspiration can be based either on Alfalfa (ET_r) or grass (ET_o), and is directly measured by weighing water lost by the plant from a lysimeter or calculated from data measured by a weather station. Generally, the reference crop recommended for landscape usage is cool-season grass. The quantity of ET_o for a given time period refers to the amount of water an actively growing clipped cool-season grass 3-6” tall requires for optimum growth (The Irrigation Association 2005).

Figure 3.4 shows the 30-year average monthly ET_o (in inches) for St. Louis during the typical growing season.

For Estimating A/C Condensation Production - Temperature and Relative Humidity

Daily outdoor air temperature and relative humidity are the primary climatic factors used when estimating the potential supply of water produced as condensation from an A/C unit. The difference in the absolute humidity ratio, which indicates the amount of water vapor in the air, between incoming outdoor air and indoor supply air leaving the unit

Month	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Avg. Amt. per Rainfall Event
March	.25	.28	.21	.31	.28	.70	.38	.21	.43	.30	.35	.35
April	.36	.32	.13	.17	.40	.34	.29	.25	.46	.66	.57	.36
May	.28	.69	.11	.25	.36	.64	.30	.31	.24	.28	.51	.38
June	.93	.10	.85	.38	.29	.17	.49	.31	.76	.66	.45	.48
July	.45	.40	.25	.20	.44	.54	.53	.39	.58	.14	.42	.40
August	.36	.28	.32	.28	.20	.27	.31	.60	.13	.37	.30	.31
Sept.	.39	.11	.66	.18	.24	1.40	.45	.29	.40	.28	.39	.44
Oct.	.28	.25	.30	.53	.25	.31	.83	.21	.28	.25	.17	.36

Table 3.3 Average Amount (inches) of Rainfall per Significant Rainfall Event for St. Louis (2003 - 2013). (Source: Weather Underground)

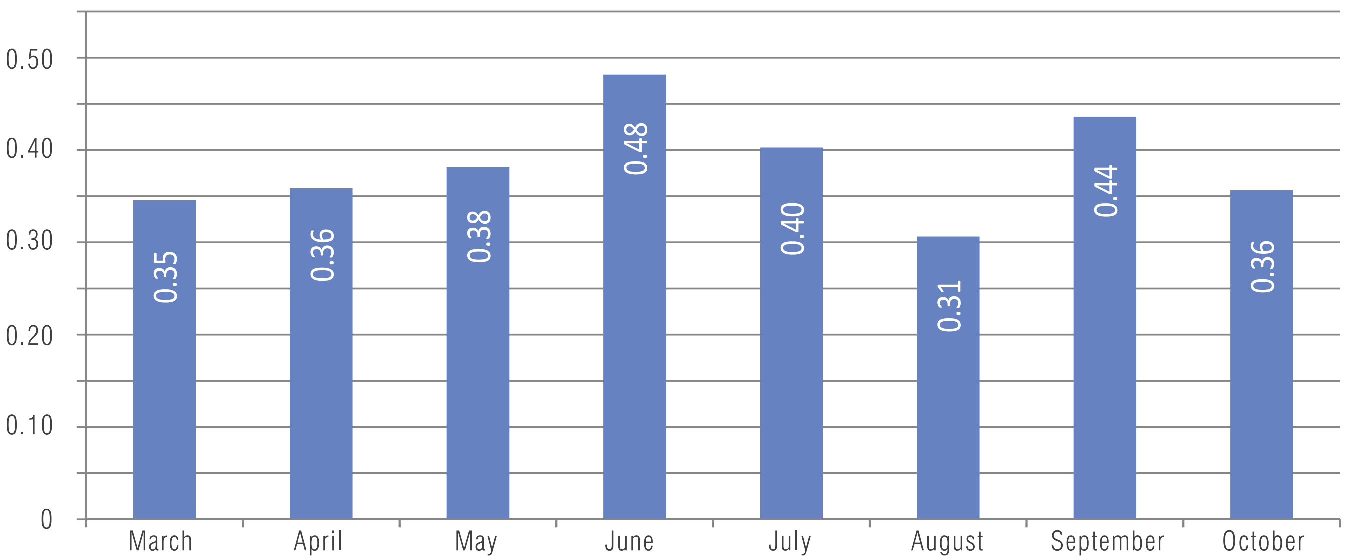


Figure 3.3 Average Amount (inches) of Rainfall per Significant Rainfall Event for St. Louis (2003 - 2013)

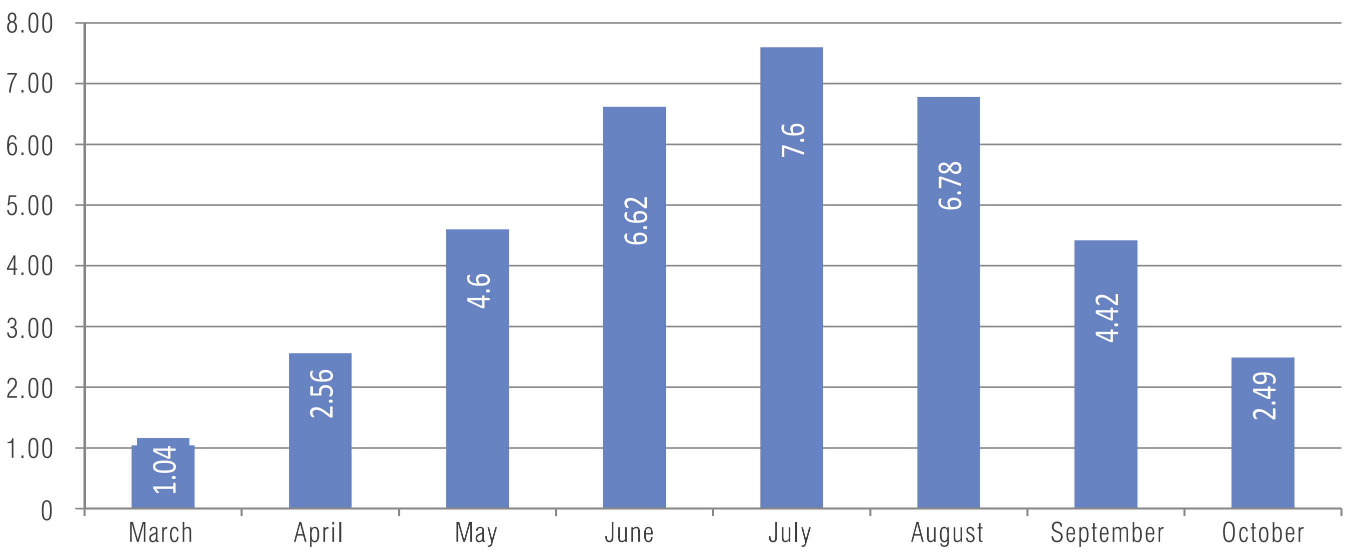


Figure 3.4 30-Year Average Monthly Evapotranspiration Quantities (inches) for St. Louis. (Source: Davis 2014)

represents the amount of condensation that occurs (Lawrence, Perry, Dempsey 2010b). If the daily outdoor air temperature and relative humidity are known, then a psychometric chart (Figure 3.5) can be used to determine the humidity ratio. Daily average temperatures and daily average humidity levels were gathered for the cooling season, May 1 – October 31, during the same 11-year period of 2003-2013. The cooling season refers to the time of year that air conditioning systems are typically used throughout the day. Figure 3.6 shows the mean daily average temperatures and mean daily average relative humidity levels for St. Louis, Missouri. The data in Figure 3.6 are derived from the actual daily climatic recordings from 2003-2013 and is presented in Appendix A. The charts on pages 142-143 in Appendix A show the daily outdoor air absolute humidity ratio gathered from the psychometric chart based on the corresponding day's average daily temperature and average daily relative humidity. Figure 3.7 shows the average daily humidity ratio for St. Louis, Missouri from 2003-2013.

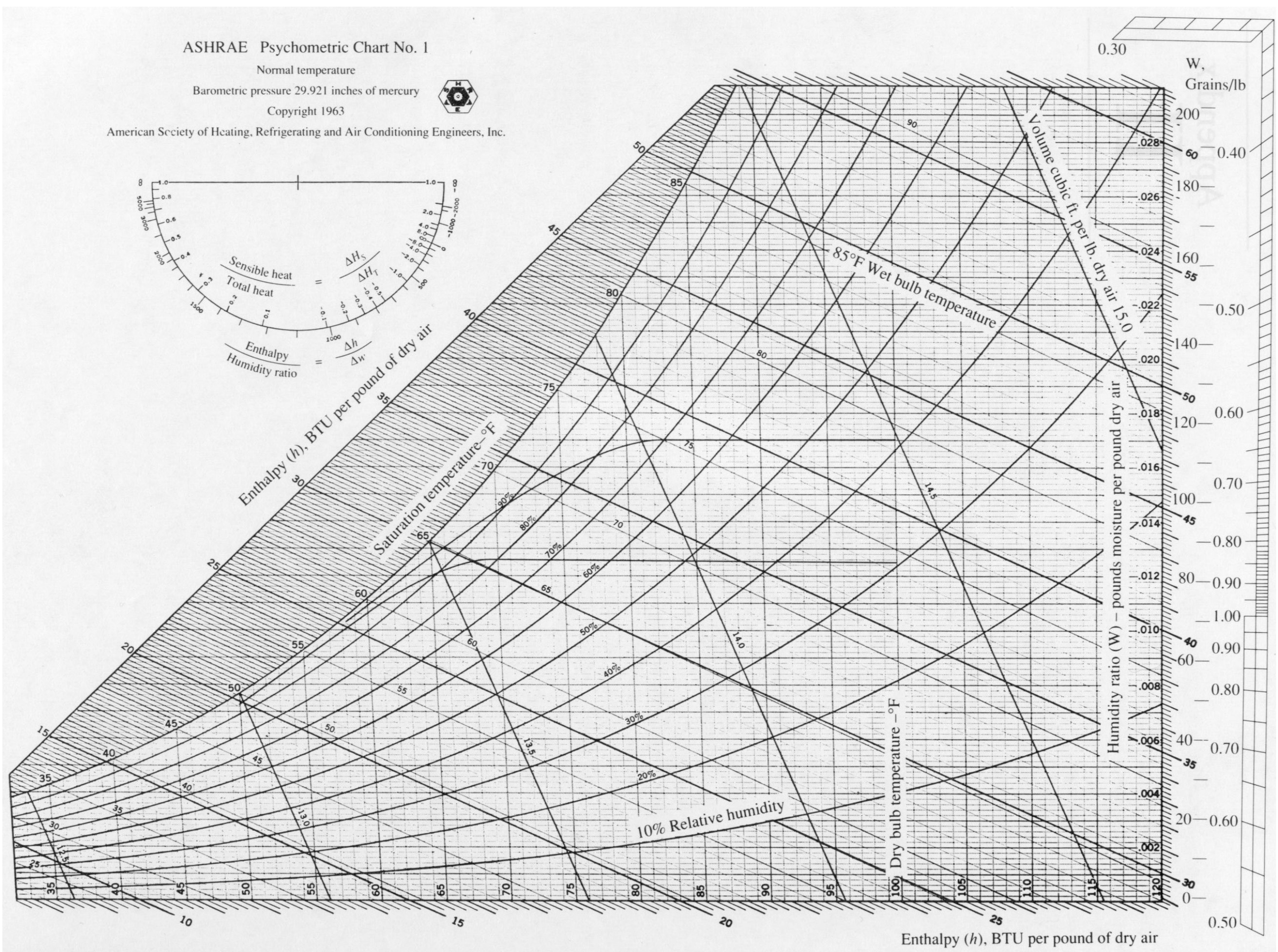


Figure 3.5 Psychometric Chart. (Source: ASHRAE 2003)

The daily humidity ratios in Figure 3.7 were determined by using the corresponding mean daily average temperature and mean daily average relative humidity level from Figure 3.6 and input into the psychometric chart above. To do so, locate the desired temperature (bottom of chart) and follow it directly up until it hits the desired relative humidity (swooping curves). Once the point of intersection between the temperature and humidity has been found, follow the intersection point to the right side of the chart on a straight line to determine the humidity ratio for that given temperature and relative humidity level.

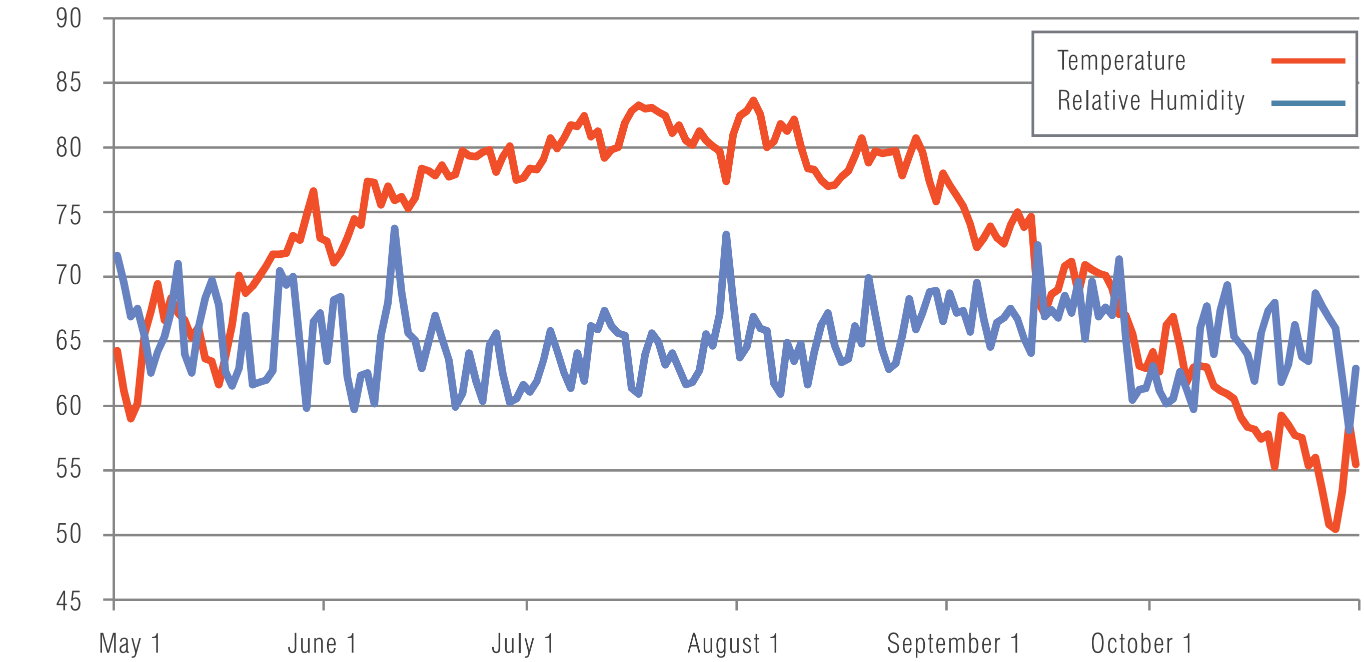


Figure 3.6 Mean Daily Average Temperature and Relative Humidity for St. Louis (2003 - 2013). (Source: Weather Underground)

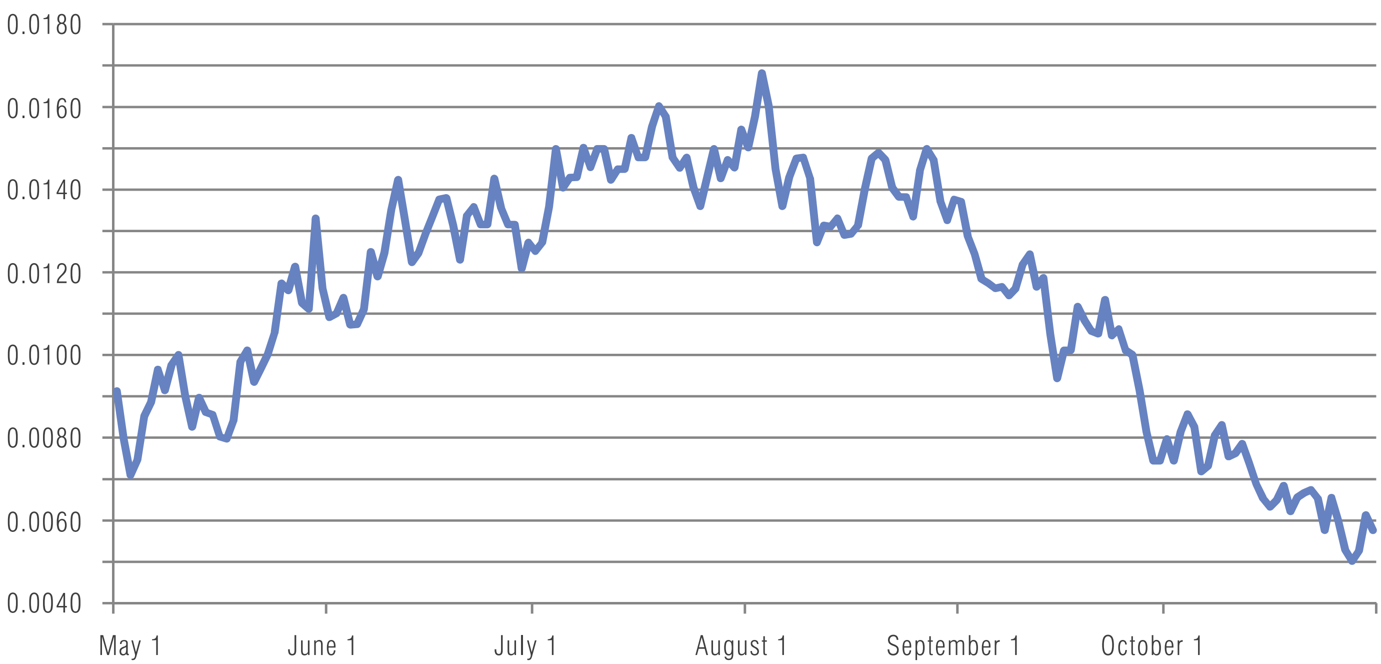


Table 3.7 Average Daily Humidity Ratio (in $lbs_{water}/lbs_{dry\ air}$) for St. Louis Missouri (2003 - 2013)

Site Inventory and Analysis

Each of the study sites were visited twice to conduct the site inventory and analysis; once between November 22-26, 2013 and once between January 15-17, 2014. Existing conditions that were documented include landscape plant identification, microclimate identification, site drainage, and vehicular and pedestrian circulation. Landscape plant identification included planting zones, individual species identification, as well as notation regarding the density of each planting zone. Identifying plants in the winter proved to be difficult and required pictures of each plant in question to be taken and shown to university faculty until each plant was positively identified. Once the planting zones were identified, characteristics of each zone's microclimate were then noted. Factors influencing the microclimate of each zone include the amount of daily sun/shade, tree coverage, proximity to paved surfaces, proximity to highly reflective structures, and protection from wind. In total, the number of separate microclimates within each site ranged from 8-14 per site.

Individual plant species, planting density, and the microclimate of each planting zone are key factors in estimating the landscape irrigation demand of a site. These factors determine what percentage of the region's ET_0 is required by each planting zone within the site, therefore adjusting the reference evapotranspiration quantity of cool-season grass to reflect other plant species massings on-site. The concept of adjusting the ET_0 is referred to as the Landscape Coefficient Method and will be further discussed in Chapter 4.

Figure 3.8 Plant ID Photo - Indiancurrant Coralberry (Image Source: Wes Haid 2014)

Figure 3.9 Plant ID Photo - Fragrant Sumac (Image Source: Wes Haid 2014)

Figure 3.10 Plant ID Photo - Common Periwinkle (Image Source: Wes Haid 2014)

chapter IV:

development of findings

IV Development of Findings

This portion of the analysis phase is intended to present a picture of the existing balance between landscape water demand and potential water supply within each study site. The predictive modeling methods presented in the Chapter 2 use the climatic and site analysis data (Chapter 3) as variables to estimate each of the three study site's existing landscape water demands and potential supply of water available to harvest. The Irrigation Association's (2005) landscape coefficient (K_L) method is used to determine each site's plant water requirements (PWR). Potential surface runoff quantities are determined using the method presented in Krishna (2005), Kinkade and Bock (2011), and Waterfall (2004). Lawrence, Perry, and Dempsey's (2010b) method of predicting condensate collection from HVAC air handling units is used to estimate the amount of water that can potentially be harvested and reused for irrigating the landscape.

Determining Landscape Water Demand

Landscape Coefficient Method

Reference evapotranspiration rate (ET_o) is the primary factor for determining the irrigation requirements of landscape plants. Because the ET_o rate represents the amount of water lost, and therefore needed, for standardized cool season turf, it must be adjusted to reflect irrigation requirements for other plants within the site. The ET_o rate is adjusted using a landscape coefficient (K_L). K_L is a dimensionless coefficient that takes into account the specific water requirement of a landscape plant species, the specific conditions of the microclimate within the site in which the plant is located, and the density of the planting (The Irrigation Association 2005, 1-9). The process for calculating K_L is:

<u>Step 1 - Calculate Landscape Coefficient</u>

$$K_L = K_S * K_{MC} * K_D$$

where:
K_L = Landscape Coefficient (dimensionless)
K_S = Species Factor - adjustment factor reflecting characteristics for a particular plant species (dimensionless)
K_{MC} = Microclimate Factor – adjustment for microclimate influences upon the planting (dimensionless)
K_D = Density Factor – adjustment for planting density (dimensionless)
(The Irrigation Association 2005, 1-9)

Multiplying the species, microclimate, and density factors results in a percentage of the cool-season turf ET_o reflective of the particular species being analyzed in the landscape setting.

Once the K_L has been calculated for a particular plant massing, it is then multiplied by the ET_o to provide the Plant Water Requirement (PWR). The formula for calculating PWR is:

Step 2 – Calculate Plant Water Requirement
$PWR = ET_o * K_L$

where:
PWR = Plant Water Requirement (inches/period)
ET_o = Reference Evapotranspiration rate for cool-season turf (inches/period)
K_L = Landscape Coefficient (dimensionless)
(The Irrigation Association 2005, 1-13)

The ET_o gathered in Chapter 3 is expressed in inches per month, therefore the PWR of the planting zone is the monthly amount of water, in inches, required to maintain a healthy plant.

After the PWR for the planting zone in question has been determined, the PWR needs to be adjusted for the amount of rainfall that contributes toward the water needs of the planting zone. This is referred to as the effective rainfall. Effective rainfall is the portion of the rainfall that is actually usable by the plants. Effective rainfall depends on the amount, intensity and duration of each rainfall event, soil type and its holding capacity, plant type, root depth and water intake rate, and the amount of moisture in the root zone prior to the rain event (The Irrigation Association 2005, 1-14). For general planning purposes, 50% of the monthly rainfall is typically used as the effective rainfall (Davis 2013). Extremely sandy soil will result in an effective rainfall less than 50% due to its inability to hold water. Conversely, heavy clay soil will result in an effective rainfall greater than 50% due to its ability to retain water. Adjusting the PWR with consideration for effective rainfall results in Net Plant Water Requirement (PWR_{net}). The formula for calculating the PWR_{net} is:

Step 3 – Calculate Net Plant Water Requirement
$PWR_{NET} = PWR - R_E$

where:
PWR_{NET} = Net Plant Water Requirement (inches/period)
PWR = Plant Water Requirement (inches/period)
R_E = Effective rainfall (inches/period) (generally 50% of rainfall/period)
(The Irrigation Association 2005, 1-19)

The result of Step 3 is the amount of water needed by the plant zone to supplement the water lost to evapotranspiration after the plants have taken in the effective rainfall.

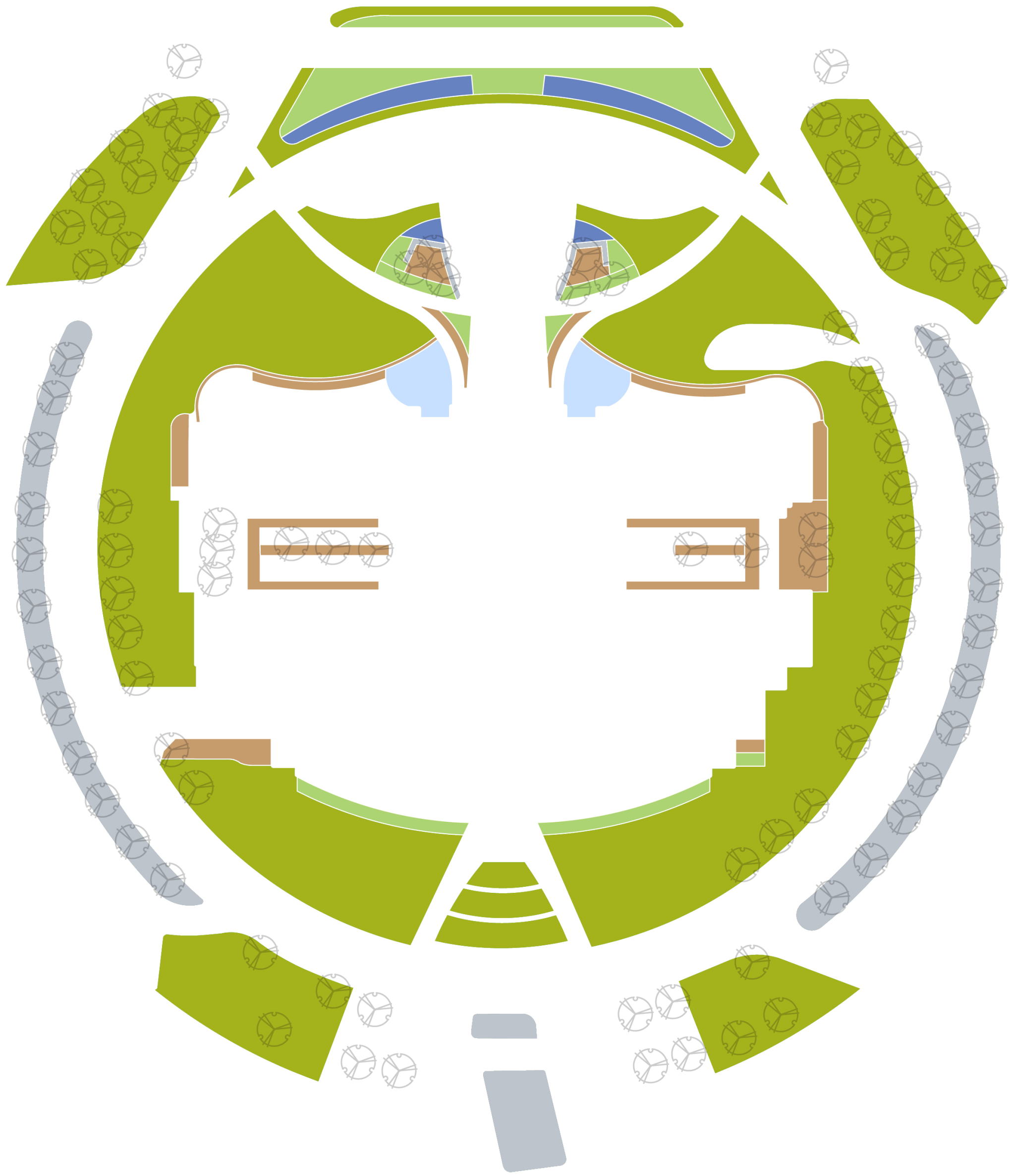
Landscape Coefficient Method – Determining the Species Factor (K_S)

The species factor, a coefficient used to calculate the K_L, takes into account the specific water requirements of a landscape plant species. Table 4.1 shows species factors for different plant types. An "average" K_S represents the typical or average species factor in relation to water use within a given landscape plant type. Similarly, "high" values represent the high end of the species factors within the category and the "low" values represent the low end of the range. For example, the low range for shrubs is 0.2 which is appropriate for a selected planting zone of drought tolerant shrub species. The high range for shrubs is .7 which is appropriate for a select group of shrubs which has greater than average water requirements (The Irrigation Association 2005, 1-10).

Species identification for each study site was conducted during site visits between November 22, 2013 – January 17, 2014. Photographs were taken of plant species which were unable to be positively identified on-site. The photographs of plants in question were reviewed by Kansas State University landscape architecture and horticulture faculty members and positively identified. Plant species for each study site were given a species factor (according to Table 4.1) based on water requirement information from the Missouri Botanical Garden and reviewed by Dr. Cathie Lavis, Professor of Landscape Maintenance, Arboriculture, and Irrigation Design at Kansas State University. Figures 4.1 - 4.3 show plant species for each of the three study sites developed from the aforementioned species identification analysis as well as each species' associated species factor.

Vegetation	*High*	*Average*	*Low*
Trees	.9	.5	.2
Shrubs	.7	.5	.2
Groundcover	.9	.5	.2
Mix of Trees, Shrubs, and Groundcover	.9	.5	.2
Turf	n/a	.8	n/a

Table 4.1 Species Factor: Values for Plant Types. (Source: The Irrigation Association 2005)



Species	*Species Factor (from Table 4.1)*	*Species*	*Species Factor (from Table 4.1)*
Prairie Dropseed	.3	Various Annuals	.6
Black-Eyed Susan	.5	Hydrangea	.5
Liriope	.3	Winged Euonymus	.5
Maiden Grass	.3	Cool-Season Turf	.8
Rhus aromatica	.2		
Pennisetum	.3		
Indiancurrent Coralberry	.2		
Inkberry	.5		
Witchhazel	.5		
Itea	.5		

Figure 4.1 Missouri History Museum Planting Plan and Species Factors

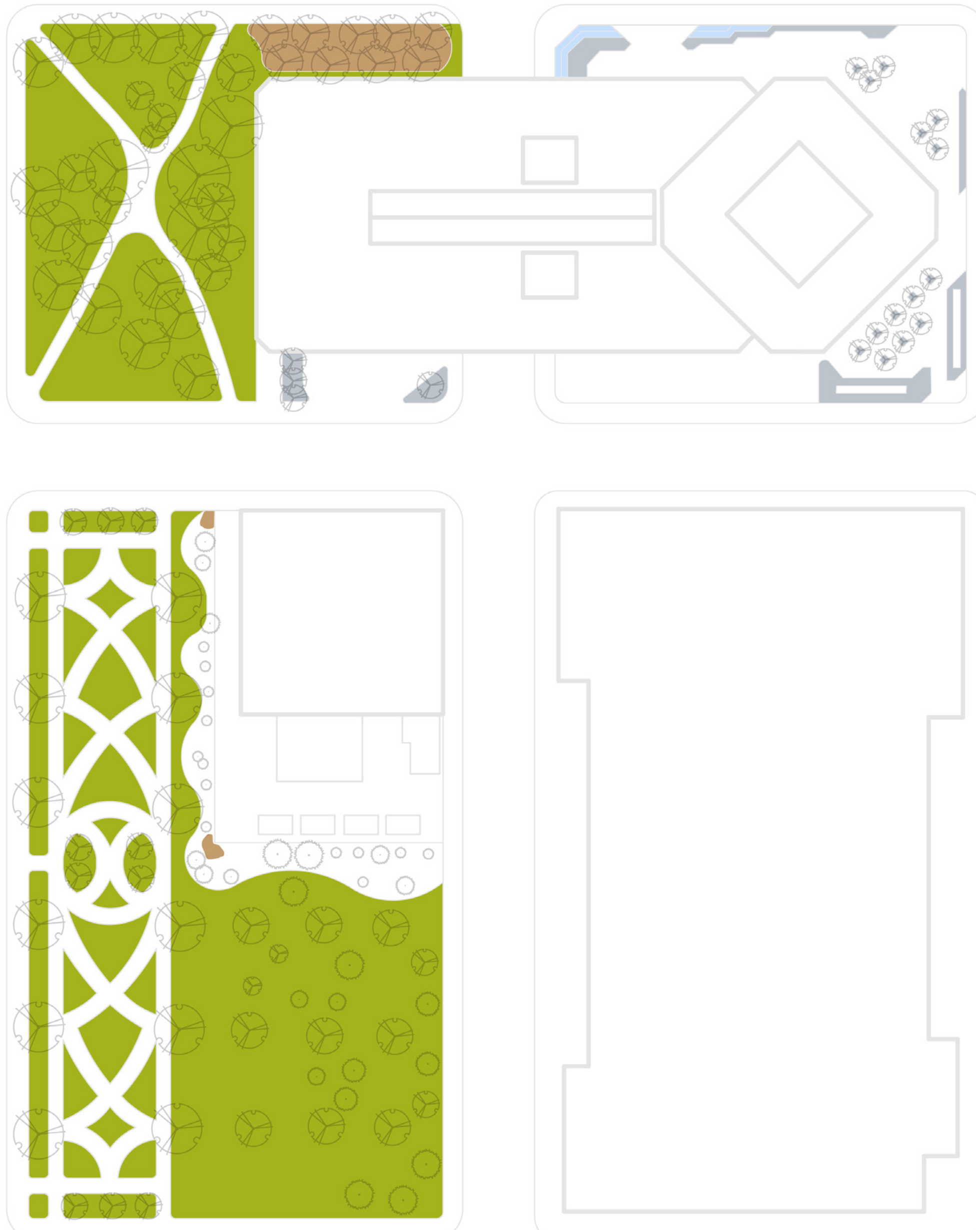
Species
Azalea
Itea
Liriope
Rose
Spirea
Vinca Minor
Karl Foerster Reed Grass
Nandina
Boxwood
Prairie Coneflower
Hibiscus syriacus
American Arborvitae
Barberry
Pennisetum
Various Annuals
Cool-Season Turf

Turf
Woody Shrubs
Groundcover
Herbaceous
Ornamental Grass
Annuals

Species	*Species Factor (from Table 4.1)*	*Species*	*Species Factor (from Table 4.1)*
Azalea	.5	Hibiscus syriacus	.4
Itea	.5	American Arborvitae	.5
Liriope	.3	Barberry	.3
Rose	.4	Pennisetum	.3
Spirea	.4	Various Annuals	.6
Vinca Minor	.3	Cool-Season Turf	.8
Karl Foerster Reed Grass	.3		
Nandina	.5		
Boxwood	.5		
Prairie Coneflower	.3		

Figure 4.2 Sigma Aldrich Planting Plan and Species Factors

Species
Boxwood
Viburnum
Wintercreeper Euonymus
English Ivy
Juniperus horizontalis
Inkberry
Various Annuals
Cool-Season Turf



Turf
Woody Shrubs
Groundcover
Herbaceous
Ornamental Grass
Annuals

Species	*Species Factor (from Table 4.1)*	*Species*	*Species Factor (from Table 4.1)*
Boxwood	.5		
Viburnum	.5		
Wintercreeper Euonymus	.3		
English Ivy	.4		
Juniperus Horizontalis	.4		
Inkberry	.5		
Various Annuals	.6		
Cool-Season Turf	.8		

Figure 4.3 Bank of America Planting Plan and Species Factors

Landscape Coefficient Method – Determining the Microclimate Factor (K_{MC})

Due to variations in the environmental conditions within a particular site, the microclimate factor (K_{MC}) is used to reflect the influences of site conditions on a particular planting zone. K_{MC} takes into account the planting zone's proximity to paved areas and highly reflective surfaces, sun, shade, protection from wind, and hot or cool areas. For example, a planting in a paved open area may have 50% more evapotranspiration than the same planting in a park setting (The Irrigation Association 2005, 1-11). Table 4.2 shows microclimate factors for different plant types. Factors in the "high" category, greater than 1 ($K_{MC} > 1$), reflect hostile microclimate conditions such as plantings surrounded by a paved surface in full sun, or plantings near a highly reflective window or heat absorbing surface. Factors in the "low" category, less than 1 ($K_{MC} < 1$), reflect more hospitable conditions such as plantings in full shade, away from heat absorbing surfaces, and fully protected from wind (The Irrigation Association 2005, 1-11). In general, planting zones in "high" microclimate categories require greater than average water quantities. Conversely, planting zones in "low" microclimate categories require less than average water quantities.

Microclimate identification for each study site was conducted during site visits between November 22, 2013 – January 17, 2014. Highly reflective surfaces, heat absorbing surfaces, and areas protected from wind were noted on a site plan for future reference. Geo-referenced SketchUp (Trimble 2014) models were used to determine a planting zone's proximity to sun and shade for each study site. Each model was set to June 21 and analyzed throughout the day to determine the amount of time each planting zone spent in the sun or shade. Figures 4.4 – 4.6 show the SketchUp sun\shade models for each study site at different periods throughout the day. Figures 4.7 – 4.9 show each study site's microclimate zones based on the site visits and SketchUp study models and documented existing conditions within each site's microclimate zones and their associated microclimate factor. The K_{MC} factor for each microclimate zone has been developed to reflect conditions relative throughout the three study sites. For example, a patch of turf in full sun in the park setting of the Missouri History Museum has a lower K_{MC} factor than a patch of turf in full sun in the dense urban setting of the Bank of America Plaza.

Vegetation	High	Average	Low
Trees	1.4	1.0	.5
Shrubs	1.3	1.0	.5
Groundcover	1.2	1.0	.5
Mix of Trees, Shrubs, and Groundcover	1.4	1.0	.5
Turf	1.2	1.0	.8

Table 4.2 Microclimate Factors: Values for Plant Types. (Source: The Irrigation Association 2005)

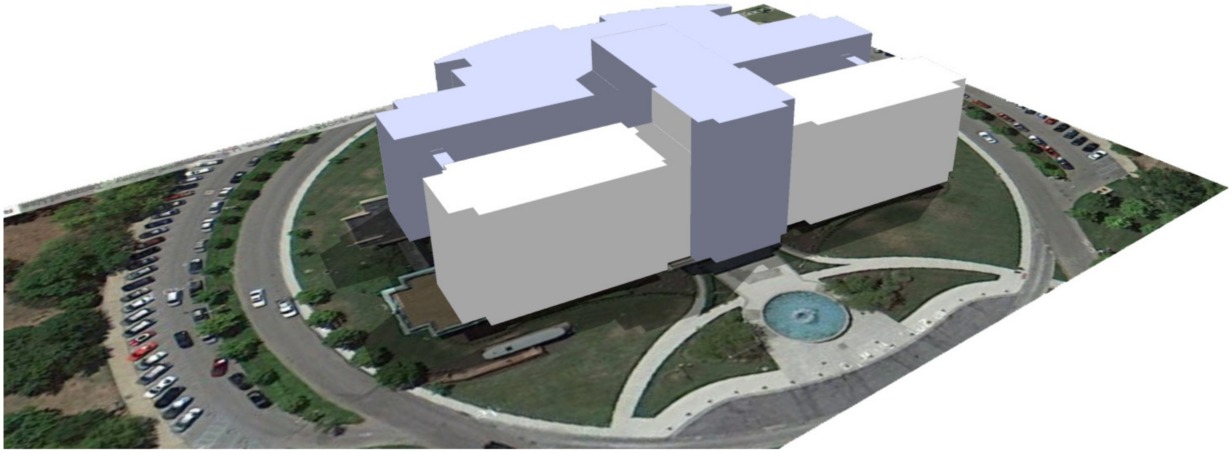


Figure 4.4 Missouri History Museum Sun/Shade Study Model for Determining Microclimates (Trimble 2014)

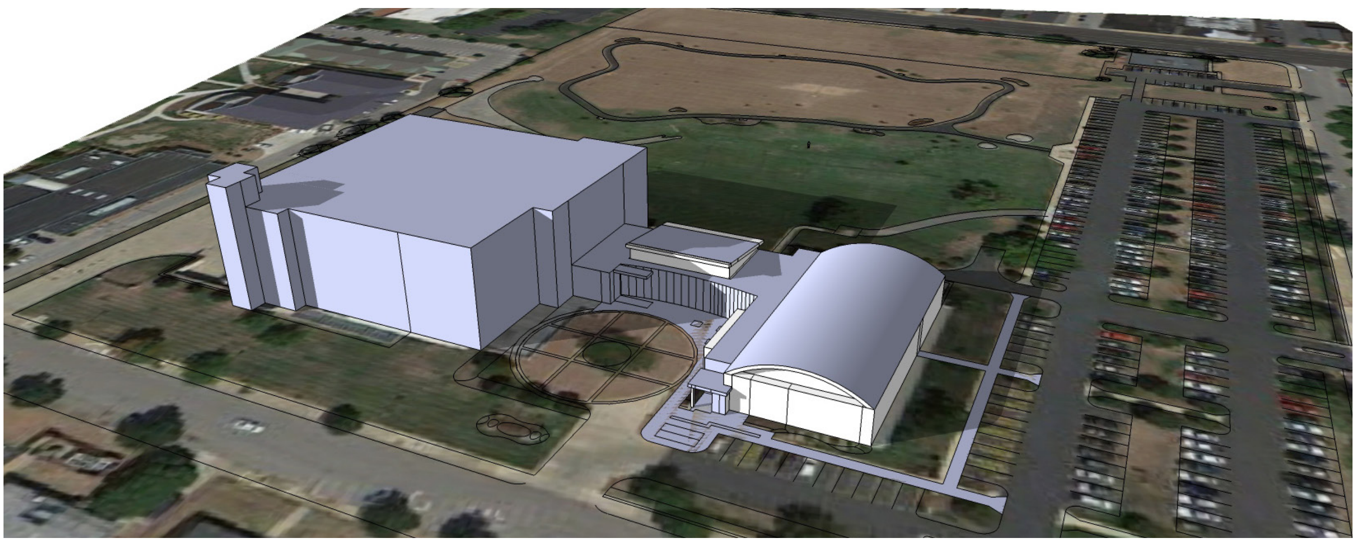


Figure 4.5 Sigma Aldrich Sun/Shade Study Model for Determining Microclimates (Trimble 2014)

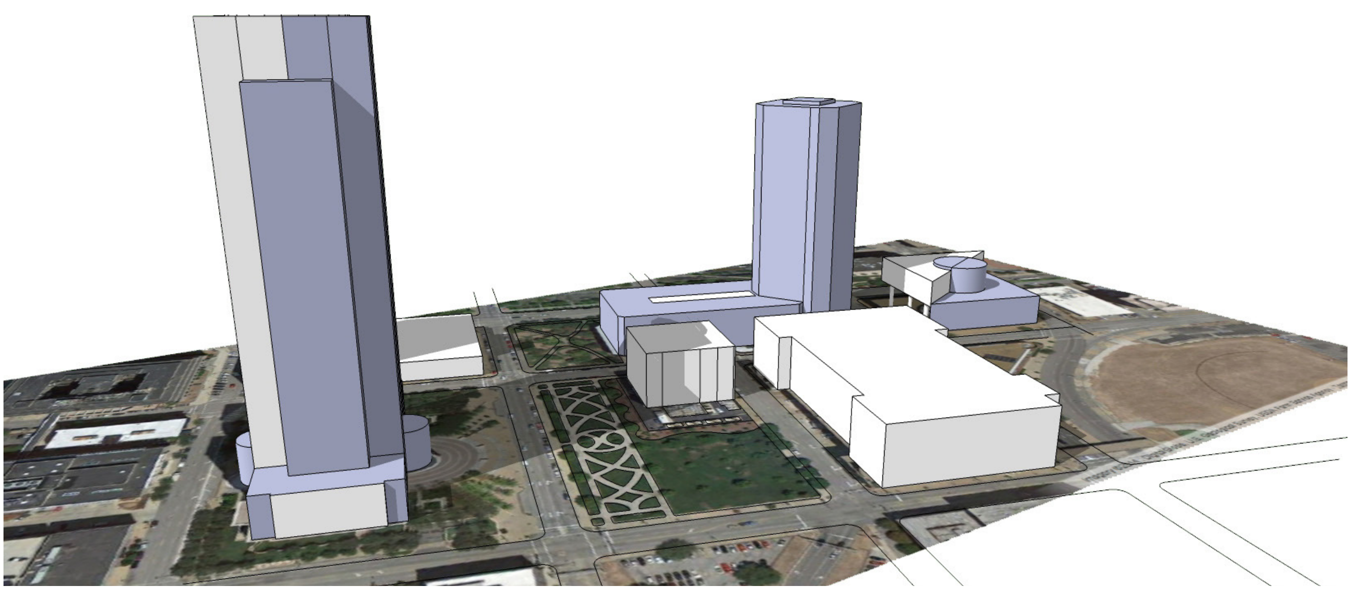
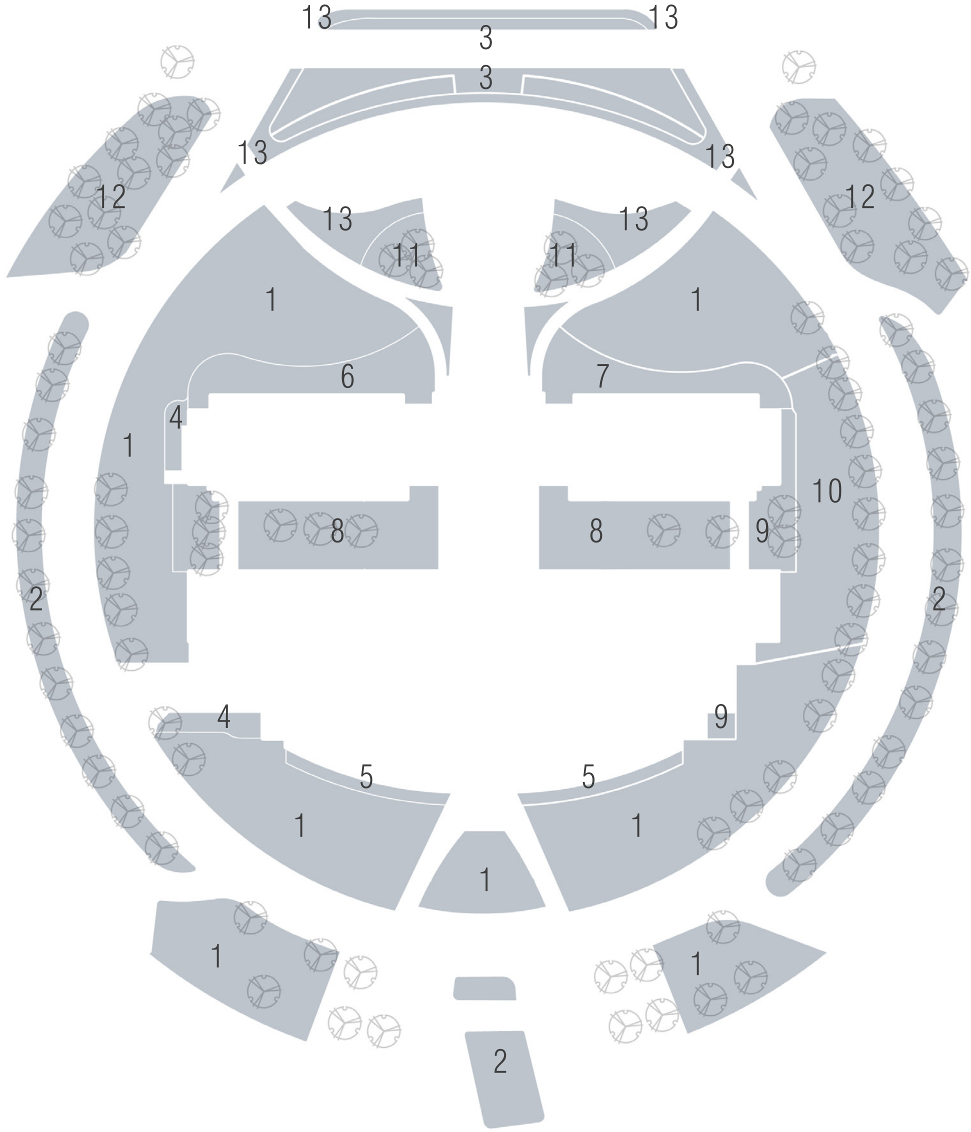
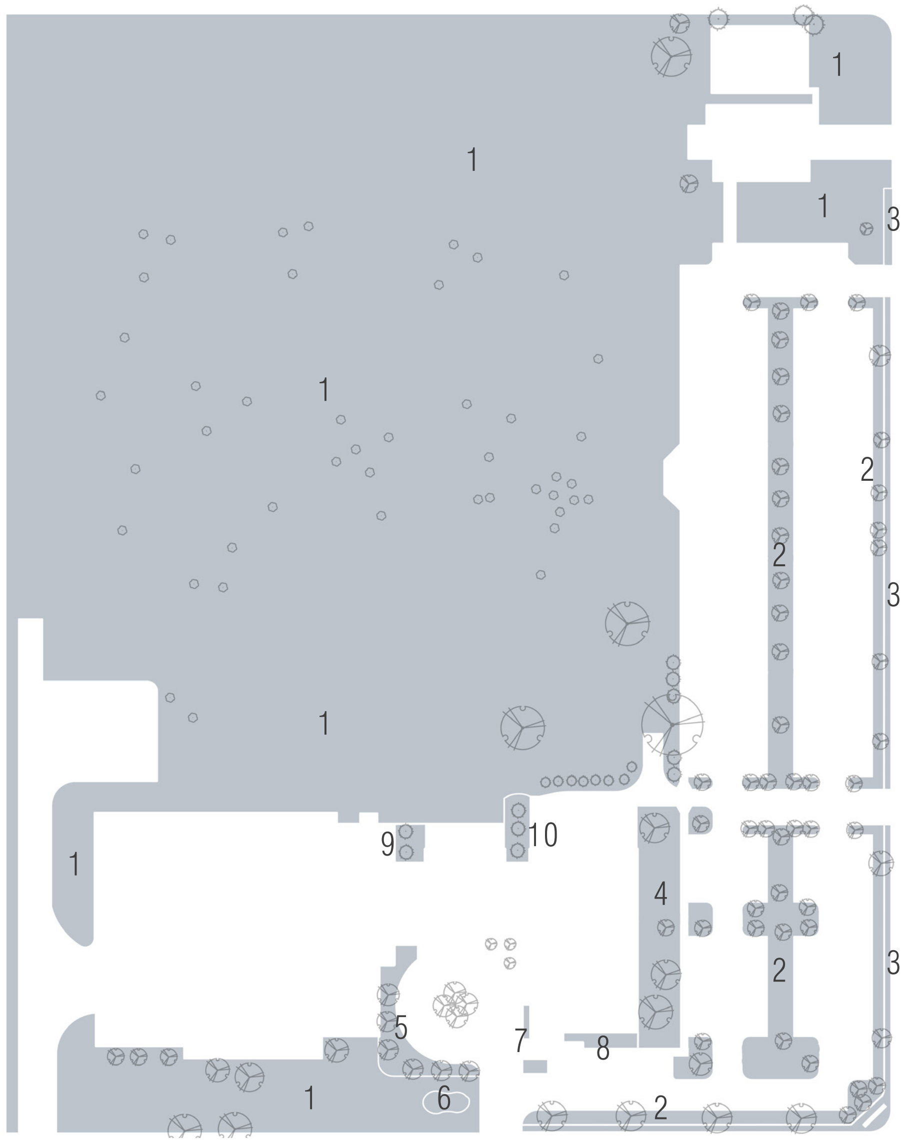


Figure 4.6 Bank of America Plaza Sun/Shade Model for Determining Microclimates (Trimble 2014)



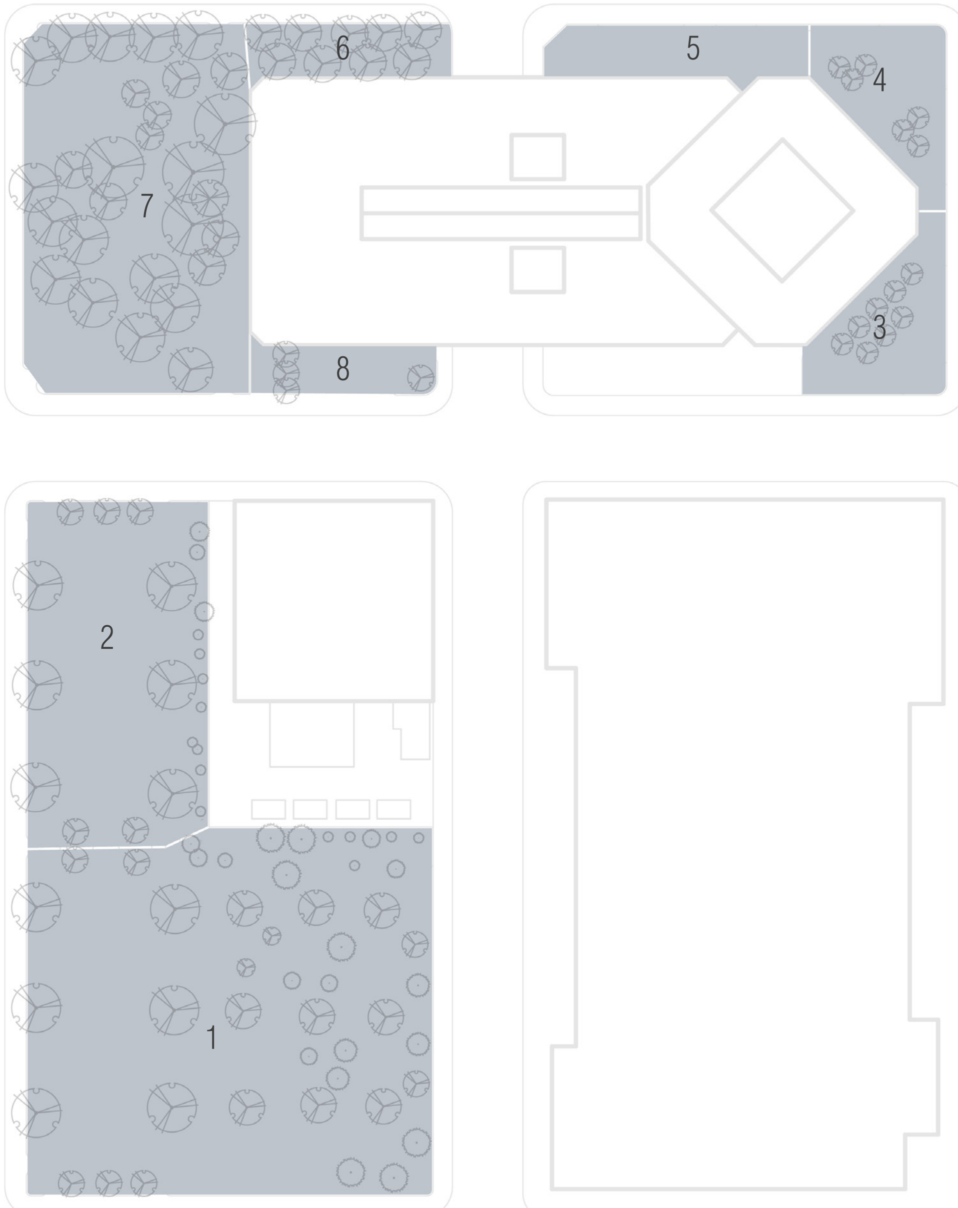
Zones	Microclimate Factor (from Table 4.2)	Description of Microclimate
1	1.10	Turf; Full sun; No protection from wind
2	1.20	Groundcover; Full sun; Near paved surface; No protection from wind
3	1.30	Perennial Bed; Full sun; Near paved surface; No protection from wind
4	1.20	Shrubs; Full sun after noon; Near heat absorbing material; No wind protection
5	1.30	Ornamental grass; Full sun; Near highly reflective window
6	0.70	Shrubs; Part shade; Protected from southern summer winds
7	0.70	Shrubs; Part shade; Protected from southern summer winds
8	1.15	Shrubs; Part sun; Complete wind protection; Near heat absorbing surface
9	0.80	Shrubs; Part shade; Protected from wind
10	1.05	Turf; Full sun until afternoon; Near paved surface; No wind protection
11	0.90	Mix; Filtered sunlight; Near paved surface; Adjacent to water feature
12	1.00	Turf; Part sun through tree canopy; Near paved surface
13	1.20	Turf; Full sun; Near paved surface; No protection from wind

Figure 4.7 Missouri History Museum Microclimate Zones and Associated Microclimate Factors



Zones	Microclimate Factor (from Table 4.2)	Description of Microclimate
1	1.10	Turf; Full sun; No protection from wind
2	1.20	Turf; Full sun; Near paved surface; No protection from wind
3	1.30	Shrub; Full sun; Near paved surface; No protection from wind
4	1.05	Turf; Full shade after 2:00 pm; Some wind protection
5	1.15	Mix; Full sun from 8:00-3:00; Near paved surface; Some wind protection
6	1.20	Shrub; Full sun; No protection from wind
7	1.15	Shrub; Part sun; Near paved surface; Some wind protection
8	1.20	Shrubs; Full sun; Near paved surface; Some wind protection
9	0.85	Mix; Full shade after 1:00; Completely protected from wind
10	0.95	Mix; Full shade after 3:00; Completely protected from wind

Figure 4.8 Sigma Aldrich Microclimate Zones and Associated Microclimate Factors



Zones	Microclimate Factor (from Table 4.2)	Description of Microclimate
1	1.30	Turf; Full sun; No protection from wind; Dense urban environment
2	1.20	Turf; Full sun 10:00-3:00; No wind protection; Urban environment
3	1.40	Mix; Full sun 8:00-5:00; Surrounded by pavement; Near reflective building
4	1.20	Mix; Full shade after 1:00; Near pavement; Near reflective building
5	1.10	Groundcover; Full shade 11:00-5:00; Near pavement & reflective building
6	1.00	Mix; Full shade all day; Near pavement & reflective building
7	1.10	Turf; Filtered sun all day; Some wind protection
8	1.35	Mix; Full sun 10:00-4:00; Near pavement & reflective building

Figure 4.9 Bank of America Plaza Microclimate Zones and Associated Microclimate Factors

Landscape Coefficient Method – Determining the Density Factor (K_D)

The density of a planting area can have a significant effect on the water requirements of a zone. In general, denser vegetation requires more water than less dense vegetation. Table 4.3 shows density factors for different plant types. "High" density factors reflect planting zones with dense plantings, which require greater than average water quantities. Conversely, "low" density factors reflect sparse planting zones and require less than average water quantities. For a typical planting zone, a plant density value of 1.0 is recommended (The Irrigation Association 2005, 1-12).

The density factors were determined through site visits between November 22 – January 17. Tables 4.4 - 4.6 show density factors for each planting zone within each of the three study sites. Density factors applied to each planting zone were developed based on my previous work experience with planting plans, knowledge of planting design, and reviewal by Dr. Lavis.

Vegetation	*High*	*Average*	*Low*
Trees	1.3	1.0	.5
Shrubs	1.1	1.0	.5
Groundcover	1.1	1.0	.5
Mix of Trees, Shrubs, and Groundcover	1.3	1.0	.6
Turf	1.0	1.0	.6

Table 4.3 Density Factors: Values for Plant Types. (Source: The Irrigation Association 2005)

Species	*Density Factor (from Table 4.3)*	*Species*	*Density Factor (from Table 4.3)*
Prairie Dropseed	1.00	Various Annuals	0.80
Black-Eyed Susan	0.60	Hydrangea	1.00
Liriope	1.05	Winged Euonymus	1.10
Maiden Grass	1.00	Cool-Season Turf	1.00
Rhus aromatica	0.75		
Pennisetum	0.80		
Indiancurrent Coralberry	1.00		
Inkberry	1.00		
Witchhazel	1.00		
Itea	1.00		

Table 4.4 Missouri History Museum Planting Density Factors

Species	*Density Factor (from Table 4.3)*	*Species*	*Density Factor (from Table 4.3)*
Azalea	0.90	Hibiscus Syriacus	0.90
Itea	0.90	American Arborvitae	1.00
Liriope	1.00	Barberry	1.00
Rose	1.00	Pennisetum	1.00
Spirea	1.10	Various Annuals	1.00
Vinca Minor	1.00	Cool-Season Turf	1.00
Karl Foerster Reed Grass	1.00		
Nandina	0.80		
Boxwood	0.90		
Prairie Coneflower	1.00		

Table 4.5 Sigma Aldrich Planting Density Factors

Species	*Density Factor (from Table 4.3)*
Boxwood	0.60
Viburnum	0.60
Wintercreeper Euonymus	1.10
English Ivy	1.10
Juniperus Horizontalis	1.00
Inkberry	1.00
Various Annuals	1.00
Cool-Season Turf	1.00

Table 4.6 Bank of America Plaza Planting Density Factors

Landscape Coefficient Method – Example of Calculating Net Plant Water Requirements Per Planting Zone

To determine the monthly water requirements for a landscape, six initial data collection tasks are needed:

- Divide the vegetation requiring irrigation into separate planting zones by individual species. Assign each species a species factor per Table 4.1.
- Determine the square footage of each planting zone
- Identify microclimate of each planting zone. If the planting zone falls in two microclimates, divide the planting zone so there is only one microclimate per planting zone. Assign each microclimate a microclimate factor per Table 4.2.
- Determine the density of each planting zone. Assign each planting zone a density factor per Table 4.3.
- Gather monthly ET_o data for the region.
- Gather monthly rainfall data for the region.

*Note: Monthly ET_o and Rainfall data should reflect the most recent climatic trends if possible.

The following example shows the calculations needed to determine the Net Plant Water requirements for patches of Liriope (groundcover) over the month of July at the Missouri History Museum.

<u>Step 1 – Calculate Landscape Coefficient (K_L)</u>

K_S = .3 (per Table 4.1)
K_{MC} = 1.2 (per Table 4.2 and Figure 4.7)
K_D = 1.05 (per Table 4.4)

$K_L = K_S * K_{MC} * K_D$
$K_L = .3 * 1.2 * 1.05$
$K_L = .378$

<u>Step 2 – Calculate Plant Water Requirement (PWR)</u>

K_L = .378
ET_o for July in St. Louis = 7.6 inches (per Figure 3.4)

$PWR = K_L * ET_o$
PWR = .378 * 7.6 inches
PWR = 2.87 inches for the month of July

<u>Step 3 – Calculate Net Plant Water Requirement</u>

PWR = 2.87 inches
R_E = 1.795 inches (50% of July monthly rainfall, per Figure 3.1)

$PWR_{NET} = PWR - R_E$
PWR_{NET} = 1.075 inches for the month of July

<u>Step 4 – Convert PWR_{NET} from inches to feet</u>

PWR_{NET} = 1.075 inches / 12 inches per foot
PWR_{NET} = .090 feet for the month of July

<u>Step 5 – Convert PWR_{NET} in feet to cubic feet.</u>

(Result is volume of water required by the Planting Zone)
PWR_{NET} = .090 feet
Area of Planting Zone = 13,697 ft^2

$PWR_{NET} = PWR_{NET}$ * Area of Planting Zone
$PWR_{NET} = .090 * 13{,}697\ ft^2$
PWR_{NET} = 1,232.73 ft^3 of water for the month of July

<u>Step 6 – Convert Planting Zone PWR_{NET} from cubic feet to gallons.</u>

1 ft^3 = 7.48 gallons
Planting Zone PWR_{NET} = 1,232.73 ft^3 * 7.48 gallons per ft^3
Planting Zone PWR_{NET} = 9,215 gallons of water for the month of July

The total July plant water requirements for the 13,697 ft^2 area of Liriope is 9,215 gallons. This method should then be repeated for every planting area shown in Figure 4.1 for every month in the typical growing season (March – October). The result will be the monthly water demand for every planting area on the site. Adding up all of the monthly water demands for each planting area for the entire growing season results in the total seasonal water demand for the study site.

Basic assumptions are inherent in using the Landscape Coefficient Method for estimating monthly plant water requirements. K_S is reflective of the water requirements for established plants. The establishment period (first 1-2 years after initial planting) is not considered for total plant water requirements. Likewise, trees on-site are not included in the calculations for this application of the method. The assumption is that mature trees in regions which receive at least 30" of rain per year do not need supplemental water (Davis 2014). Mature trees can withstand long periods of drought and can survive on the combination of rainfall and excess irrigation from the understory planting zone in which it is located. Finally, the total monthly

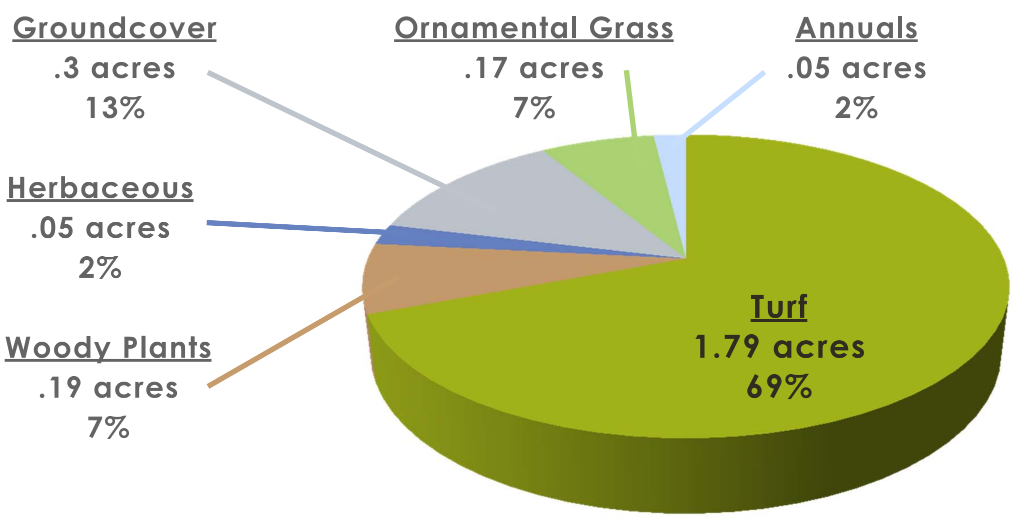
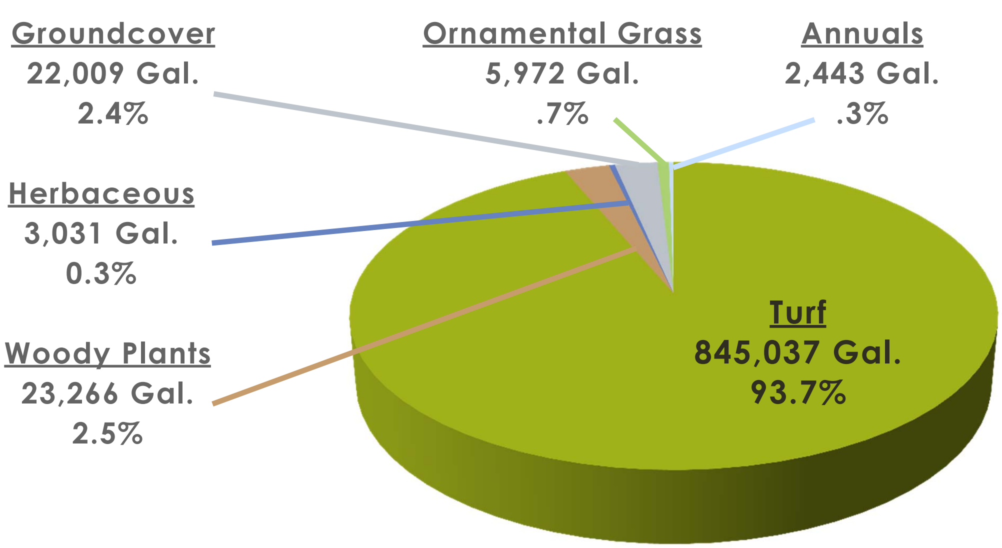


Figure 4.10 shows that turf makes up 1.79 acres or 69% of the vegetation at the Missouri History Museum

Figure 4.10 Missouri History Museum % of Landscape Area by Planting Type



While turf makes up only 69% of the landscape at the Missouri History Museum, It requires almost 94% of the site's irrigation.

Figure 4.11 Missouri History Museum % of Landscape Water Demand by Planting Type plant water requirement is not an exact indicator of the threshold for the livelihood of a particular plant. For example, if the Liriope planting zone in the example were to only receive 9,200 gallons for the month of July, 15 gallons less than the estimation calculation indicates, it more than likely will not die. The estimation calculation is based on the subjective assignment of species factors, microclimate factors, and density factors that result in an approximate assessment of plant water needs for general irrigation planning purposes.

Figures 4.10– 4.21 show estimated landscape water demand results for each of the three study sites in this investigation.

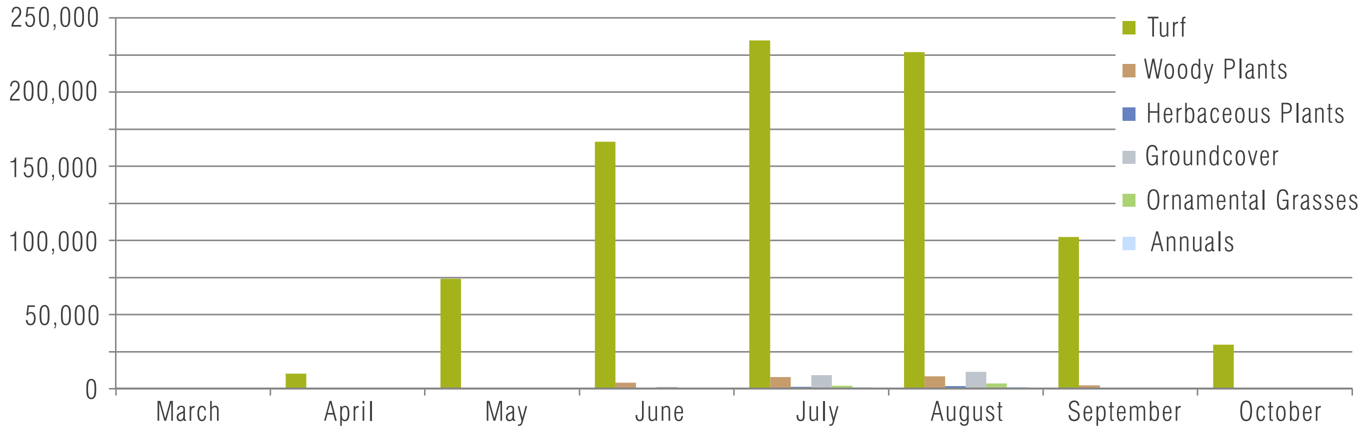


Figure 4.12 Missouri History Museum Monthly Landscape Water Demand (in gallons) (March - October)

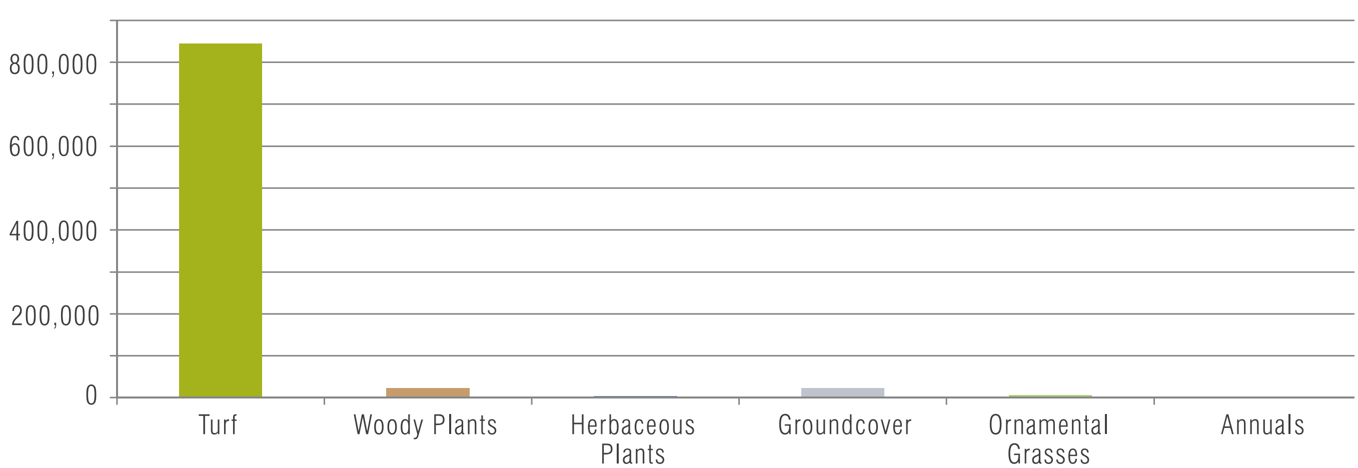


Figure 4.13 Missouri History Museum Total Landscape Water Demand (in gallons) (March - October)

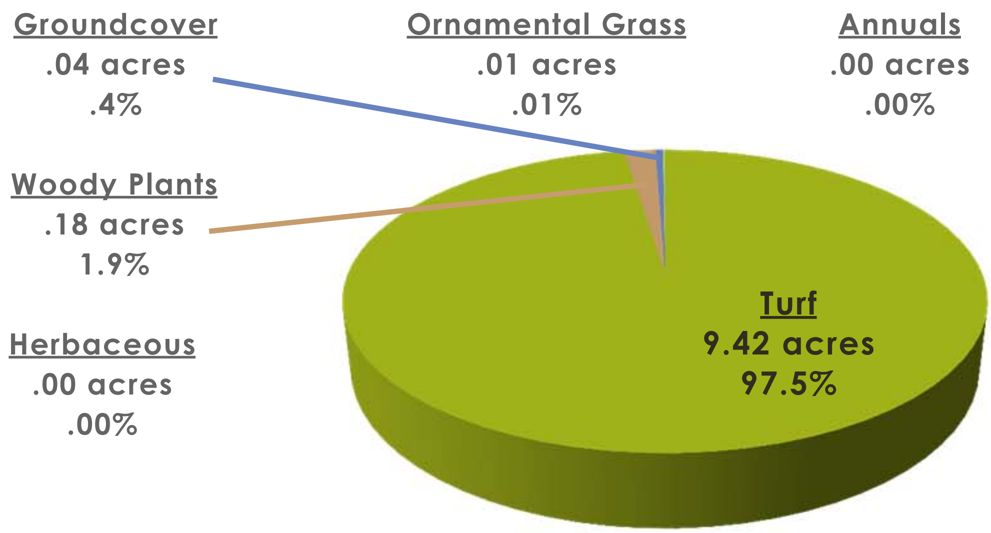
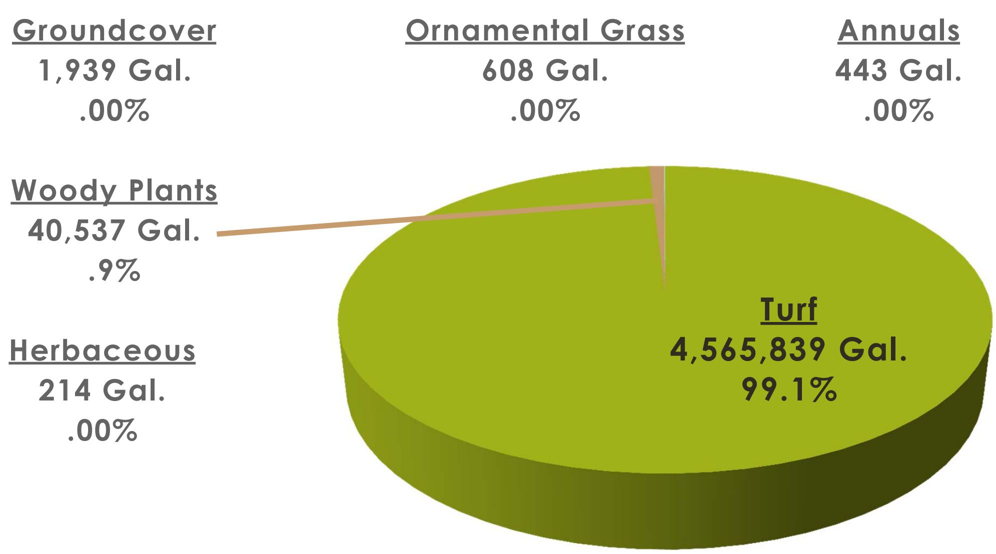


Figure 4.14 shows that turf makes up 9.42 acres or 97.5% of the vegetation at Sigma Aldrich

Figure 4.14 Sigma Aldrich % of Landscape Area by Planting Type



While turf makes up 97.5% of the landscape at the Sigma Aldrich, It requires 99% of the site's irrigation.

Figure 4.15 Sigma Aldrich % of Landscape Water Demand by Planting Type

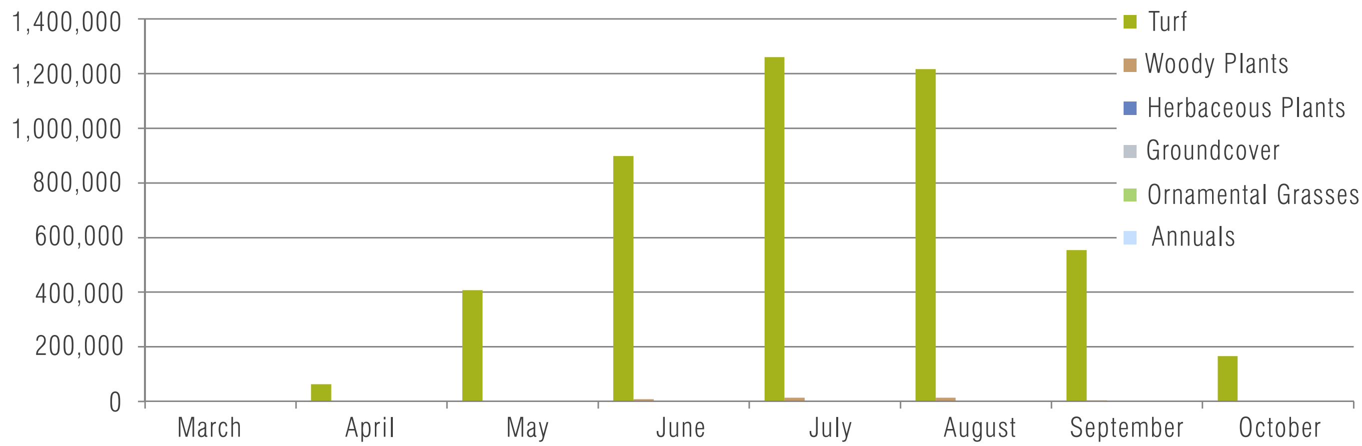


Figure 4.16 Sigma Aldrich Monthly Landscape Water Demand (in gallons) (March - October)

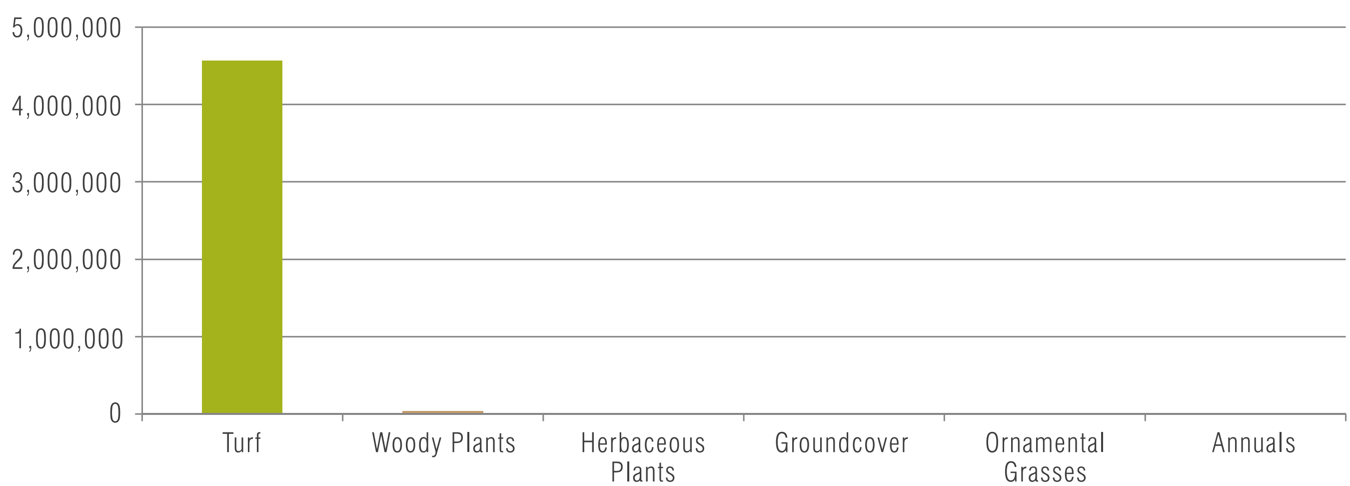


Figure 4.17 Sigma Aldrich Total Landscape Water Demand (in gallons) (March - October)

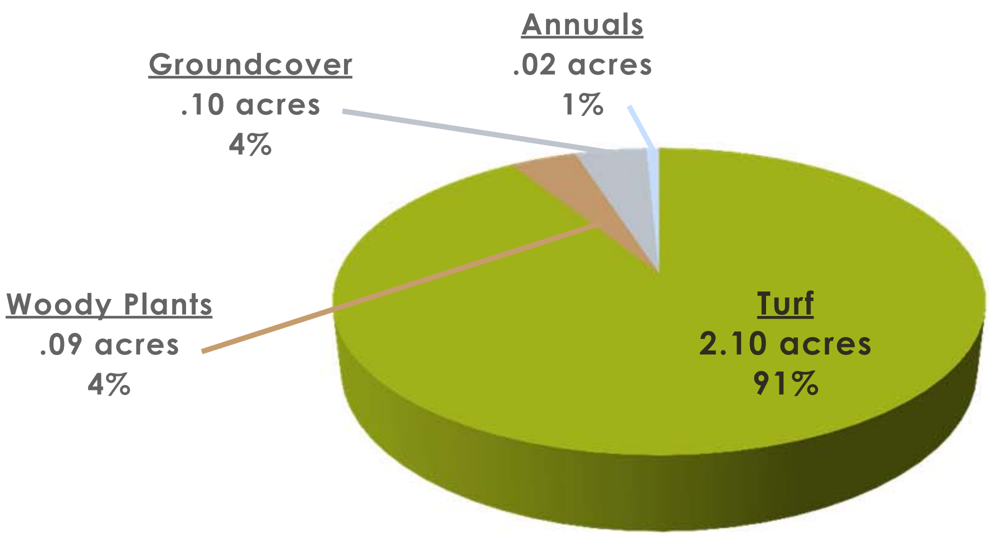
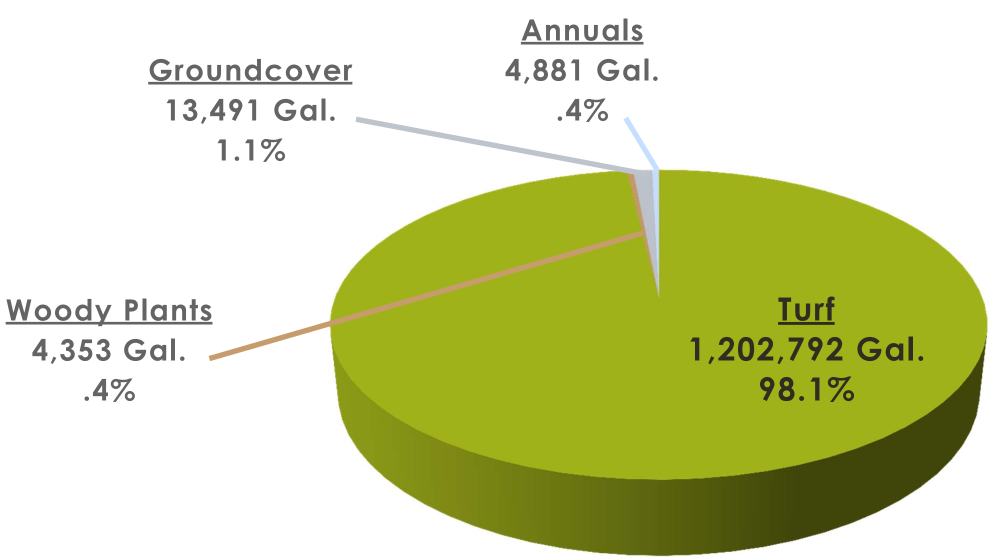


Figure 4.18 shows that turf makes up 2.10 acres or 91% of the vegetation at the Bank of America Plaza.

Figure 4.18 Bank of America Plaza % of Landscape Area by Planting Type



While turf makes up 91% of the landscape at the Bank of America Plaza, It requires 98% of the site's irrigation.

Figure 4.19 Bank of America Plaza % of Landscape Water Demand by Planting Type

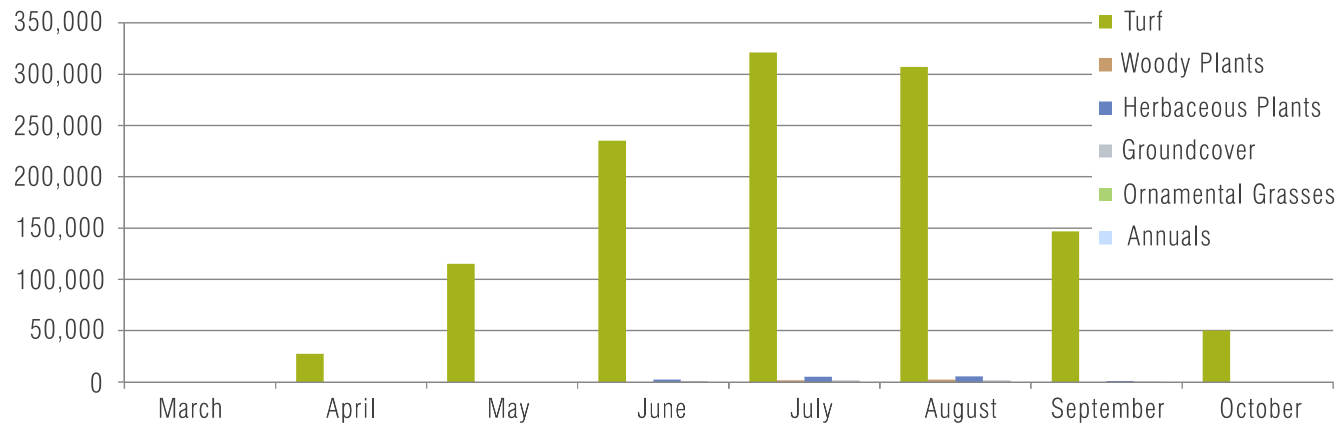


Figure 4.20 Bank of America Plaza Monthly Landscape Water Demand (in gallons) (March - October)

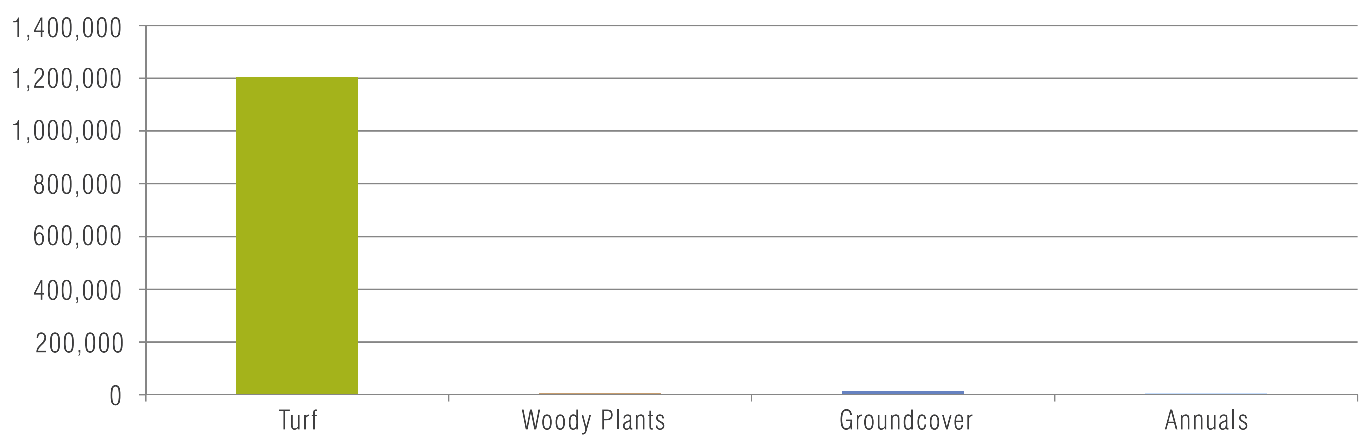


Figure 4.21 Bank of America Plaza Total Landscape Water Demand (in gallons) (March - October)

Determining Potential Supply

Calculating Potential Supply from Surface Runoff

To determine the potential supply of water that can be harvested from surface runoff, the method provided in Krishna (2005), Kinkade and Bock (2011), and Waterfall (2004) is used:

Potential Supply of Water = Catchment area * Amount of Rainfall * Runoff Coefficient

where:
Catchment area = Area of surface from which runoff will be collected (ft^2)
Monthly rainfall = Rainfall (feet/period)
Runoff Coefficient = Coefficient relating to the percentage of water that leaves a particular surface as runoff (expressed as a decimal).

The potential supply of water to be harvested from surface runoff for the three study sites is limited to only impervious surfaces on-site, not including public streets that may run through the site. Vegetated surfaces, such as lawns or meadows, are not included in the baseline study due to the inability of each surface to produce significant amounts of runoff necessitating collection. Runoff producing surfaces included in this portion of the study include: rooftops, paved walkways, paved plaza/gathering areas, driveways and parking lots, and gravel paths. Figures 4.22, 4.25, and 4.28 show the breakdown of the potential supply from collection surfaces for each of the three study sites.

Example of Calculating Supply for Surface Runoff

The following example shows the steps needed to estimate the potential supply of water that can be collected from the rooftop of the Missouri History Museum for the month of April.

Step 1- Gather all of the information relating to the input variables
Catchment Area = 53,227 ft^2
Amount of Rainfall = 4.04 inches (per Figure 3.1)
Runoff Coefficient = .9 for rooftop

Step 2 – Convert Rainfall from inches to feet
Amount of Rainfall = 4.04 inches / 12 inches per foot
Amount of Rainfall = .336 feet for the month of April

<u>Step 3 – Input variables into the equation</u>
Catchment Area = 53,227 ft^2
Amount of Rainfall = .336 feet
Runoff Coefficient = .9

Potential Supply of Water = Catchment area * Amount of Rainfall * Runoff Coefficient
Potential Supply of Water = 53,227 ft^2 * .336 ft. * .9
Potential Supply of Water = 16,095 ft^3 of water for the month of April

<u>Step 4 – Convert cubic feet to gallons</u>
Potential Supply of Water = 16,095 ft^3
1 ft^3 = 7.48 gallons

Potential Supply of Water = 16,095 ft^3 * 7.48 gallons per ft^3
Potential Supply of Water = 120,397 gallons for the month of April

Given the 4.04 inches of rain that St. Louis has averaged for the month of April over the last 11 years, approximately 120,397 gallons can be potentially collected from the 53,227 ft^2 roof of the Missouri History Museum. This same procedure should then be followed for every surface in which surface runoff harvesting is desired to provide the total amount of water available to harvest and reuse for irrigation during the typical growing season.

Figures 4.23, 4.24, 4.26, 4.27, 4.29, and 4.30 show the results for the potential supply of water from surface runoff that can be harvested and reused for landscape irrigation for each of the three study sites. It should be noted that this phase of analyzing *potential* supply quantities does not factor cost and feasibility of collecting and harvesting water for reuse. The analysis is a hypothetical estimation which investigates how much water is *possible* to collect, regardless of cost or practicality of means of collection.

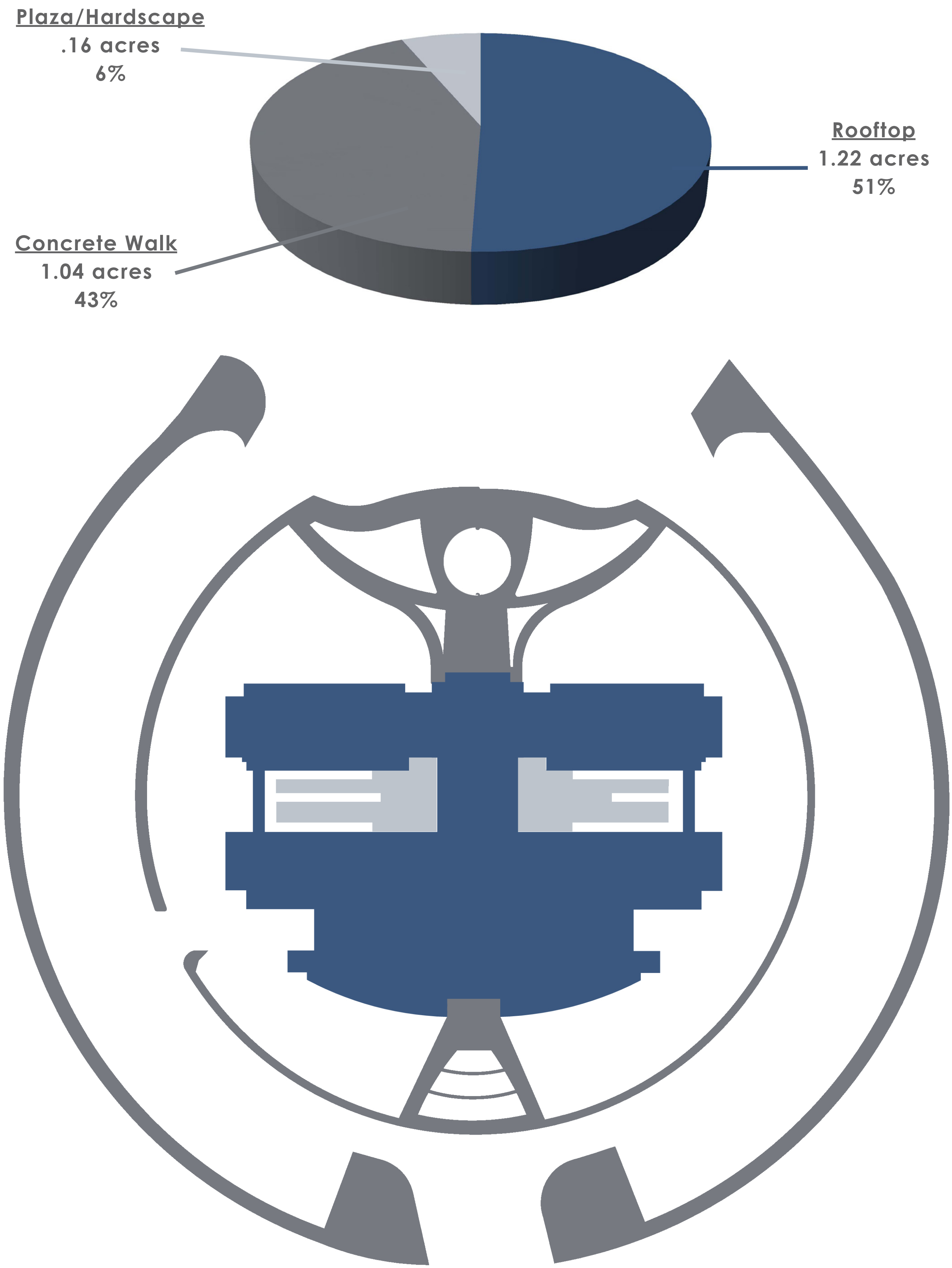


Figure 4.22 Missouri History Museum Stormwater Runoff Collection Surfaces

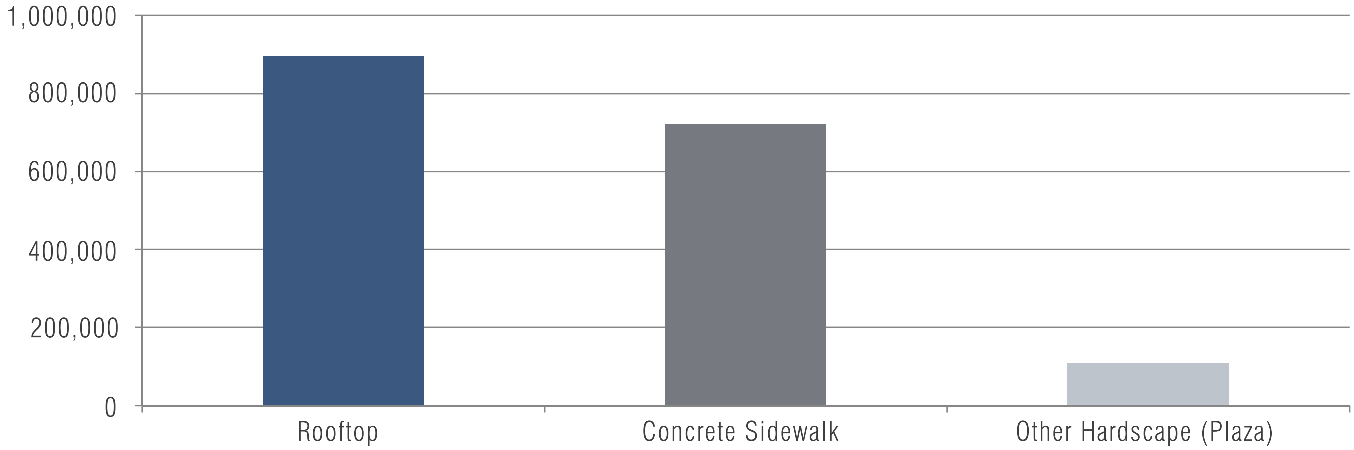


Figure 4.23 Missouri History Museum Total Potential Supply from Stormwater Runoff (in gallons)

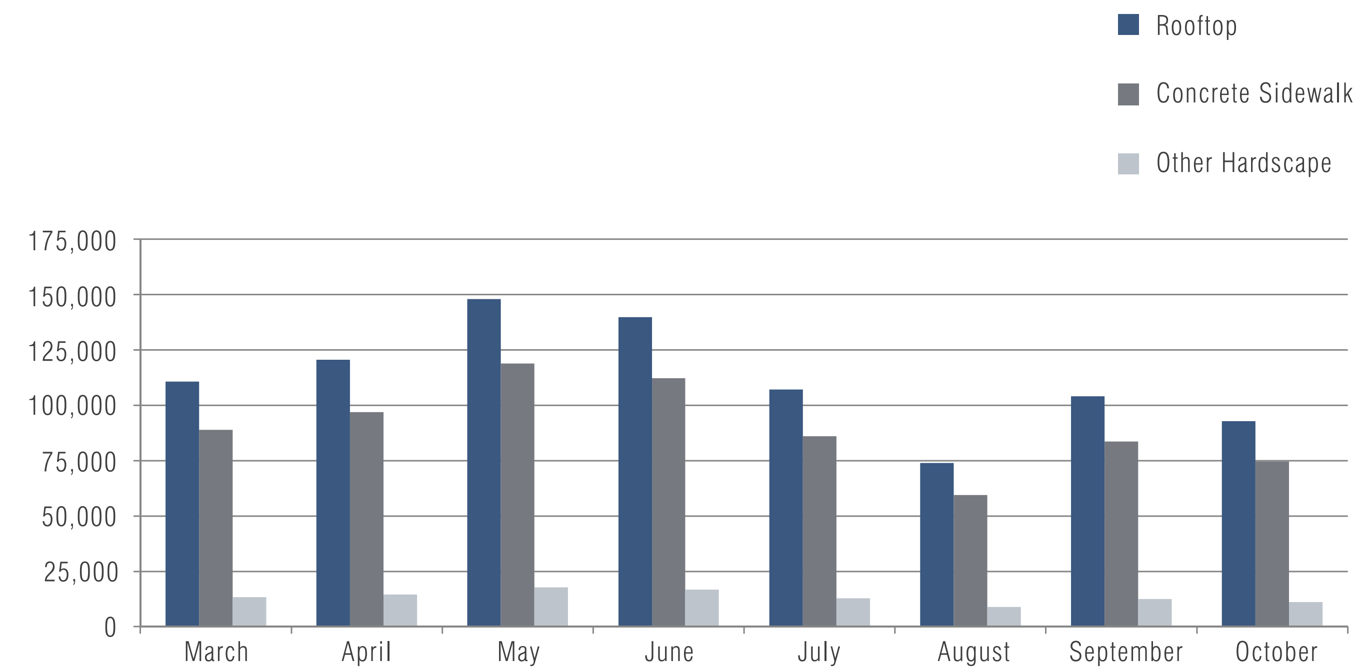


Figure 4.24 Missouri History Museum Monthly Potential Supply from Stormwater Runoff (in gallons)

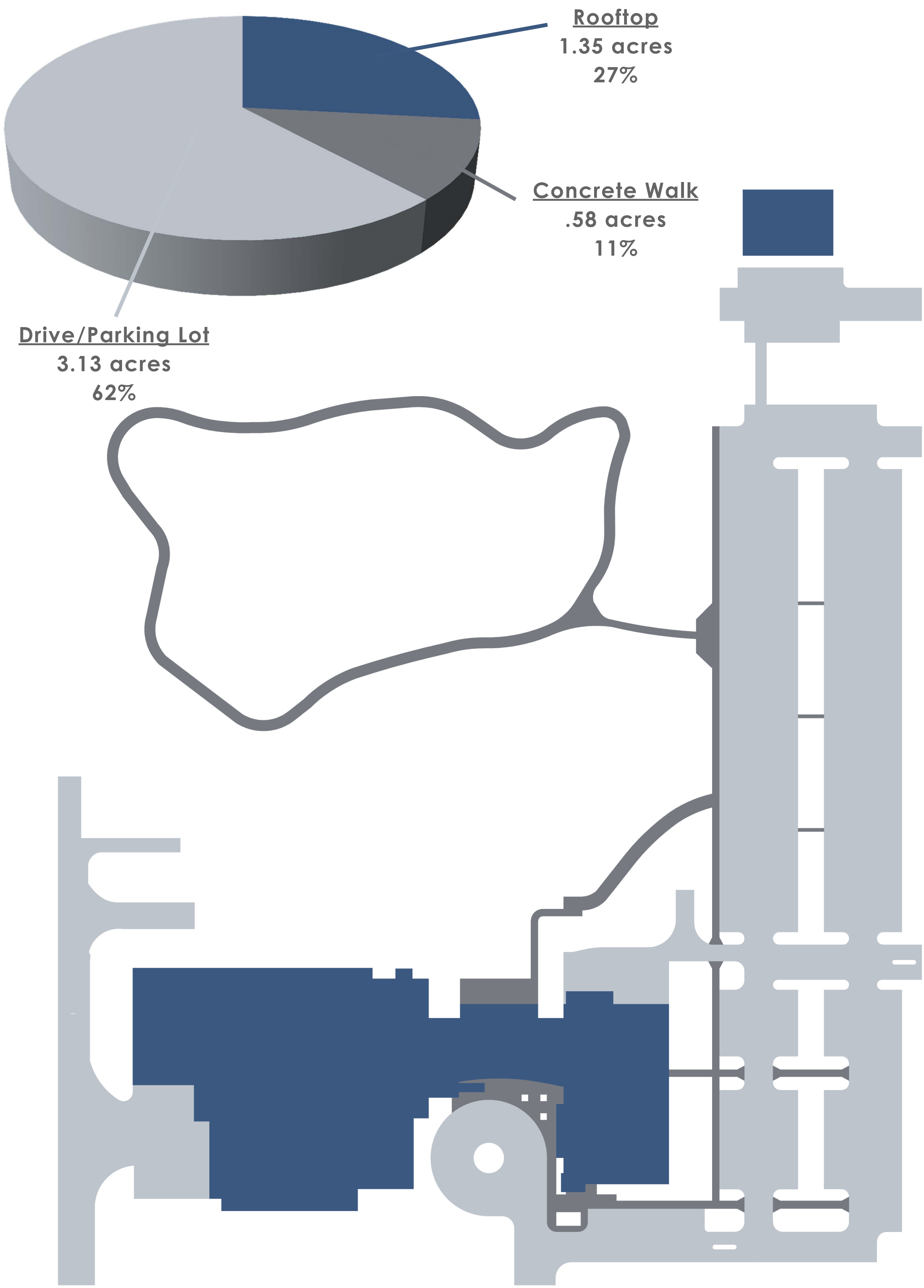


Figure 4.25 Sigma Aldich Stormwater Runoff Collection Surfaces

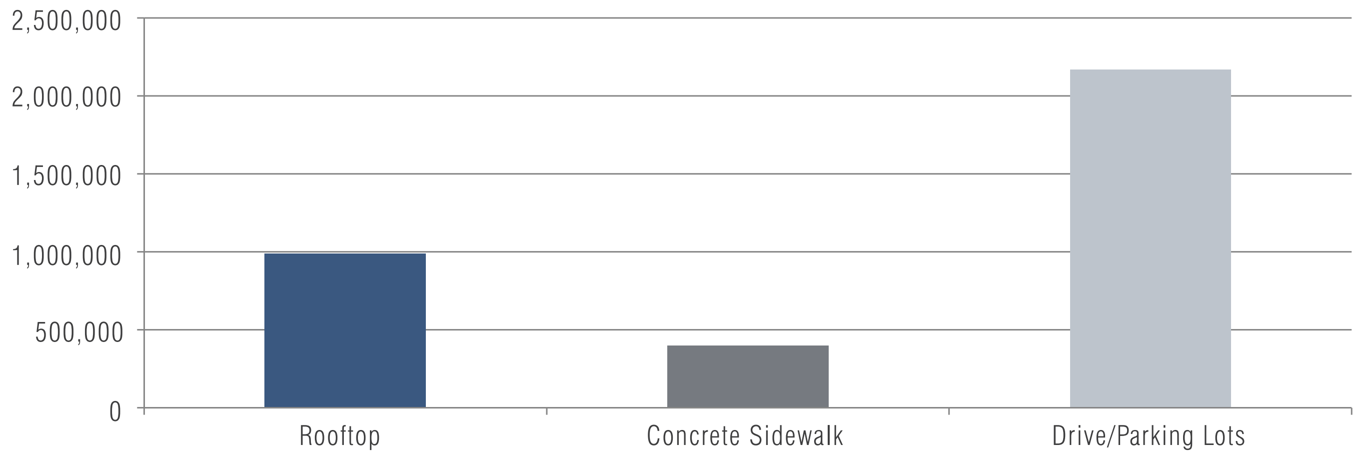


Figure 4.26 Sigma Aldrich Total Potential Supply from Stormwater Runoff (in gallons)

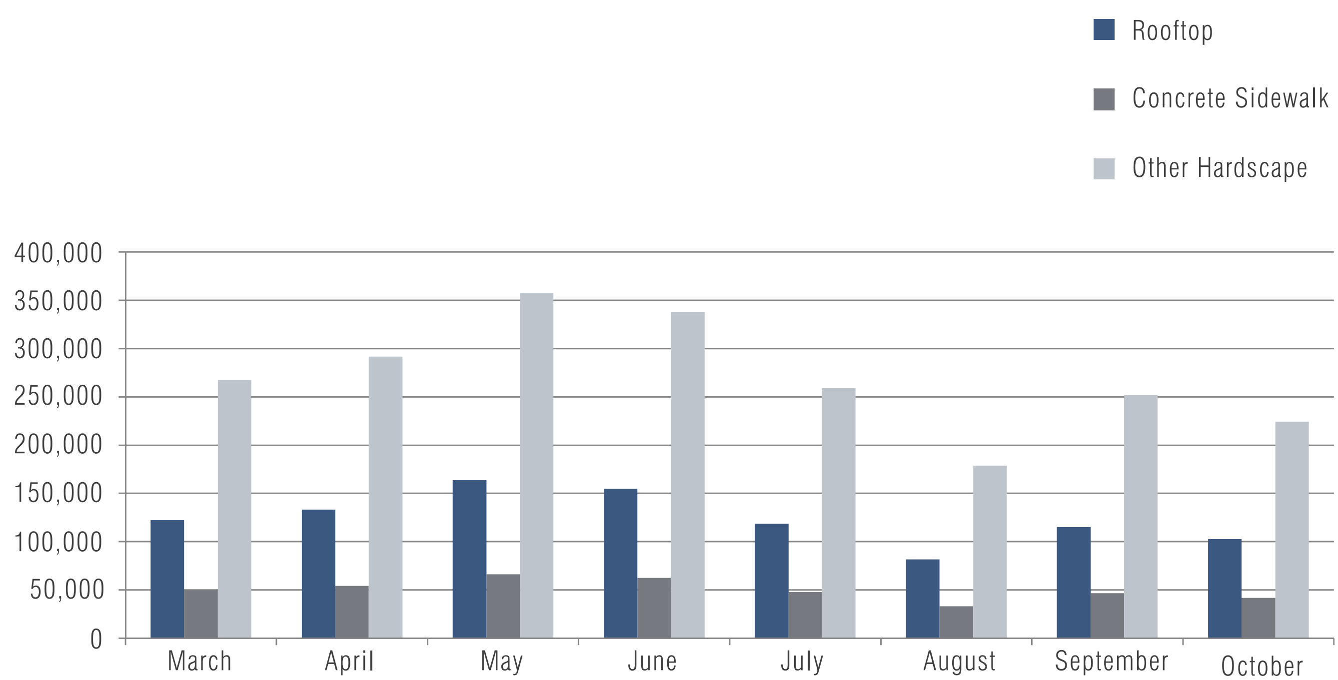


Figure 4.27 Sigma Aldrich Monthly Potential Supply from Stormwater Runoff (in gallons)

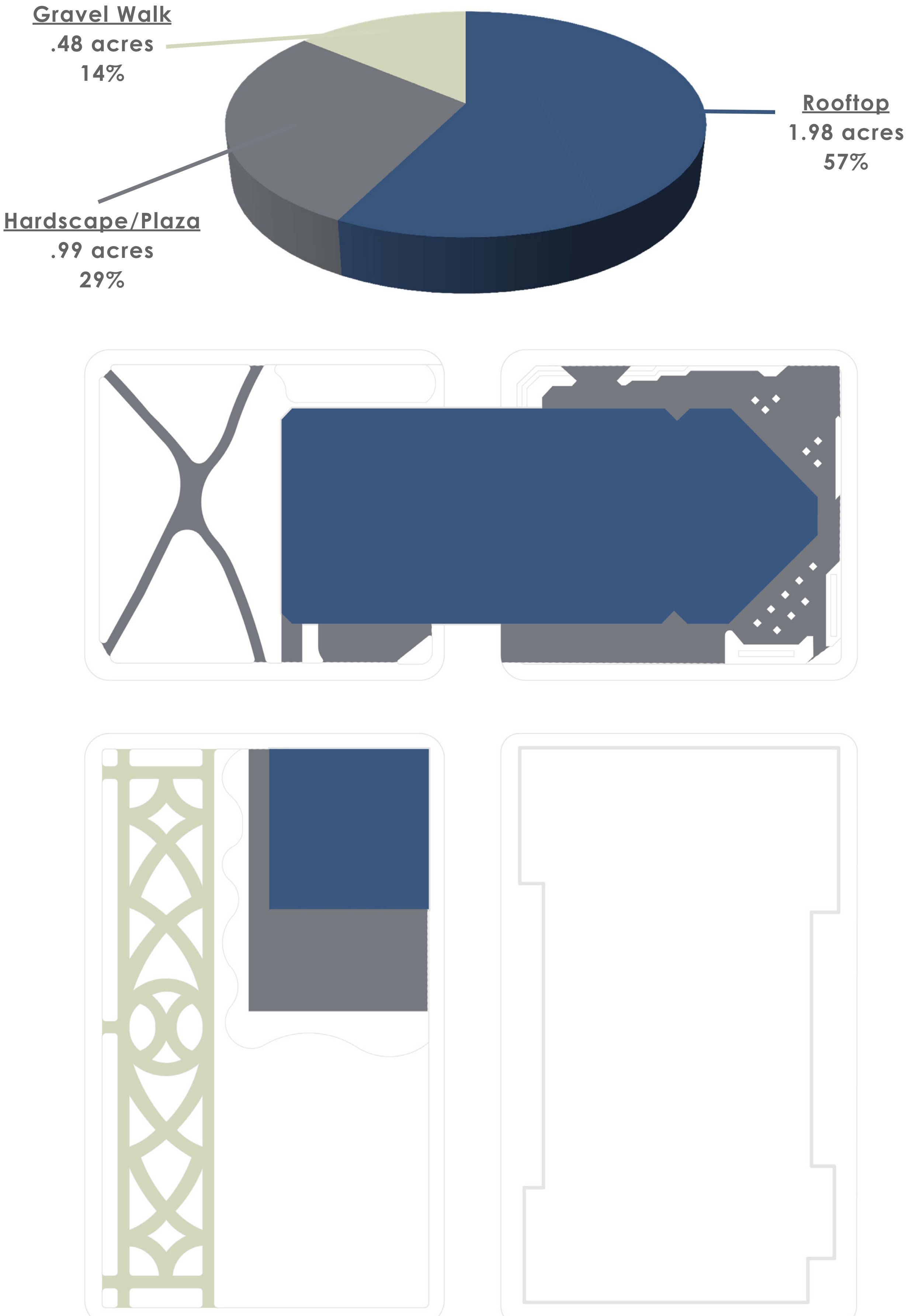


Figure 4.28 Bank of America Plaza Stormwater Runoff Collection Surfaces

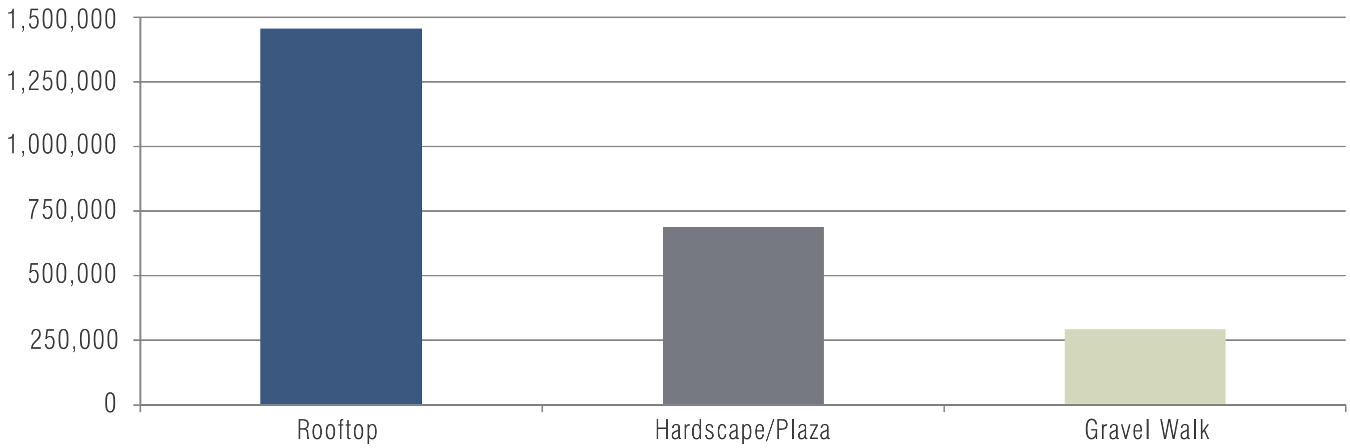


Figure 4.29 Bank of America Total Potential Supply from Stormwater Runoff (in gallons)

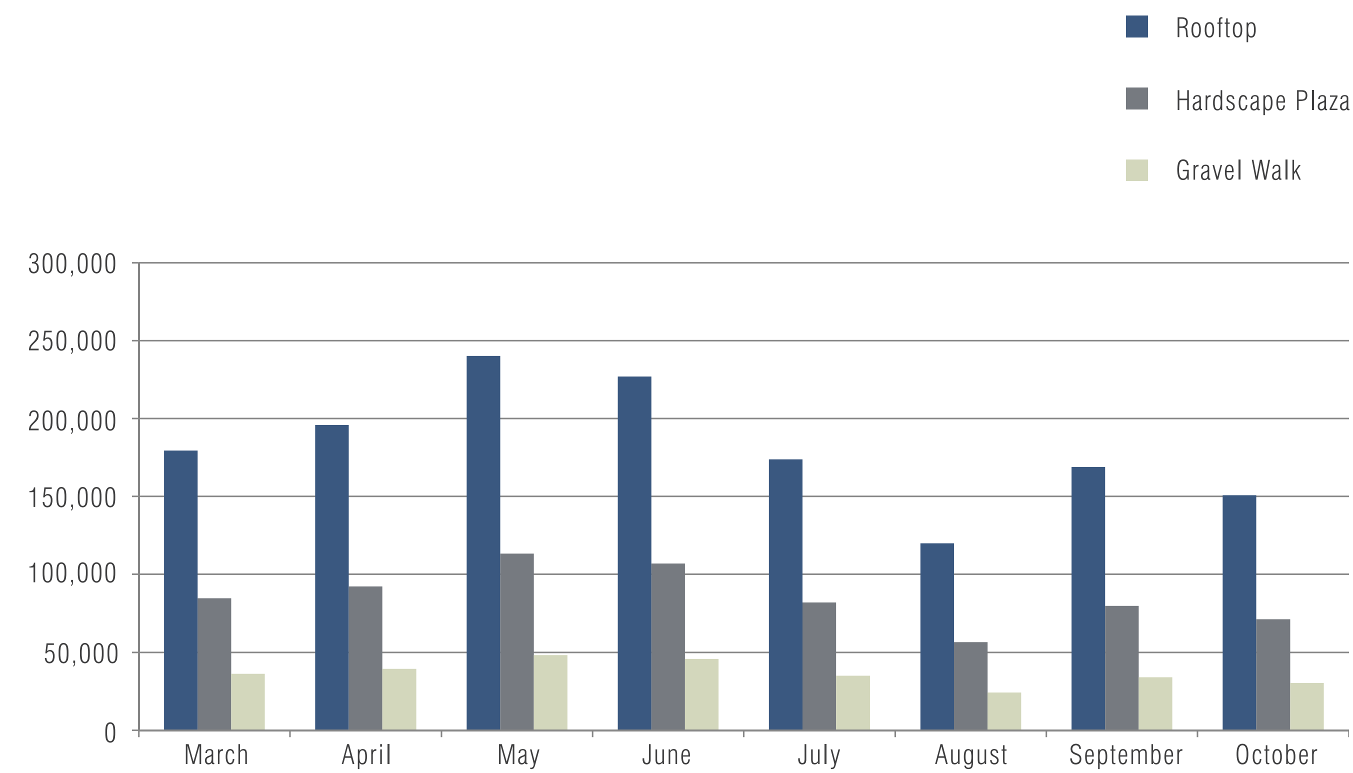


Figure 4.30 Bank of America Plaza Monthly Potential Supply from Stormwater Runoff (in gallons)

Calculating Potential Supply of Water Through Air Conditioning Condensation Collection

There is a finite quantity of water available on earth. Water cannot be destroyed. Water cannot be created. The closest we can come to creating water is by harvesting it through condensation. Air conditioning systems for large buildings provide an incredible, and largely untapped source of free, clean water via condensation. Kinkade-Levario (2007) provides a description of how condensation occurs in an A/C system:

> "Simply put, condensation is the process by which water vapor turns from a gas state into a liquid state. Consider what happens when you set a glass of ice water outside on a warm day. As the water vapor in the air surrounding the glass cools down, it changes from a gaseous state to a liquid state and the glass appears to sweat….As the air cools, its ability to hold water in the form of water vapor decreases. As a result, the water vapor turns into liquid condensation."
> (Kinkade-Levario 2007, 183)

The same concept occurs in an air conditioning system. As warm moist air from the outside enters an air conditioning unit, it crosses the unit's cooling coils where the air cools down to the temperature and humidity levels of the air inside the building.

As mentioned above, when the air cools, it loses its ability to hold water in the form of water vapor, and condensation occurs. Three major factors play a role in determining how much condensation can occur in a given A/C system: the amount of air coming through the unit, the amount of water vapor in the outside air (referred to as absolute humidity), and the amount of water vapor in the supply or indoor air. Air temperature and relative humidity determine the absolute humidity ratio of the air, and is expressed in $lb_{water}/lb_{dry\ air}$. A psychometric chart (Figure 3.5) is used to determine the absolute humidity ratio for a given dry bulb air temperature and relative humidity. For example, given an outdoor air temperature of 85°F and relative humidity of 70%, the absolute humidity ratio would be .0184 $lb_{water}/lb_{dry\ air}$. At the same time, an indoor air temperature of 70°F and relative humidity of 50% has an absolute humidity ratio of .0078 $lb_{water}/lb_{dry\ air}$. As the outside air enters the A/C unit, the humidity ratio changes across the cooling coil from .0184 to .0078 $lb_{water}/lb_{dry\ air}$. The difference in absolute humidity ($\Delta\Omega$) between incoming outdoor air and supply air leaving the unit represents the amount of condensation that occurs. Thus, for every pound of air supplied by the unit, .0184 - .0078, or .0107 pounds of water are condensed (Lawrence, Perry, Dempsey 2010b, 5). If the humidity ratio of the outside air is less than or equal to the humidity ratio of the indoor designed conditions, then condensation cannot be collected (Loveless, Farooq, Ghaffour 2012, 1354).

The equation used to estimate the total amount of condensation expected to be produced per hour is shown below:

*Condensate Collected = Airflow (ft^3/minute) * Air Density (lb./ft^3) * 60 (min/hr.) * ΔΩ ($lb_{water}/lb_{dry\ air}$)*

For example, if 1,000 ft^3/minute of outdoor air is being conditioned, the total amount of condensate expected would be:

Airflow = 1000 ft^3/minute
Air Density = .076 lb./ft^3 - standard air density (Lawrence 2014)
Outdoor Air Temperature = 85^o F
Outdoor Air Relative Humidity = 70%
Outdoor Air Humidity Ratio = .0184 $lb_{water}/lb_{dry\ air}$ (per Figure 3.5)
Indoor Designed Air Temperature = 70^{o}F
Indoor Designed Air Relative Humidity = 50%
Indoor Designed Air Humidity Ratio = .0078 $lb_{water}/lb_{dry\ air}$ (per Figure 3.5)
ΔΩ = .0184 - .0078 $lb_{water}/lb_{dry\ air}$

Condensate Collected = 1000 (ft^3/minute) * .076 (lb./ft^3) * 60 (min/hr.) * (.0184 - .0078) $lb_{water}/lb_{dry\ air}$
Condensate Collected = 1000 (ft^3/minute) * .076 (lb./ft^3) * 60 (min/hr.) * .0107 $lb_{water}/lb_{dry\ air}$
Condensate Collected = 4,560 lbs./hr. * .0107 $lb_{water}/lb_{dry\ air}$
Condensate Collected = 48.79 lbs/hour
Condensate Collected = 48.79 lbs/hour / 8.338 lb./gallon
Condensate Collected = 5.785 gallons of water per hour
(Lawrence, Perry, Dempsey 2010b, 5)

For condensate estimation in this report, an Excel spreadsheet model was used. Daily average temperatures and daily average humidity levels were gathered for the St. Louis area over an 11-year period. The daily averages were then averaged over the 11-year period to result in mean daily average temperature and mean daily average relative humidity levels for the typical cooling season (May – October; Figure 3.6). The mean daily averages were used to determine the absolute humidity ratio of the outside air for the corresponding day (Figure 3.7). For each of the three study sites, indoor designed air conditions were assumed to be 70^{o}F and 50% relative humidity, resulting in a constant indoor air absolute humidity ratio of .0078 $lb_{water}/lb_{dry\ air}$ throughout the cooling season.

General Assumptions – Using Mean Daily Temperature and Mean Daily Relative Humidity to Determine Outdoor Air Absolute Humidity

The condensation prediction equation above determines the amount of condensate expected to occur over a one hour period, given a constant outdoor temperature and relative humidity level over that hour. To determine daily quantities of expected condensate production, the mean daily average temperature and mean daily average humidity levels were assumed to remain constant for a 24-hour period throughout the day. The theory is, at points throughout the day when the temperature and humidity levels are higher than the mean for the day, more condensation will occur. Likewise, at points throughout the night when temperature and humidity levels are below the mean for the day, less condensation will occur. Over the entire 24 hour period however, using the mean temperature and relative humidity will balance out the times of more or less quantities of condensate production. Thus, if the condensation prediction is run using the average daily temperature and average daily humidity readings to determine the absolute humidity ratio, the result of the *one-hour* condensate production estimation can be multiplied by a factor of 24 to determine *daily* condensate production numbers that are within a reasonable level of accuracy.

A series of tests were then run to determine the validity of the theory of assuming a constant outdoor humidity ratio throughout the day using mean daily temperature and relative humidity. Ten days were selected from the 11-year period for the tests. For each day, actual hourly temperature and relative humidity recordings were used to determine the humidity ratio of the outside air for each hour in that particular day. Indoor air humidity ratios were assumed to remain constant throughout the day. The condensate prediction equation was run for each hour of the day using the actual hourly recordings. The result was (24) *one-hour* condensate production estimates for the day. The (24) *one-hour* production estimates were added up to reveal the actual expected condensate production for that particular day. The actual expected condensate production results for each particular day were then compared to the results for that same day from the equation that was run *once* and multiplied by 24 using the mean daily temperature and mean daily relative humidity level assumed over a 24 hour period (Table 4.7). The results of the ten tests are shown in Table 4.8. The findings from the tests reveal that using the mean daily temperature and relative humidity levels to determine outside air humidity ratio produce a daily quantity of expected condensate that is consistently within +/- 15% of the actual 24 hour tests for each day (Table 4.8). Consultation with Dr. Steve Eckels, Professor of Mechanical Engineering at Kansas State University, determined that the +/- 15% margin of error is within an acceptable level of accuracy, given the inherent limitations of the expected condensate prediction model being used in this study.

General Assumption - Change in Humidity Ratio ($\Delta\Omega$) -

The humidity ratio is directly related to the daily fluctuations in air temperature and relative humidity. The previously mentioned assumption regarding daily temperature and relative humidity uses the daily mean temperature and daily mean relative humidity as a constant throughout the 24 hours in a given day. Likewise as a result, the humidity ratio corresponding to each daily mean temperature and daily mean relative humidity is assumed constant throughout the same 24-hour period. For example, the humidity ratio for June 30 is .0127 $lb_{water}/lb_{dry\ air}$ based on the 11-year average of mean daily temperature of 77°F and mean daily relative humidity of 62%, per Figure 3.5 (Psychometric Chart). Therefore for June, 30 the result of the ($\Delta\Omega$) portion of the condensation prediction calculation (.0127 - .0078) is assumed to remain constant throughout the entire period of daily A/C system run time.

General Assumption - Air Density

Air density refers to the density of the air at the supply conditions. Typically air density is approximately .076 lb./ft^3 and is assumed to remain

Hourly Calculations (Changing RH & Temp)				Daily Calcs (Constant RH & Temp)			
Hour	Temp.	R.H.	Gallons	Hour	Avg. R.H.	Avg.Temp	Gallons
12:00 am	84	60%	558	12:00 am	71%	83.3	732
1:00 am	82	66%	595	1:00 am	71%	83.3	732
2:00 am	81	67%	574	2:00 am	71%	83.3	732
3:00 am	80	69%	570	3:00 am	71%	83.3	732
4:00 am	80	69%	570	4:00 am	71%	83.3	732
5:00 am	80	69%	570	5:00 am	71%	83.3	732
6:00 am	79	71%	565	6:00 am	71%	83.3	732
7:00 am	82	69%	651	7:00 am	71%	83.3	732
8:00 am	85	65%	576	8:00 am	71%	83.3	732
9:00 am	88	58%	447	9:00 am	71%	83.3	732
10:00 am	92	55%	774	10:00 am	71%	83.3	732
11:00 am	90	57%	736	11:00 am	71%	83.3	732
12:00 pm	75	88%	668	12:00 pm	71%	83.3	732
1:00 pm	81	82%	845	1:00 pm	71%	83.3	732
2:00 pm	87	74%	987	2:00 pm	71%	83.3	732
3:00 pm	90	61%	833	3:00 pm	71%	83.3	732
4:00 pm	90	59%	785	4:00 pm	71%	83.3	732
5:00 pm	88	65%	834	5:00 pm	71%	83.3	732
6:00 pm	85	72%	844	6:00 pm	71%	83.3	732
7:00 pm	84	71%	777	7:00 pm	71%	83.3	732
8:00 pm	86	69%	828	8:00 pm	71%	83.3	732
9:00 pm	82	84%	932	9:00 pm	71%	83.3	732
10:00 pm	75	88%	668	10:00 pm	71%	83.3	732
11:00 pm	74	87%	610	11:00 pm	71%	83.3	732
Daily Total			16,807	Daily Total			17,577

Table 4.7 Comparison of Hourly A/C Condensate Prediction Test Results to Daily Prediction Results for August 20, 2010

May 2, 2003 Test using recorded hourly readings - 3,683 Gal. Using avg. daily temp and humidity - 3,477 Gal. (95% of Test)	*August 20, 2010* Test using recorded hourly readings - 16,807 Gal. Using avg. daily temp and humidity - 17,577 Gal. (105% of Test)
May 15, 2009 Test using recorded hourly readings - 6,257 Gal. Using avg. daily temp and humidity - 7,081 Gal. (113% of Test)	*September 4, 2006* Test using recorded hourly readings - 6,236 Gal. Using avg. daily temp and humidity - 7,171 Gal. (115% of Test)
May 30, 2011 Test using recorded hourly readings - 8,975 Gal. Using avg. daily temp and humidity - 10,078 Gal. (112% of Test)	*September 21, 2007* Test using recorded hourly readings - 1,702 Gal. Using avg. daily temp and humidity - 2,023 Gal. (118% of Test)
July 10, 2013 Test using recorded hourly readings - 15,125 Gal. Using avg. daily temp and humidity - 13,349 Gal. (88% of Test)	*October 3, 2005* Test using recorded hourly readings - 13,599 Gal. Using avg. daily temp and humidity - 13,812 Gal. (102% of Test)
July 31, 2006 Test using recorded hourly readings - 14,953 Gal. Using avg. daily temp and humidity - 16,340 Gal. (109% of Test)	*October 15, 2007* Test using recorded hourly readings - 1,618 Gal. Using avg. daily temp and humidity - 1,807 Gal. (112% of Test)

Table 4.8 Hourly A/C Condensate Prediction Test Results

constant throughout the entire period of daily A/C system run time (Lawrence 2013).

Condensation Prediction Input Variables and Assumptions for Each Study Site

Sigma Aldrich - Airflow

Given the nature of the laboratory activities that take place in the Sigma Aldrich facility, the A/C system constantly runs for 24 hours per day throughout the entire cooling season. Daily condensation production calculations for each month reflect the 24 hour daily run time of the A/C system. See Table 4.9 for daily run time assumptions for each study site.

Sigma Aldrich's Facilities Manager provided information about the existing A/C system. The facility uses (4) one-pass laboratory units utilizing 100% of outdoor make-up air. The combined airflow for the (4) units is 120,000 ft^3/minute. The facility also uses (5) non-laboratory units with return air totaling 106,350 ft^3/minute. For the (5) non-laboratory units, 20% of the 106,350 ft^3/minute is assumed to be outside make-up air, resulting in an incoming outside airflow of 21,270 ft^3/minute. That results in a total combined airflow between laboratory and non-laboratory units of 140,270 ft^3/minute used in the condensation prediction equation. The 140,270 ft^3/minute of airflow is assumed constant throughout the 24 hour daily period.

Missouri History Museum – Airflow

The Missouri History Museum is open to the public from 10:00 a.m. – 8:00 p.m. Tuesday through Thursday and 10:00 a.m. – 5:00 p.m. Friday through Monday. Because of this, the daily A/C system run time assumptions for the cooler spring and fall months of May and October are assumed to be 12 hours. Daily system run times for the hotter summer months of June – September are assumed to be 24 hours (Table 4.9).

Month	*Sigma Aldrich*	*Missouri History Museum*	*Bank of America Plaza*
March	24	0	0
April	24	0	0
May	24	12	12
June	24	24	24
July	24	24	24
August	24	24	24
September	24	24	24
October	24	8	8

Table 4.9 Daily Run Time Assumptions for A/C Units at Each Study Site (in hours per day)

Data for the rate of airflow for the Missouri History Museum was unavailable. However, the approximate airflow of the building can be estimated per the Table 6.1, "Minimum Ventilation Rates in Breathing Zone" of The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Standard 62.1 (ASHRAE 2003). See Tables 4.10 - 4.11. The process for calculating the ventilation rate, or airflow, is as follows:

*Ventilation to Breathing Zone = (# of people * R_P) + (Floor Area * R_A)*

where: # of people = Occupant Density
R_P = People Outdoor Air Rate (in ft^3/minute / person)
R_A = Area Outdoor Air Rate (in ft^3/minute / ft^2)
Floor Area = Building Square Footage

To gather the variables needed to complete the equation, building type and square footage must be known. Once building type is known, then the number of people, R_P and R_A can be determined by referring to Tables 4.10 - 4.11. The following is an example of calculating the Ventilation to Breathing zone, or airflow, for the Missouri History Museum:

\# of people = 129,000 ft^2 @ 40 people/1000 ft^2 = 5,160 people
R_P = 7.5 ft^3/minute / person (per Table 4.10)
R_A = .06 ft^3/minute / ft^2 (per Table 4.10)
Floor Area = 129,000 ft^2

Ventilation to Breathing Zone = (# of people * R_P) + (Floor Area * R_A
Ventilation to Breathing Zone = (5,160 people * 7.5 ft^3/minute / person) + (129,000 ft^2 * .06 ft^3/minute / ft^2)
Ventilation to Breathing Zone = (38,700 ft^3/minute) + (7,740 ft^3/minute)
Ventilation to Breathing Zone (Airflow) = 46,440 ft^3/minute

It should be noted that the result of this airflow calculation is an approximation based on standard ventilation default numbers presented in ASHRAE Standard 62-1, Table 6.1. The actual airflow coming through the A/C system may differ from the result of this equation.

Bank of America Plaza – Airflow

The Bank of America Plaza is a 31-story office building in downtown St. Louis. The actual hours of operation were not able to be obtained. Thus, the daily A/C system run times are estimated to be similar to the Missouri History Museum. In the spring and fall months of May and September, daily run times are assumed to be 12 hours. In the hotter summer months of June through September, daily run times are assumed to be 24 hours (Table 4.9)

Data for the actual rate of airflow for the Bank of America Plaza building was unavailable. Therefore, the Ventilation to Breathing Zone calculation was completed with the following input variables:

\# of people = 750,000 ft^2 @ 15 people/1000 ft^2 = 11,250 people
R_P = 5 ft^3/minute / person (per Table 4.11)
R_A = .06 ft^3/minute / ft^2 (per Table 4.11)
Floor Area = 750,000 ft^2

Occupancy Category	People Outdoor Air Rate R_P		Area Outdoor Air Rate R_A		Notes	Default Values		
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)	
	cfm/person	L/s•person	cfm/ft^2	L/s•m^2		#/1000 ft^2 (#/100 m^2)	cfm/person	L/s•person
Correctional Facilities								
Cell	5	2.5	0.12	0.6		25	10	4.9
Day room	5	2.5	0.06	0.3		30	7	3.5
Guard stations	5	2.5	0.06	0.3		15	9	4.5
Booking/waiting	7.5	3.8	0.06	0.3		50	9	4.4
Educational Facilities								
Daycare (through age 4)	10	5	0.18	0.9		25	17	8.6
Classrooms (ages 5-8)	10	5	0.12	0.6		25	15	7.4
Classrooms (age 9 plus)	10	5	0.12	0.6		35	13	6.7
Lecture classroom	7.5	3.8	0.06	0.3		65	8	4.3
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3		150	8	4.0
Art classroom	10	5.0	0.18	0.9		20	19	9.5
Science laboratories	10	5.0	0.18	0.9		25	17	8.6
Wood/metal shop	10	5	0.18	0.9		20	19	9.5
Computer lab	10	5	0.12	0.6		25	15	7.4
Media center	10	5	0.12	0.6	A	25	15	7.4
Music/theater/dance	10	5.0	0.06	0.3		35	12	5.9
Multi-use assembly	7.5	3.8	0.06	0.3		100	8	4.1
Food and Beverage Service								
Restaurant dining rooms	7.5	3.8	0.18	0.9		70	10	5.1
Cafeteria/fast food dining	7.5	3.8	0.18	0.9		100	9	4.7
Bars, cocktail lounges	7.5	3.8	0.18	0.9		100	9	4.7
General								
Conference/meeting	5	2.5	0.06	0.3		50	6	3.1
Corridors	-	-	0.06	0.3		-		
Storage rooms	-	-	0.12	0.6	B	-		
Hotels, Motels, Resorts, Dormitories								
Bedroom/living room	5	2.5	0.06	0.3		10	11	5.5
Barracks sleeping areas	5	2.5	0.06	0.3		20	8	4.0
Lobbies/prefunction	7.5	3.8	0.06	0.3		30	10	4.8
Multi-purpose assembly	5	2.5	0.06	0.3		120	6	2.8
Office Buildings								
Office space	5	2.5	0.06	0.3		5	17	8.5
Reception areas	5	2.5	0.06	0.3		30	7	3.5
Telephone/data entry	5	2.5	0.06	0.3		60	6	3.0
Main entry lobbies	5	2.5	0.06	0.3		10	11	5.5
Miscellaneous spaces								
Bank vaults/safe deposit	5	2.5	0.06	0.3		5	17	8.5
Computer (not printing)	5	2.5	0.06	0.3		4	20	10.0
Pharmacy (prep. area)	5	2.5	0.18	0.9		10	23	11.5
Photo studios	5	2.5	0.12	0.6		10	17	8.5

Table 4.10 ASHRAE Input Variable Table for Determining Airflow. (Source: ASHRAE Standard 62-2001, Table 6.1. 2003)

Occupancy Category	People Outdoor Air Rate R_P		Area Outdoor Air Rate R_A		Notes	Default Values		
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)	
	cfm/person	L/s•person	cfm/ft^2	L/s•m^2		#/1000 ft^2 (#/100 m^2)	cfm/person	L/s•person
Shipping/receiving	-	-	0.12	0.6	B	-		
Transportation waiting	7.5	3.8	0.06	0.3		100	8	4.1
Warehouses	-	-	0.06	0.3	B	-		
Public Assembly Spaces								
Auditorium seating area	5.0	2.5	0.06	0.3		150	5	2.7
Places of religious worship	5.0	2.5	0.06	0.3		120	6	2.8
Courtrooms	5.0	2.5	0.06	0.3		70	6	2.9
Legislative chambers	5.0	2.5	0.06	0.3		50	6	3.1
Libraries	5.0	2.5	0.12	0.6		10	17	8.5
Lobbies	5.0	2.5	0.06	0.3		150	5	2.7
Museums (children's)	7.5	3.8	0.12	0.6		40	11	5.3
Museums/galleries	7.5	3.8	0.06	0.3		40	9	4.6
Retail								
Sales (except as below)	7.5	3.8	0.12	0.6		15	16	7.8
Mall common areas	7.5	3.8	0.06	0.3		40	9	4.6
Barber shop	7.5	3.8	0.06	0.3		25	10	5.0
Beauty and nail salons	20	10	0.12	0.6		25	25	12.4
Pet shops (animal areas)	7.5	3.8	0.18	0.9		10	26	12.8
Supermarket	7.5	3.8	0.06	0.3		8	15	7.6
Coin-operated laundries	7.5	3.8	0.06	0.3		20	11	5.3
Sports and Entertainment								
Sports arena (play area)	-	-	0.30	1.5		-		
Gym, stadium (play area)	-	-	0.30	1.5		30		
Spectator areas	7.5	3.8	0.06	0.3		150	8	4.0
Swimming (pool and deck)	-	-	0.48	2.4	C	-		
Disco/dance floors	20	10	0.06	0.3		100	21	10.3
Health club/aerobics room	20	10	0.06	0.3		40	22	10.8
Health club/weight rooms	20	10	0.06	0.3		10	26	13.0
Bowling alley (seating)	10	5.0	0.12	0.6		40	13	6.5
Gambling casinos	7.5	3.8	0.18	0.9		120	9	4.6
Game arcades	7.5	3.8	0.18	0.9		20	17	8.3
Stages, studios	10	5.0	0.06	0.3	D	70	11	5.4

GENERAL NOTES FOR TABLE 6.1

1 **Related Requirements:** The rates in this table are based on all other applicable requirements of this standard being met.

2 **Smoking:** This table applies to no-smoking areas. Rates for smoking-permitted spaces must be determined using other methods.

3 **Air Density:** Volumetric airflow rates are based on an air density of 1.2 kg_{da}/m^3 (0.075 lb_{da}/ft^3), which corresponds to dry air at a barometric pressure of 101.3 kPa (1 atm) and an air temperature of 21 °C (70 °F). Rates may be adjusted for actual density, but such adjustment is not required for compliance with this standard.

4 **Default Occupant Density**: The default occupant density shall be used when actual occupant density is not known.

5 **Default Combined Outdoor Air Rate (per person)**: This rate is based on the default occupant density.

6 **Unlisted Occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities, and building construction shall be used.

7 **Residential facilities, Health care facilities, and Vehicles:** Rates shall be determined in accordance with Appendix E.

ITEM-SPECIFIC NOTES FOR TABLE 6.1

A For high school and college libraries, use values shown for *Public Spaces – Libraries*.

B Rate may not be sufficient when stored materials include those having potentially harmful emissions.

C Rate does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture.

D Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.

Table 4.11 ASHRAE Input Variable Table for Determining Airflow. (Source: ASHRAE Standard 62-2001, Table 6.1. 2003)

Ventilation to Breathing Zone = (# of people * R_P) + (Floor Area * R_A

Ventilation to Breathing Zone = (11,250 people * 5 ft^3/minute / person) + (750,000 ft^2 * .06 ft^3/minute / ft^2)

Ventilation to Breathing Zone = (56,250 ft^3/minute) + (45,000 ft^3/minute)

Ventilation to Breathing Zone (Airflow) = 101,250 ft^3/minute

It should be noted that the result of this airflow estimation calculation is an approximation based on standard ventilation default numbers presented in ASHRAE Standard 62-1, Table 6.1. The actual airflow coming through the A/C system may differ from the result of this equation.

Figure 4.31 shows the results for the potential supply of water from air conditioning condensate that can be harvested and reused for landscape irrigation for each of the three study sites. In Lawrence et al's (2010b) discussion of the condensation prediction calculation used in the above estimations, the authors acknowledge the fact that their predicted condensate quantities were consistently lower than actual condensate quantities measured in their 2009 field study. In their study, the predicted amount of condensate produced for the entire cooling season was 134,021 gallons. The actual amount collected was 171,793 gallons, resulting in a net under production error of 28%.

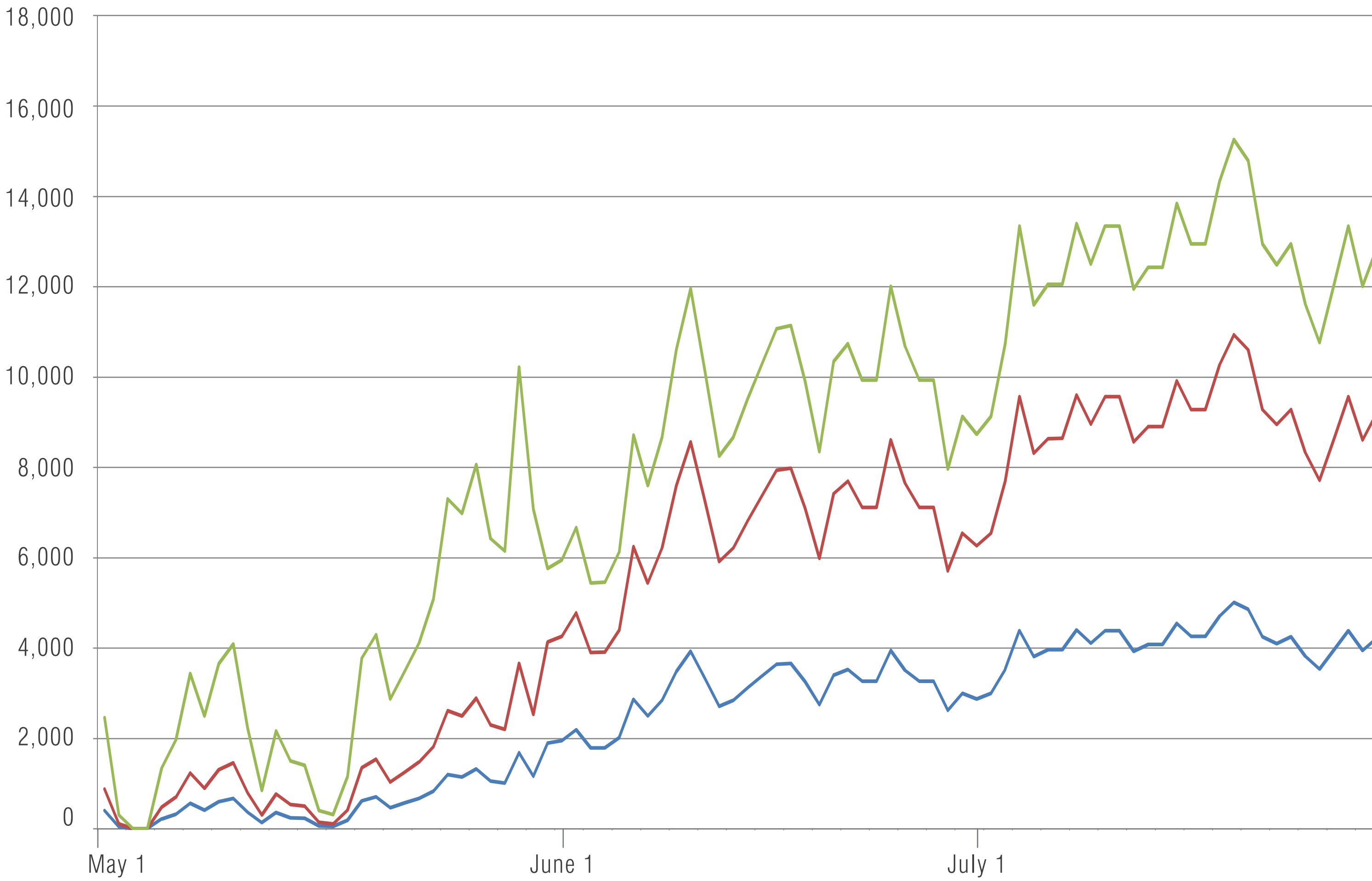
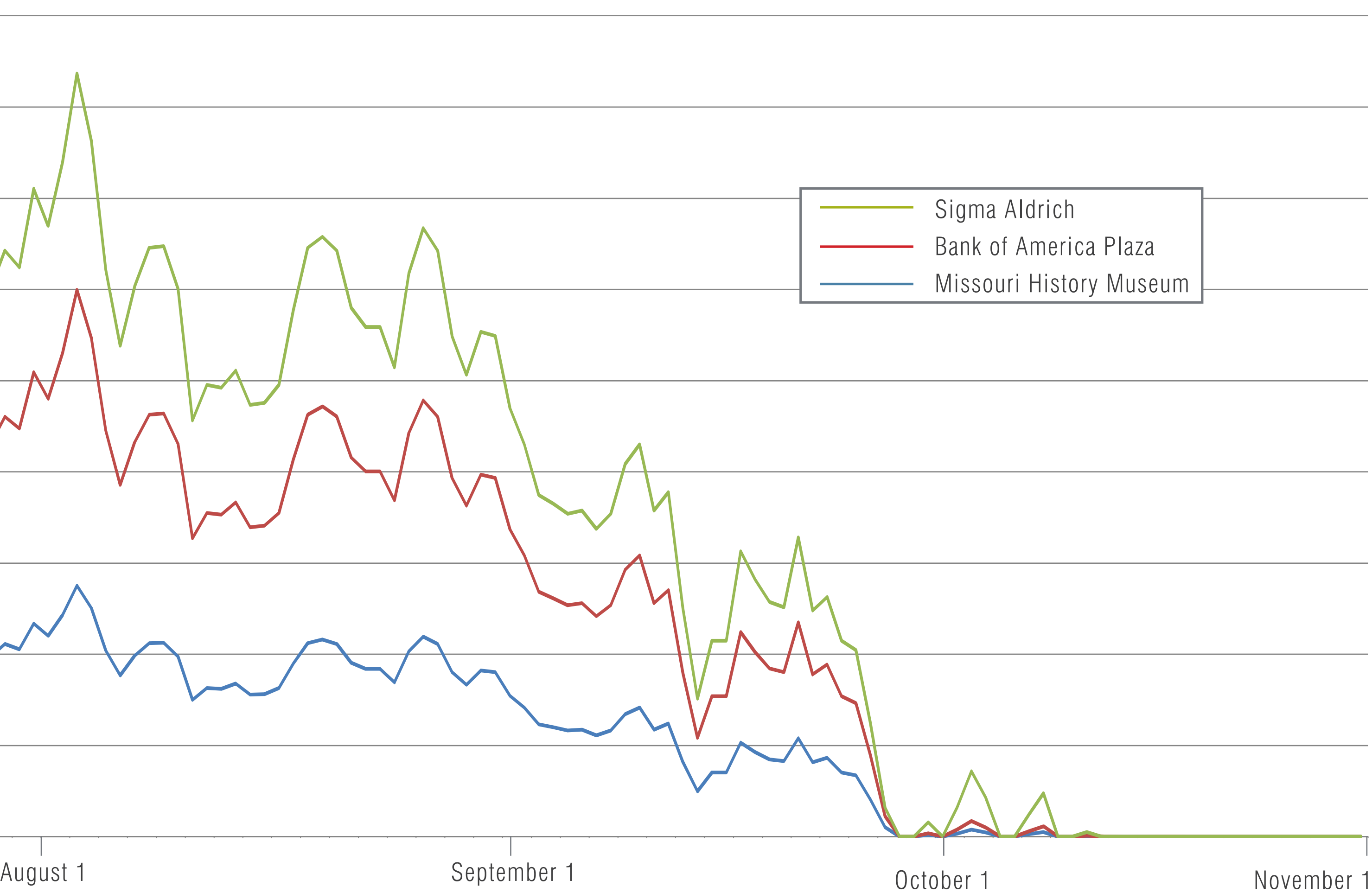


Figure 4.31 Daily Potential A/C Condensate Production Quantities for All Three Study Sites (in gallons)


Sigma Aldrich
Bank of America Plaza
Missouri History Museum
August 1
September 1
October 1
November 1

Comparison of Landscape Water Demand Vs. Potential Water Supply Between Each Study Site

Figures 4.32 – 4.37 show a final comparison of the results from the existing demand and potential supply estimation calculations described in this chapter.

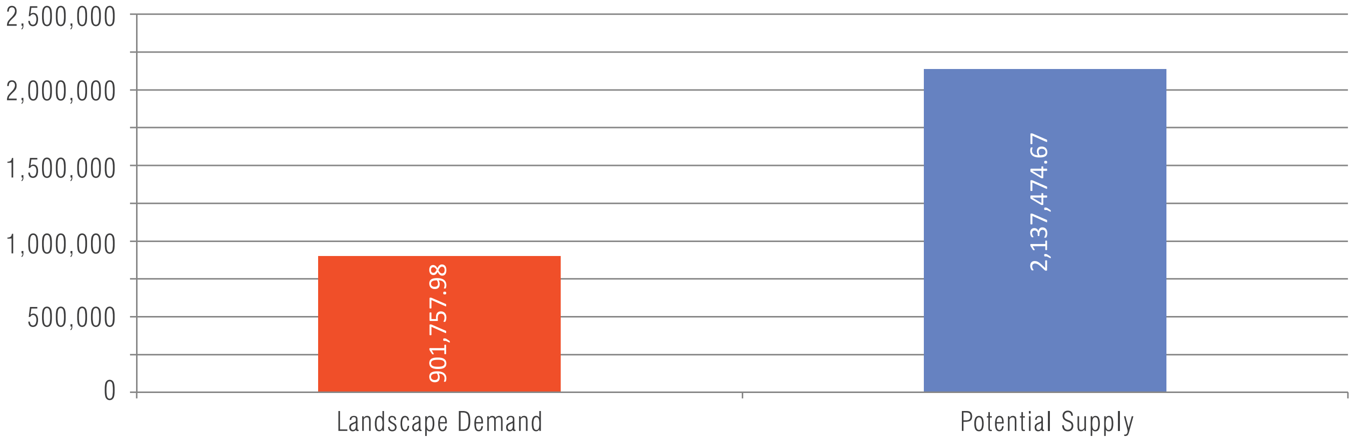


Figure 4.32 Total Potential Water Supply Vs. Landscape Demand - Missouri History Museum (in gallons)

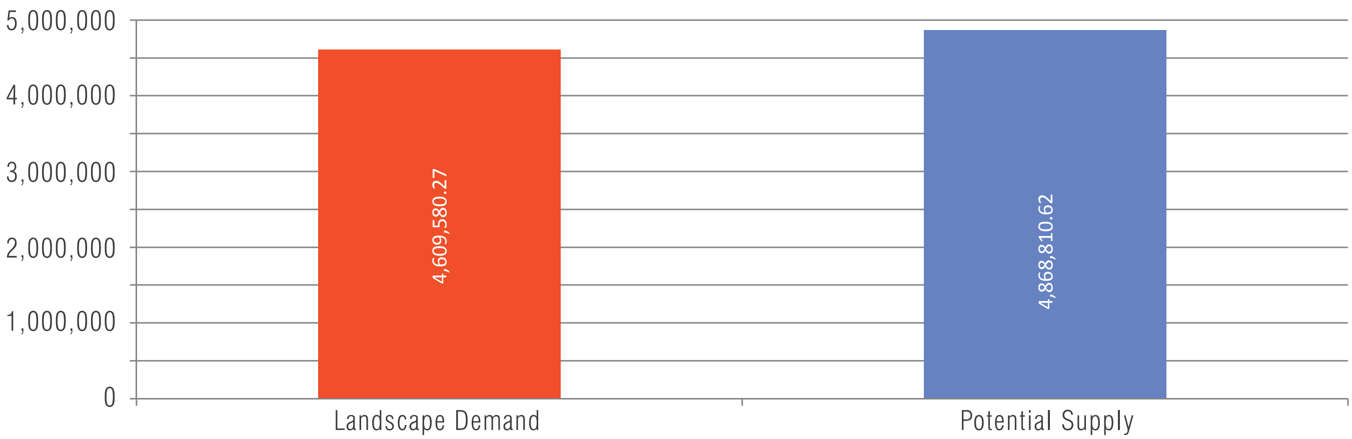


Figure 4.33 Total Potential Water Supply Vs. Landscape Demand - Sigma Aldrich (in gallons)

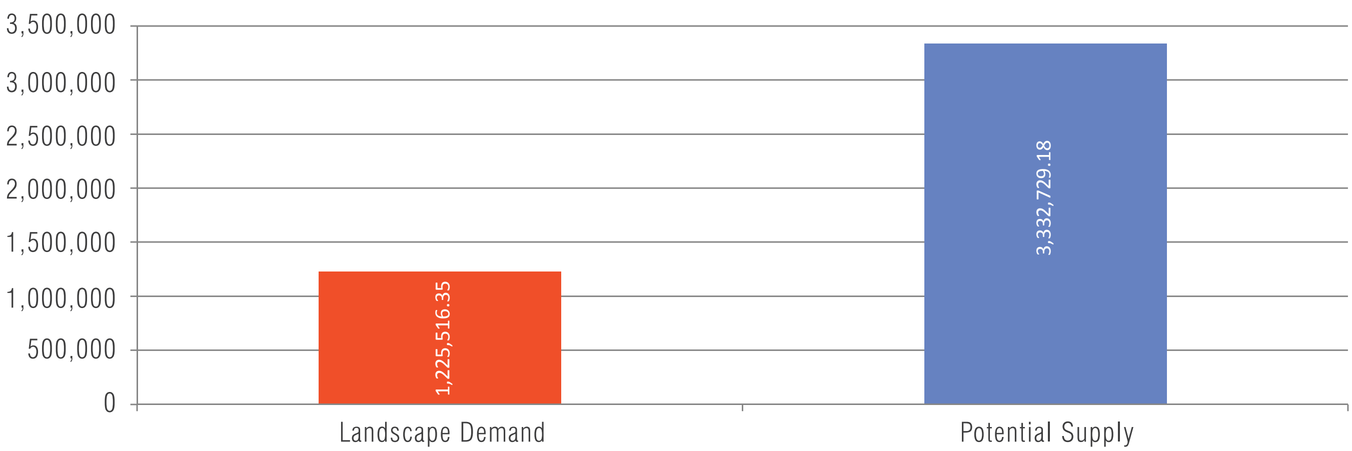


Figure 4.34 Total Potential Water Supply Vs. Landscape Demand - Bank of America Plaza (in gallons)

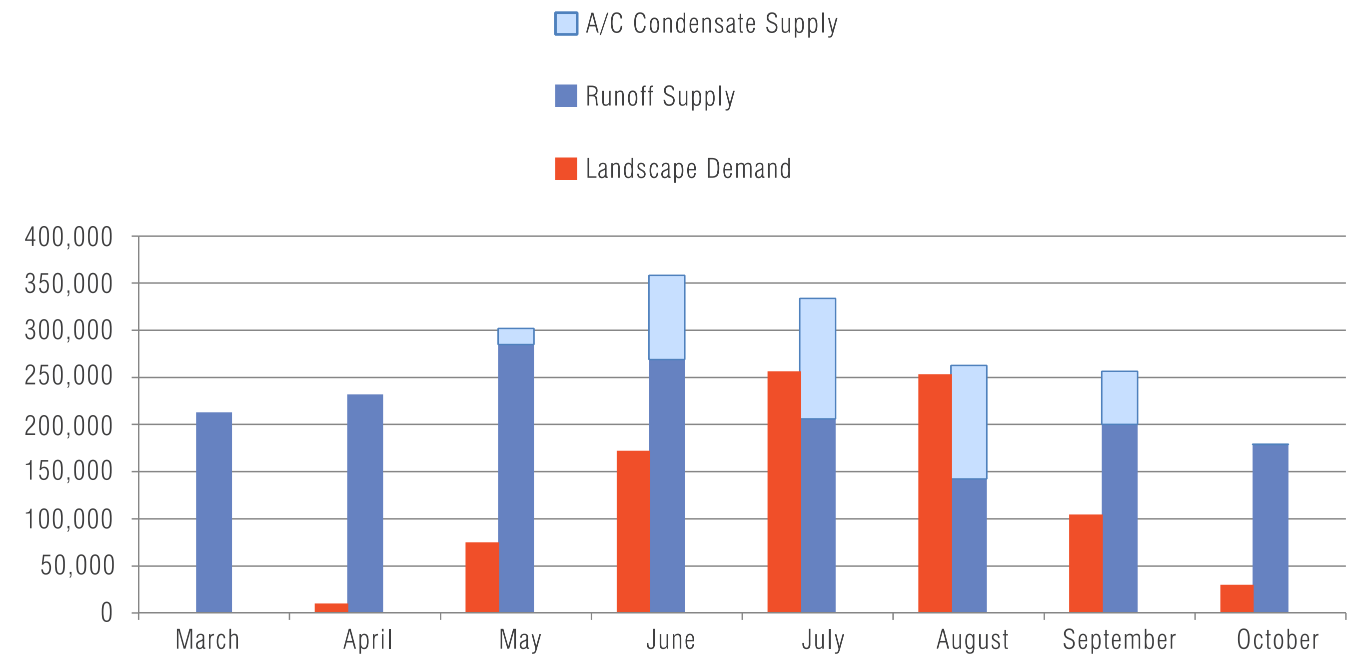


Figure 4.35 Monthly Potential Water Supply Vs. Landscape Demand - Missouri History Museum (in gallons) (March - October)

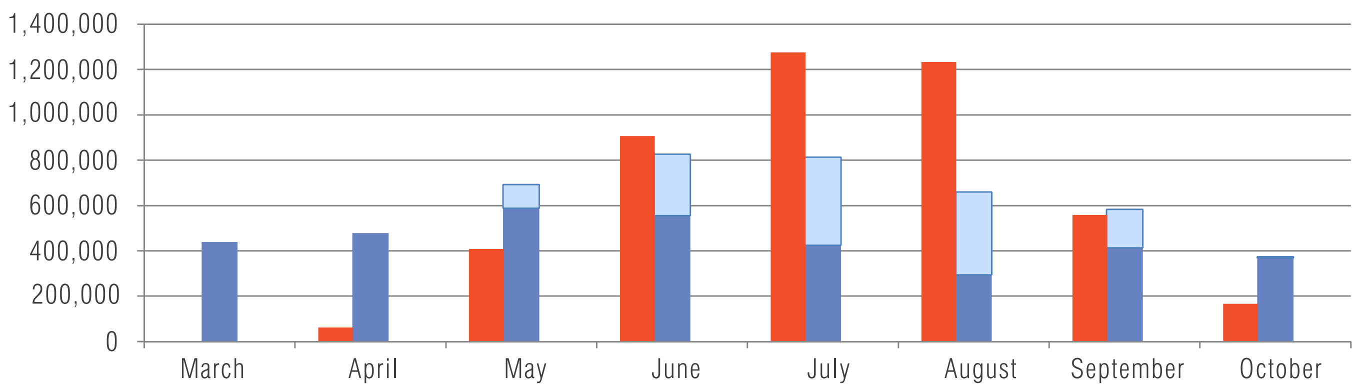


Figure 4.36 Monthly Potential Water Supply Vs. Landscape Demand - Sigma Aldrich (in gallons) (March - October)

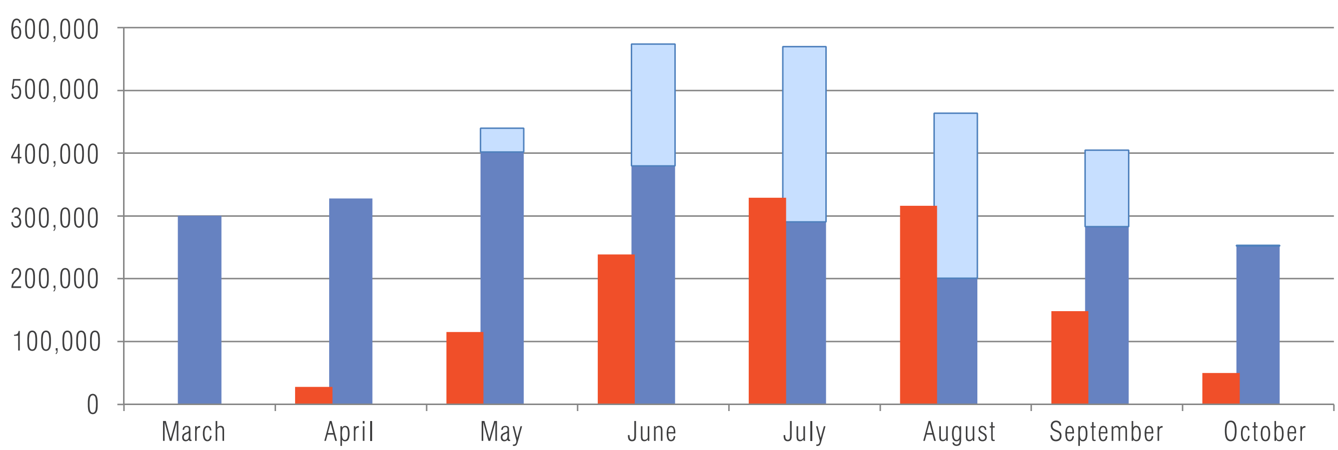
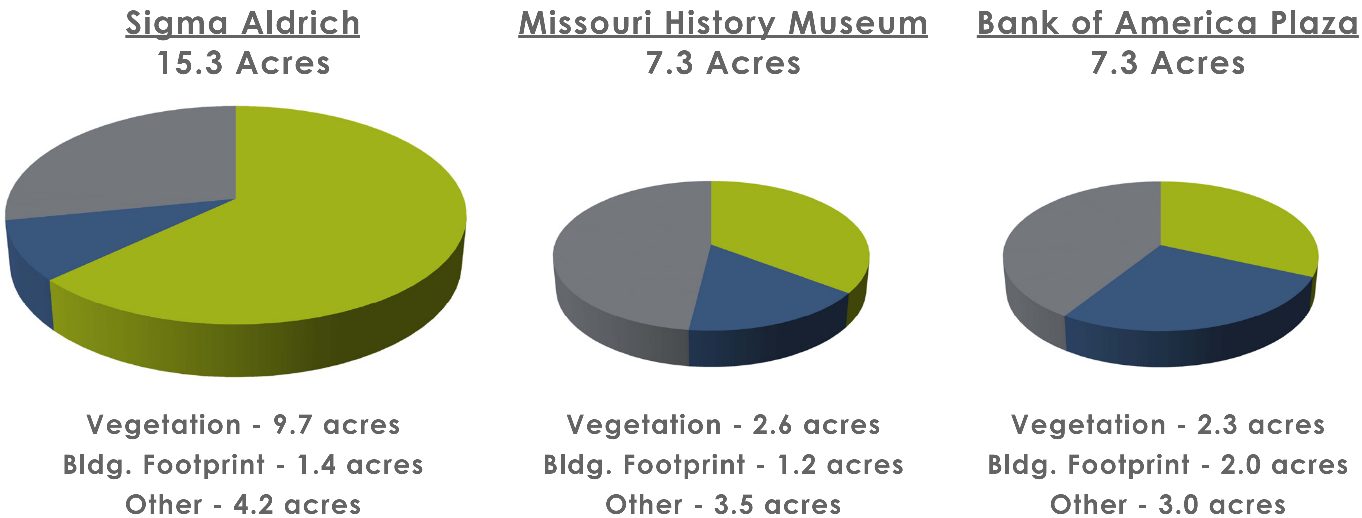


Figure 4.37 Monthly Potential Water Supply Vs. Landscape Demand - Bank of America Plaza (in gallons) (March - October)



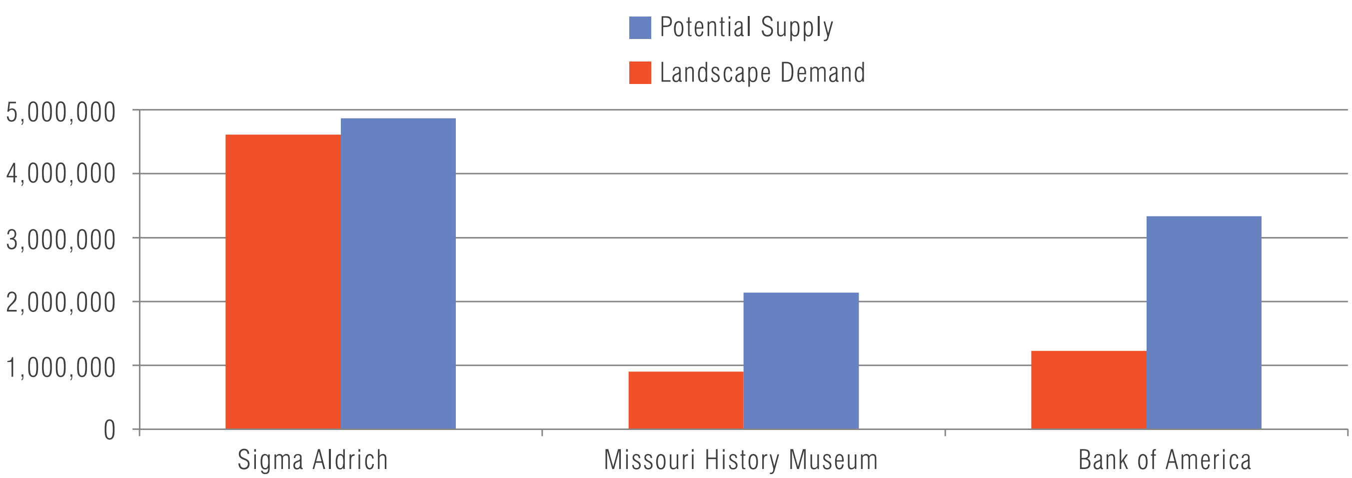


Figure 4.38 Total Potential Water Supply Vs. Landscape Demand - All Three Study Sites (in gallons)

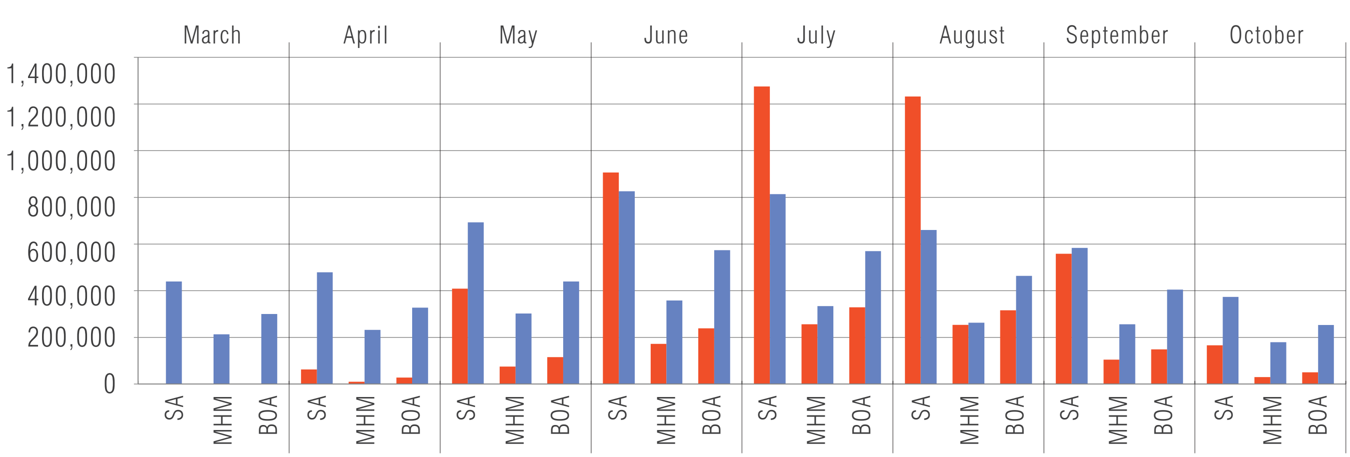


Figure 4.39 Monthly Potential Water Supply Vs. Landscape Demand - All Three Study Sites (in gallons) (March - October)

Discussion of Findings

The results shown in Figure 4.38 reveal that all three study sites appear to have the potential to generate enough water on-site to meet all of the irrigation demands when looking at the entire growing season. However, Figure 4.39 shows that only the Missouri History Museum and the Bank of America Plaza generate enough supply for each month in the growing season. For June, July, and August, landscape water demand exceeds supply for the Sigma Aldrich campus. The reason for the discrepancy between total supply versus demand and monthly supply versus demand is that the extreme excess of water supply in March and April significantly inflates the total water balance for the growing season.

Another significant finding is revealed when looking at the ratio of vegetation-to-building footprint-to-impervious surfaces for each study site. Sites with a relatively even ratio (Missouri History Museum and Bank of America Plaza) appear to have the ability to generate enough water supply to potentially meet all of the site’s irrigation requirements. Site’s with an overwhelming majority of vegetation (primarily turf) do not appear to have the potential to meet all irrigation demands (Sigma Aldrich). These findings suggest that if a new commercial/corporate development seeks to achieve a fully balanced landscape in regards to water supply versus demand, then the site should have a relatively even ratio of vegetation, building footprint, and other impervious surfaces.

chapter V:

design development

V Design Development

Results from the analyses conducted in Chapter 4 revealed the answer to the primary research question: *Is it possible to harvest enough water on a site to meet the current water demand of an existing site-scale landscape in St. Louis, Missouri?* The second part of this MP+R addresses the secondary research questions: *How can it be done? What landscape design adjustments are needed to better balance the irrigation demand of the landscape with the supply of harvested water?* These questions will be answered by proposing a landscape retrofit for Study Site #3, Sigma Aldrich, which is the only study site having an excess of water demand over supply, The retrofit will consist of comprehensively planning a water harvesting system and then adjusting the landscape planting plan to rely on 100% harvested water under typical conditions. The goal is to achieve little or no dependence on a municipal treated water supply for landscape irrigation.

Water Harvesting System Planning

An extensive literature review revealed many considerations when planning a comprehensive water harvesting system. Some of these general considerations include: types, components, and various materials of storage containers, gravity fed water supply options, first flush, filtration of impervious surface runoff, and cost.

Storage Containers

Three main types of storage containers, or cisterns, include: surface (at-grade or above-ground), below-grade, and integral cisterns that are part of architectural structures. Each type of cistern has the same major and minor components. Major components include a waterproof base, sides, and cover. Minor components consist of an inlet, outlet, access hatch for maintenance purposes, and an overflow for draining. The shape, size, and dimensions of a cistern are generally dependent on the chosen material. Common storage container materials and sizes typically associated with each material are listed below:

- Concrete or Ferro-Cement (200 – 500 gallons)
- Fiberglass (500 – 20,000 gallons)
- Corrugated or Galvanized Steel (150 – 100,000 gallons)
- Polyethylene (200 – 5,000 gallons)
- Polypropylene (300 – 20,000 gallons)
- Welded Steel (1,000 – 1 million gallons)
- Wooden (700 – 2 million gallons)
- Stone (any size)
- Crates (any size)

(Kinkade-Levario 2007, 94)

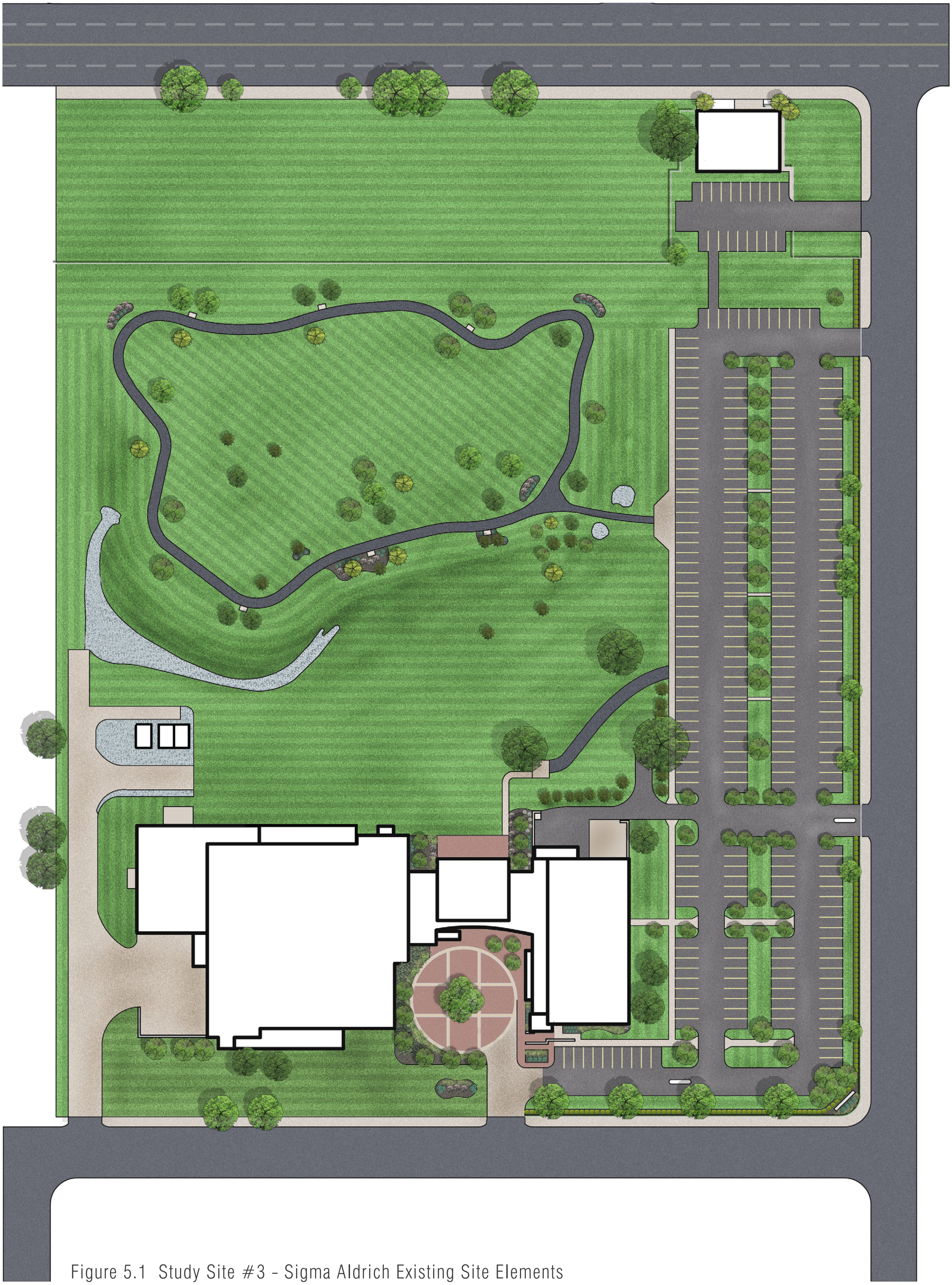


Figure 5.1 Study Site #3 - Sigma Aldrich Existing Site Elements

Other general considerations affecting the selection, planning, and construction of a storage container include:

- A proper foundation must be installed. Five hundred gallons of water typically weighs more than two tons, plus the weight of the container itself, which exerts much force affecting stability of the soil supporting the container.
- The container should not allow sunlight to enter. Photosynthesis cannot occur without sunlight, which means algal growth within a container devoid of sunlight cannot occur.
- The container must have a secured lid and no other openings that could allow access by small animals, breeding mosquitoes, and other organisms.
- The overflow outlet of the system should be of equal or greater size than the inlet volume and irrigation delivery outlet.
- The overflow outlet should typically be located 10-12” below the top of the cistern and a few inches below the water inlet into the cistern
- Whenever an alternate make-up source is used with the storage system, a minimum air gap of 14” should be maintained between the high water line and the inlet of the alternate water to prevent contamination of the alternate water source.

(Kinkade-Levario 2007, 26-29)

Gravity Fed Water Delivery Considerations

If the storage container is located above the area that will receive irrigation from the container, gravity fed delivery of water may be an option. Most drip irrigation systems require a minimum of 20 pounds per square inch (psi) and most rotor/spray nozzles require between 30-35 psi to adequately apply water to the landscape. As a general rule of thumb, water will gain 1.0 psi of pressure for every 2.31 feet of rise (Kinkade-Levario 2007, 29). For example, in order to generate the adequate amount of pressure for a zone of drip irrigation (20 psi) through gravity feeding, the low water level of the storage container must be at least 46.2 feet above the highest point of the planting zone (Figure 5.2). For most cases however, gravity fed delivery cannot generate enough pressure which requires a pump delivery system.

First Flush Considerations

Proper filtration must be addressed when harvesting runoff from any surface. While harvested water intended for human consumption must be purified, non-potable water harvested from collection surfaces such as rooftops and parking lots only needs to be filtered. Buildup of debris, pollutants, metals, leaves, and sediment continuously occurs on these collection surfaces. While rainwater dislodges and carries away these deposits of suspended solids and

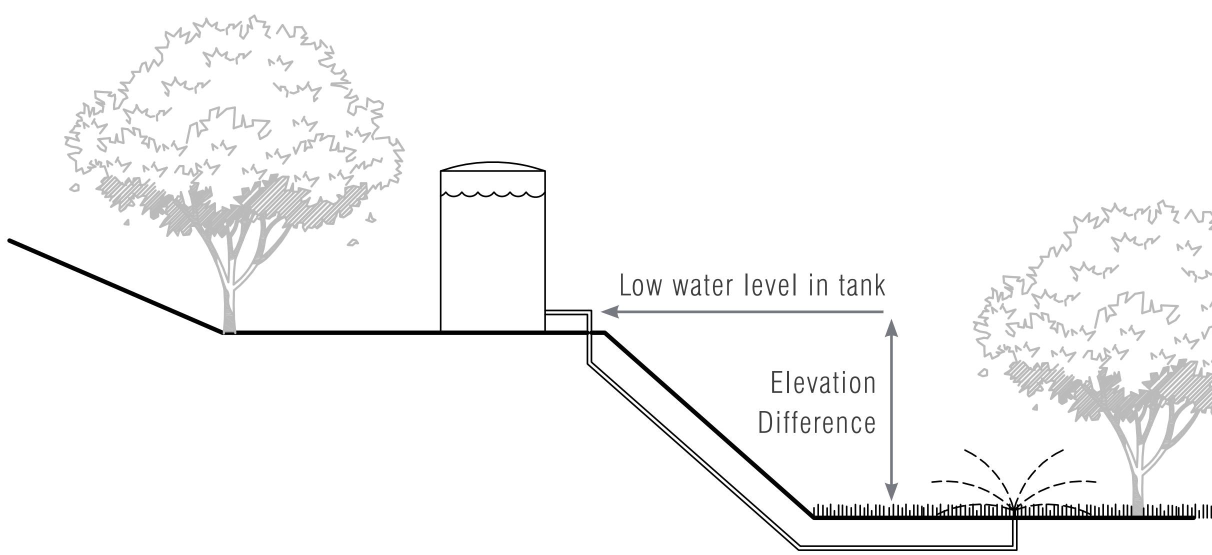


Figure 5.2 Example of Gravity-Fed Irrigation Delivery Elevation Considerations. Drawing Not to Scale

pollutants, the stormwater that falls first carries away the highest concentration of debris. This is known as the first flush. For each storage container that is intended to collect runoff from such surfaces, a first flush filtration system must be implemented to divert and dispose of debris before it contaminates previously harvested stormwater. Several reasons for reducing debris and pollutants that may enter a storage container have been identified:

- Reduction of frequency of cistern cleaning
- Reduction of bacterial inflow that is often attached to suspended solids
- Reduction in the nutrient level in cisterns that, in turn, reduces or eliminates mosquito growth
- Reduction in organic loading, creating less of a chance of anaerobic conditions and odor in the storage container

(Kinkade-Levario 2007, 22)

The size of a first flush diversion device will vary depending on the type of surface contributing runoff that must be filtered. In general, water from a rooftop surface will be cleaner than water collected from a parking lot surface. This means that the first flush device for rooftop catchment systems will not need to be as large as devices diverting debris from a parking lot. Heather Kinkade-Levario has suggested appropriate sizes for various first flush diversion devices relative to runoff surface type (Table 5.1). She notes that stormwater collected from pavement areas may require longer settling periods for suspended solids and an absorbent pillow to remove oil and grease, so she recommends a larger and more sophisticated first flush device (Kinkade-Levario 2007, 23). Most first flush diverters should be drained after every significant storm event. Therefore, any underground first flush device should have some sort of access hatch or above-ground lever system in place to allow for easy maintenance and drainage.

First Flush Sizing Guidelines for Common Collection Surfaces

Small Rooftops (>1,000 ft^2) - Capacity for initial 5 gallons of collected rainwater

Large Rooftops (1,000 ft^2 - 1 acre) - Capacity for initial 10 gallons of rainfall per 1,000 ft^2 of roof area

Very Large Rooftop or paved catchment area (<1 acre) - Capacity for a maximum of 500 gallons (or 1,000 gallons if collected from dirty pavement) for each rain event

*Stormwater collected from surface or pavement areas may require longer settling periods for suspended solids and an oil absorbent pillow to remove oil and grease.

Table 5.1 First Flush Sizing Guidelines. (Source: Kinkade-Levario 2007, 23)

Programming the Harvest

After the commencing design considerations have been accounted for, programming the harvesting system needs to be done. An initial distinction must be made when determining how much water needs to be harvested. There is a substantial difference between the amount of water required by the landscape to maintain its health and the amount of collected water needed to compensate for quantities lost through conveyance. The difference lies in the amount of water lost to irrigation inefficiencies and filtration of harvested water. As a general rule of thumb, efficiencies for typical irrigation delivery components are as follows:

- Drip irrigations – 90% efficient
- Micro-emitters – 90% efficient
- Rotating multi-stream nozzles – 70% efficient
- Spray – 62.5% efficient
- Rotors – 62.5% efficient

(Davis 2014)

For example, if a patch of turf that requires 1,000 gallons of water per day based on the Landscape Coefficient Method discussed in previous chapters, then 1,600 gallons must be collected in order to properly deliver 1,000 gallons to the turf (1,000/.625 = 1,600) via rotors. This means that once the water is sent from the storage container through the delivery system, 600 gallons are lost due to leakage, wind dispersal, or other inefficiencies. Figures 5.3 – 5.4 show the difference between the existing irrigation demand of the landscape at Sigma Aldrich and the amount of water needed to be drawn from the municipal water source in order to properly apply enough water to meet the existing irrigation requirements. It should be noted that the irrigation demand from the landscape takes into account the amount of rainfall absorbed by the vegetation for the entire month, also known as effective rainfall (See Chapter 4 for accounting for effective rainfall).

Irrigation Priority Areas

Figure 5.4 shows that the potential supply of water harvested through A/C condensate and surface stormwater runoff is not nearly enough to meet 100% of the irrigation demands. Therefore,irrigation priority areas within the landscape must be identified to ensure that the areas of highest priority are irrigated by the most reliable water sources. Figure 5.5 shows the irrigation priority areas within the Sigma Aldrich site. Highest priority is given to areas which have the most exposure to the greatest amount of people and views into, within, and from the site. These high priority areas are areas where vegetation needs the most reliable sources of water in order to maintain their health and intended form. The lowest priority areas of vegetation are the areas that have the least amount of activity present within them, the least amount of exposure to adjacent streets, and the least need to maintain the existing planting scheme. After all potential water sources have been allocated to irrigating areas of highest priority, plants (especially turf) in lower priority areas will need to be replaced by drought tolerant species that require little to no supplemental irrigation.

Figure 5.6 shows the sources of water available on the site. These sources are limited to rooftop and parking lot surfaces that have a clearly defined catchment area and all runoff is clearly flowing to a single pick-up point within each catchment. Total

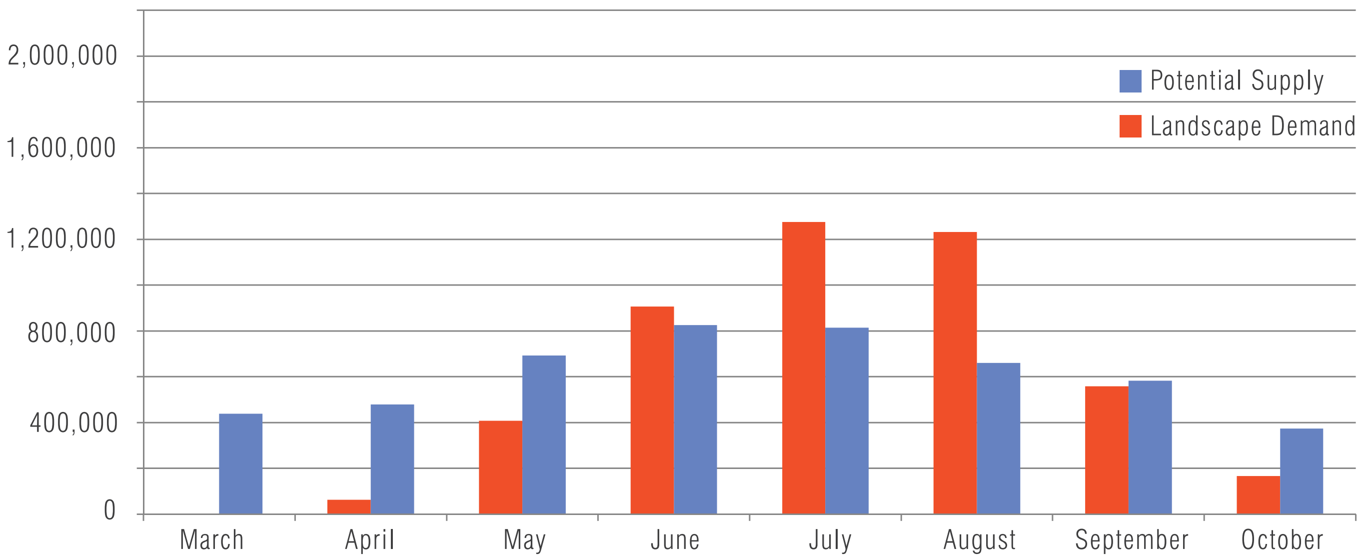


Figure 5.3 Sigma Aldrich Estimated Existing Monthly Landscape Water Demand After Accounting For Effective Monthly Rainfall

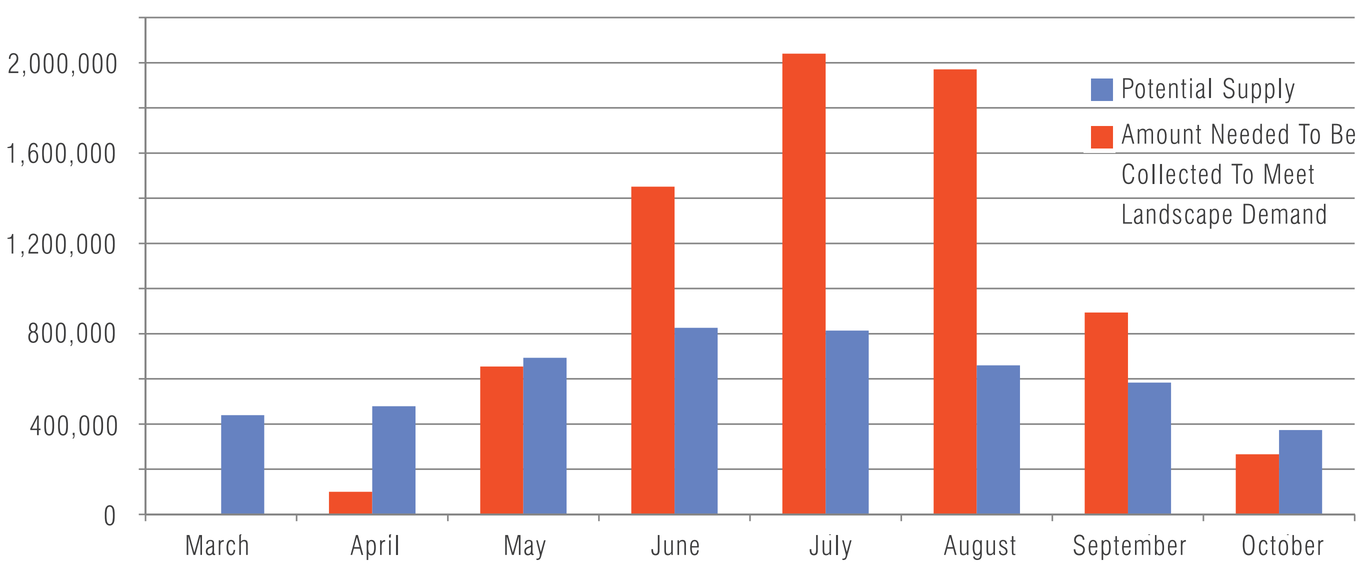


Figure 5.4 Sigma Aldrich Estimated Monthly Water Quantities Needed to be Collected Due to Irrigation Inefficiencies. Quantities are After Effective Monthly Rainfall has been Accounted for.

Figure 5.5 Irrigation Priority Areas

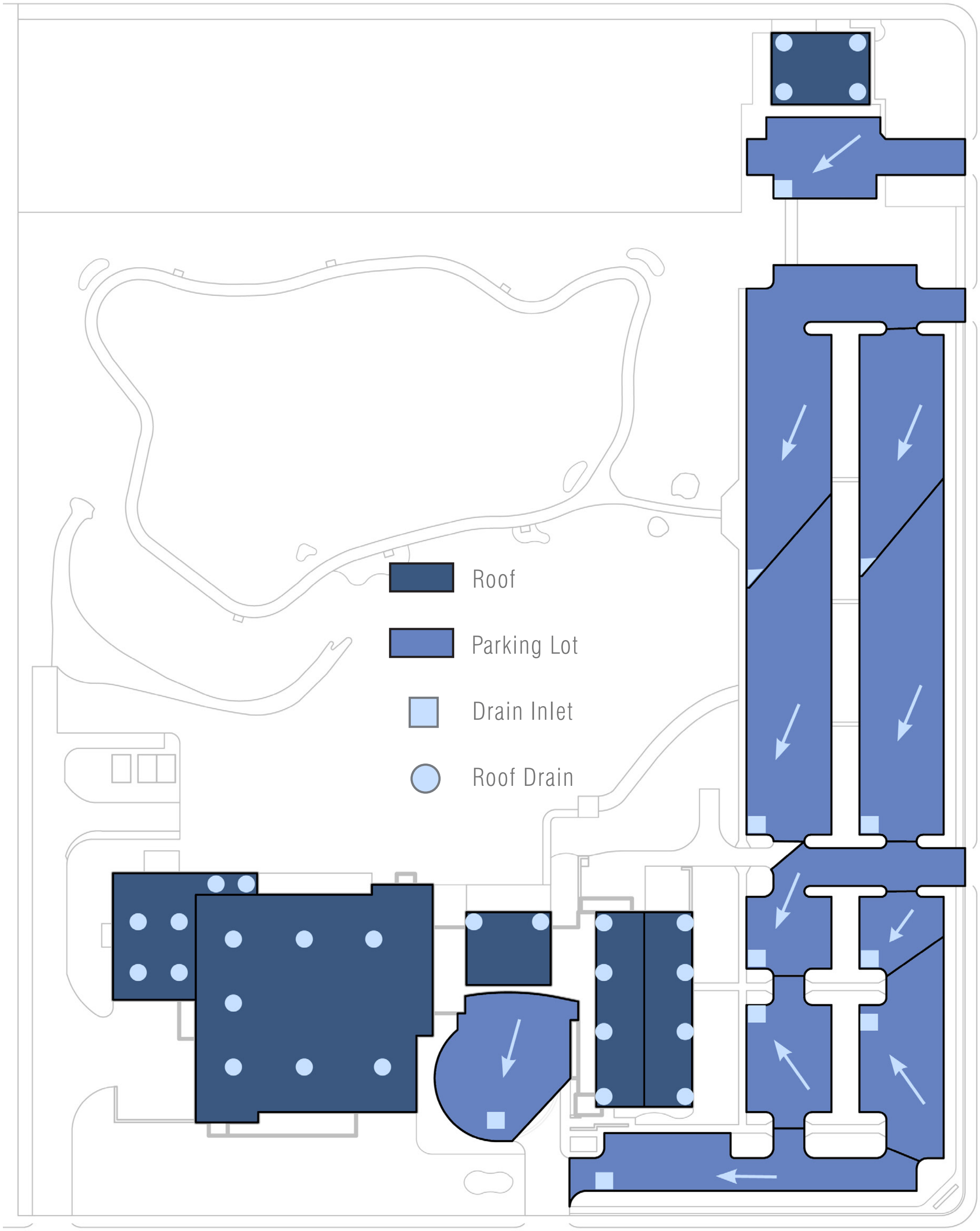


Figure 5.6 Existing Runoff Collection Surfaces with Defined Catchment Area and Pick-Up Points

water sources include 17 collection surfaces within the site, as well as condensate produced from (4) laboratory A/C units located on the bottom floor of the building. Due to the fact that there is a finite amount of water that can be generated on-site, and the supply will not meet the total irrigation demands, sources of irrigation must be dedicated to areas of highest priority. Figures 5.7 – 5.12 show functional diagrams depicting how each source of water is dedicated to providing the irrigation requirements for the areas of highest irrigation priority. Determining which on-site water source (runoff or condensate) can supply irrigation for each vegetation area was based on:

- Proximity of on-site water source to vegetated areas to be irrigated
- Whether the on-site water source is uphill or downhill from the vegetation area. There is a critical need to take advantage of gravity in order to limit the amount of pumping required
- Catchment area of the water source in regard to the area's ability to collect and direct enough water to the storage container to meet the water demands of the associated vegetation area during the month when the water demand is the highest and rainfall is the lowest (August).

All of Irrigation Zone 1 is fed by the condensate collected through two air conditioning units located on the bottom floor of the building. The condensate is collected from the cooling coils and pumped underground into the smaller 300 gallon cistern. Water is pumped from this cistern through drip irrigation for all of the perennial planting beds in the front of the building. Overflow from the 300 gallon cistern flows into the larger 11,500 gallon cistern which is dedicated to supplying irrigation for all of the turf as shown in Figure 5.7. Water is pumped from the larger cistern to rotor irrigation heads within the front lawn.

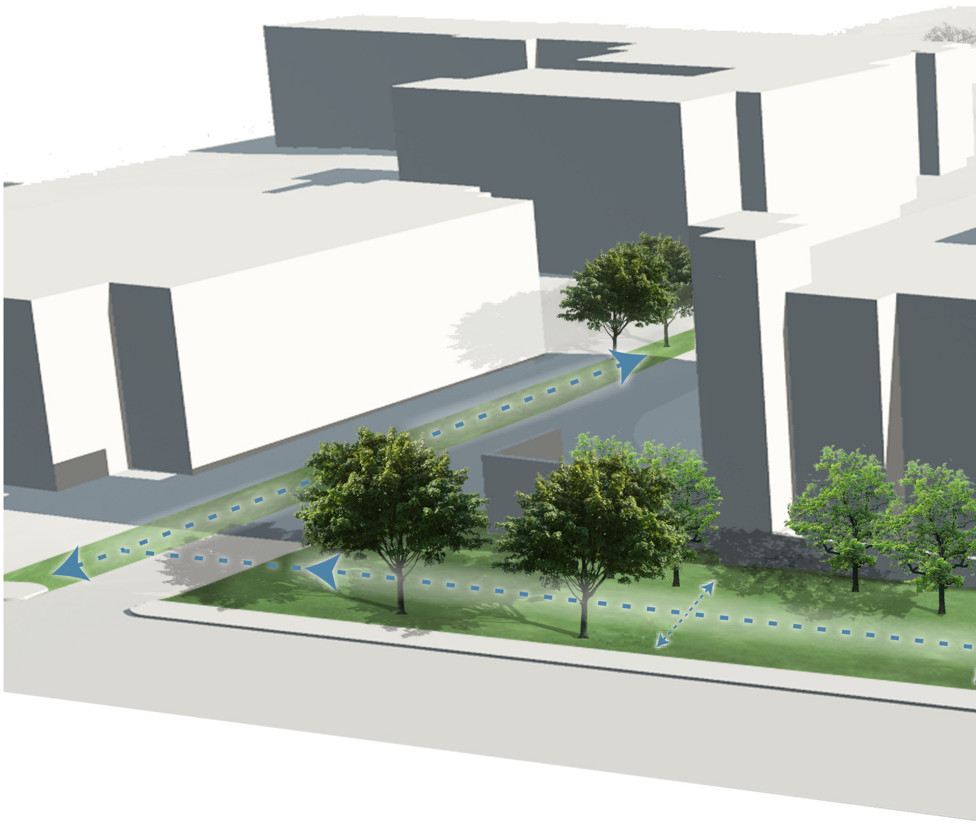


Figure 5.7 Irrigation Zone 1 Functional Diagram

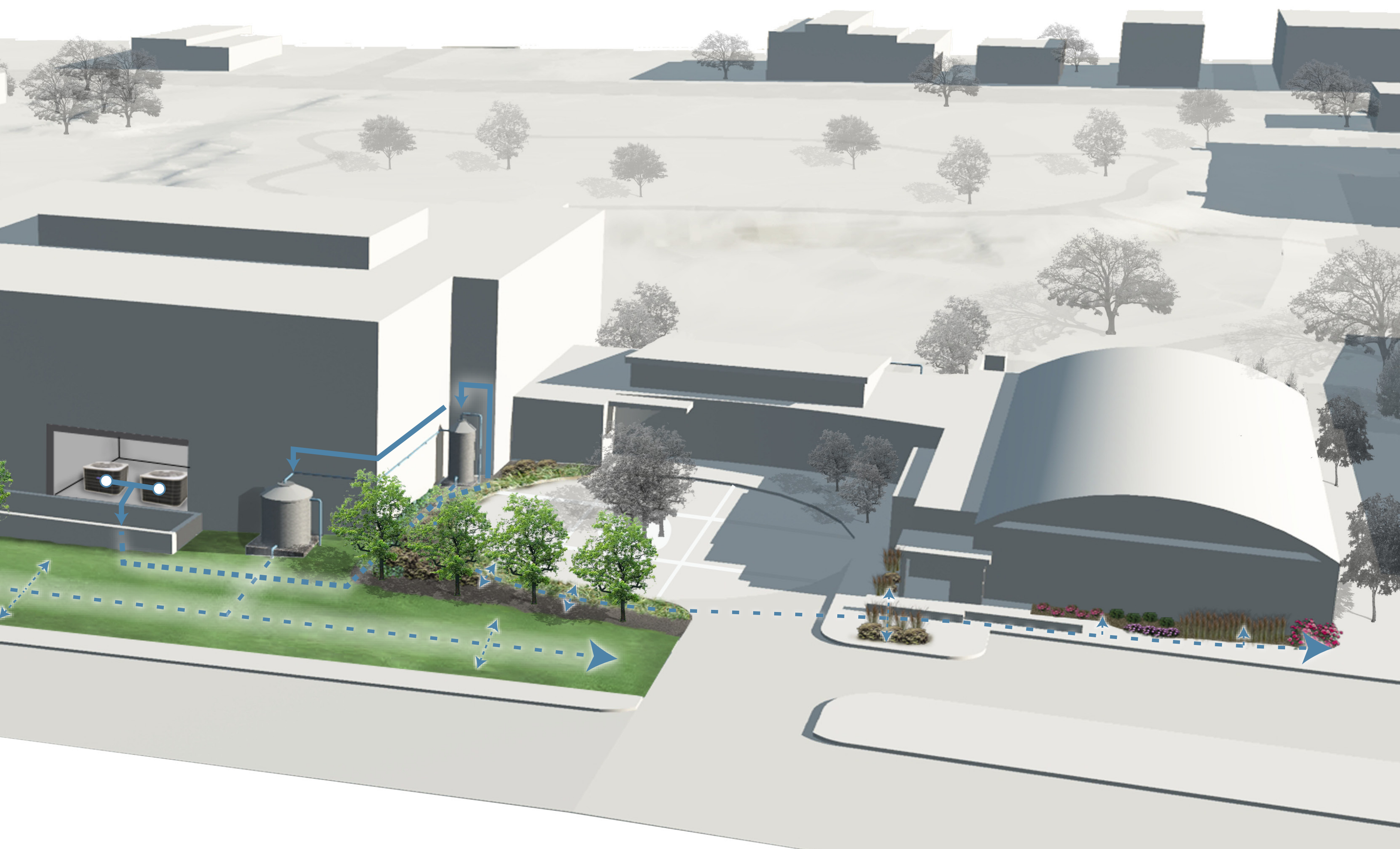
watersource
(2) Laboratory A/C Units in Basement of Building

zone 1
~24,000 ft² of turf
~3,200 ft² of perennials

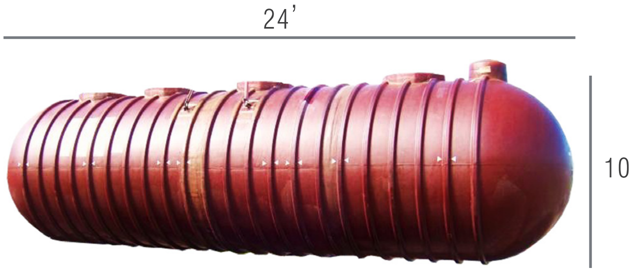
storagecontainers
(1) 300 Gallon Steel Above-Ground Cistern for Perennial Bed Irrigation
(1) 11,500 Gallon Galvanized Steel Above-Ground Cistern for Turf

300 Gallon
Galvanized Steel Cistern

11,500 Gallon
Galvanized Steel Cistern



All of Irrigation Zone 2 is fed by surface runoff collected from the rooftop of the auditorium and from the adjacent parking lot. Water from the rooftop drains to a single point which flows into an underground first flush diverter, then into the underground cistern. Surface runoff is directed to the existing drain inlets within the parking lot. These inlets are all connected and eventually flow into the same underground first flush diverter, then into the cistern. Water from the cistern is then pumped to rotor heads within the lawn to provide the turf with irrigation.



12,000 Gallon Fiberglass Cistern

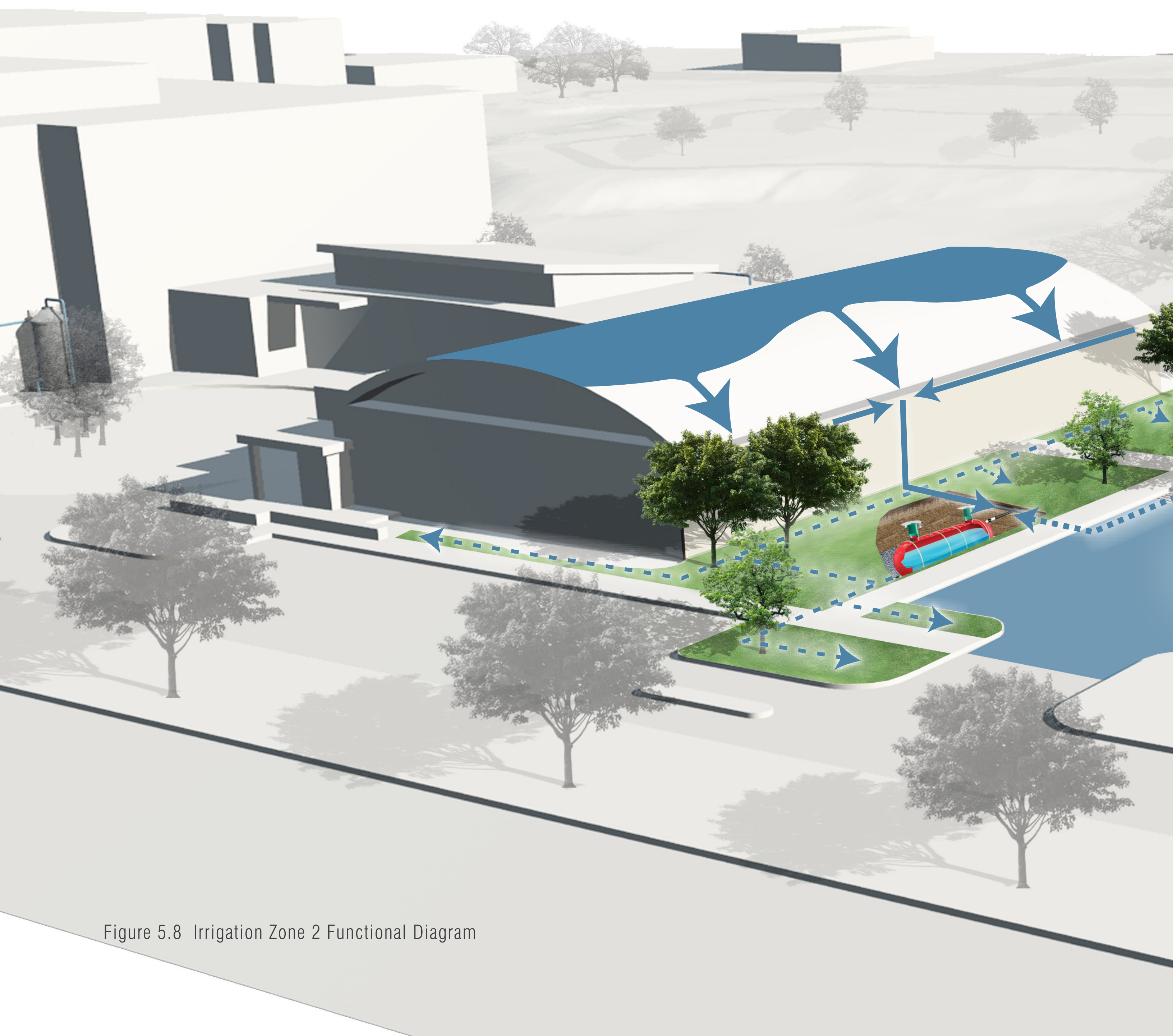


Figure 5.8 Irrigation Zone 2 Functional Diagram

zone2

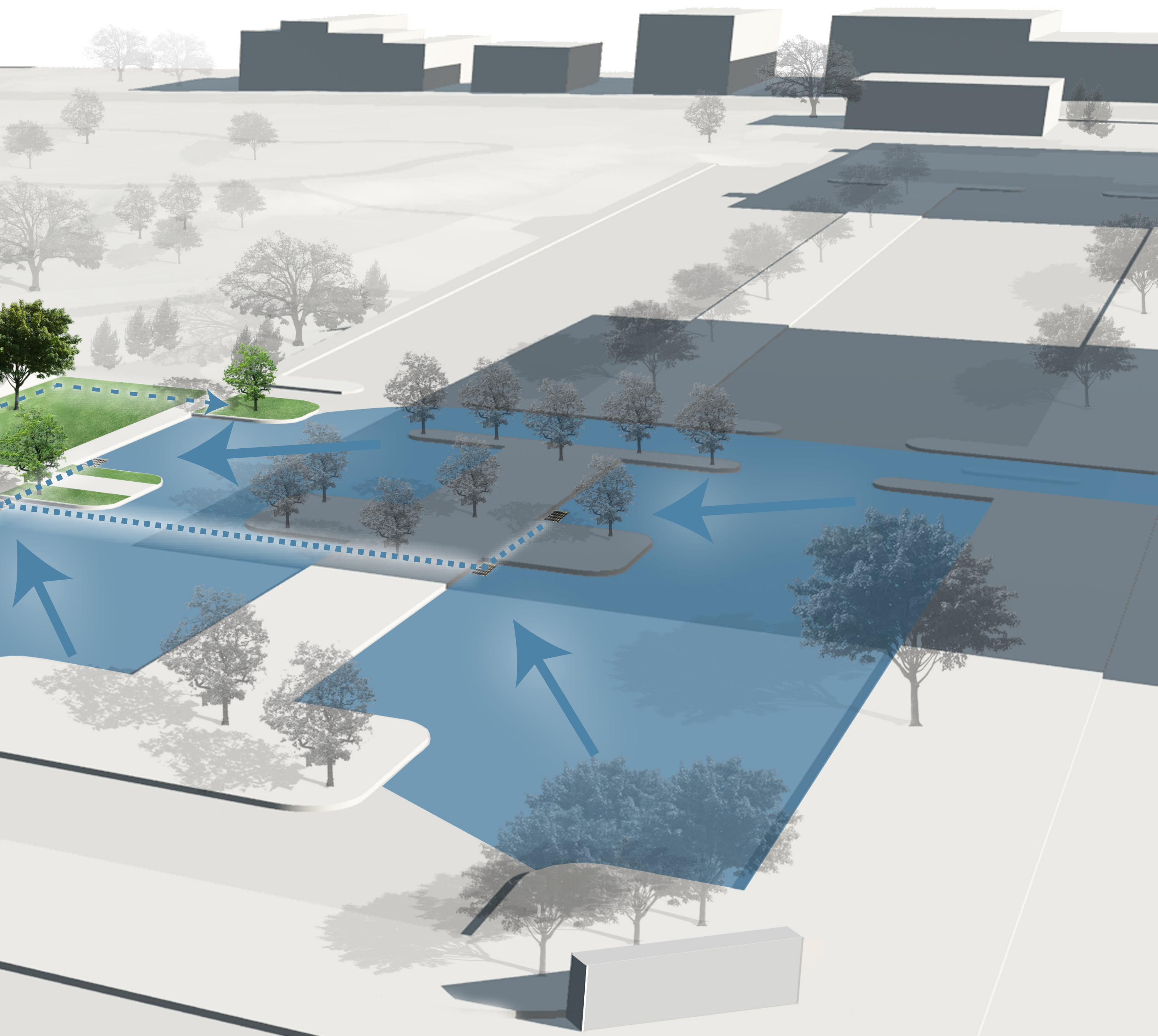
~8,900 ft² of turf

watersources

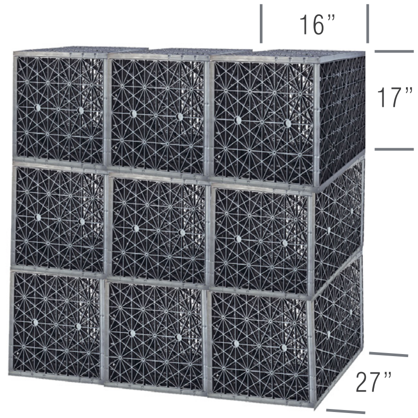
26,234 ft² Parking Lot Surface
10,956 ft² of Rooftop Surface

storagecontainer

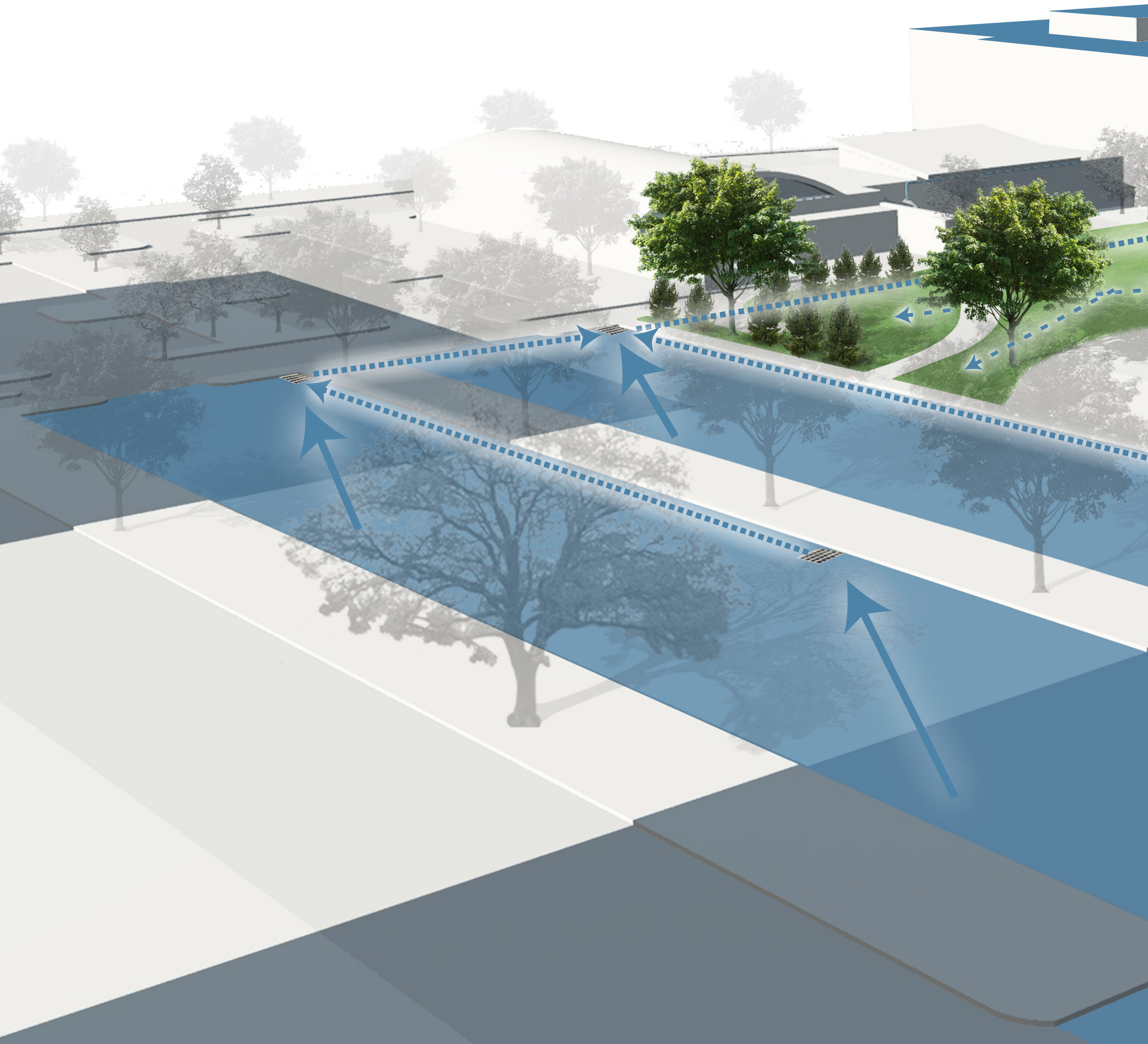
(1) 12,000 Gallon Underground Fiberglass Cistern



Irrigation for Zone 3 is provided by air conditioning condensate, rooftop runoff, and parking lot surface runoff. All sources of water flow to a centrally located cistern constructed with a 50,000 gallon Atlantis crate water harvesting cistern. Before water reaches the cistern, it first flows through a 1,000 gallon first flush diverter to remove all suspended solids, pollutants, debris, and heavy metals. Harvested water is pumped from the cistern to rotor heads spread throughout the lawn.



Crate Dimensions



zone3

~55,500 ft² of turf

watersources

(2) Laboratory A/C Units in Basement of Building
56,967 ft² of Parking Lot Surface
37,217 ft² of Parking Lot Surface

storagecontainer

(1) 50,000 Gallon Underground Atlantis Crate System
20' wide x 7' tall x 54' long
15 crates wide x 5 crates tall x 24 crates long

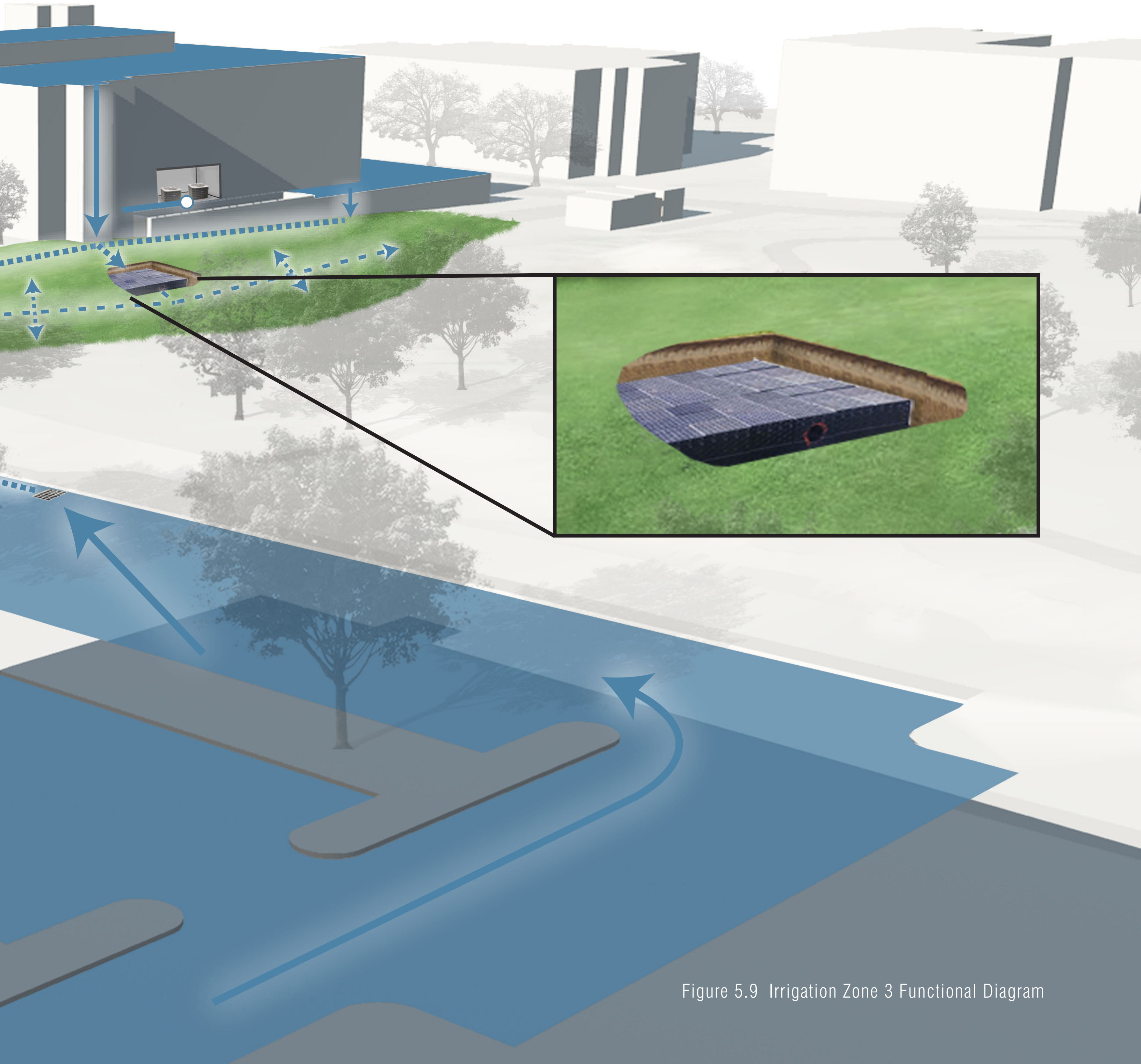


Figure 5.9 Irrigation Zone 3 Functional Diagram

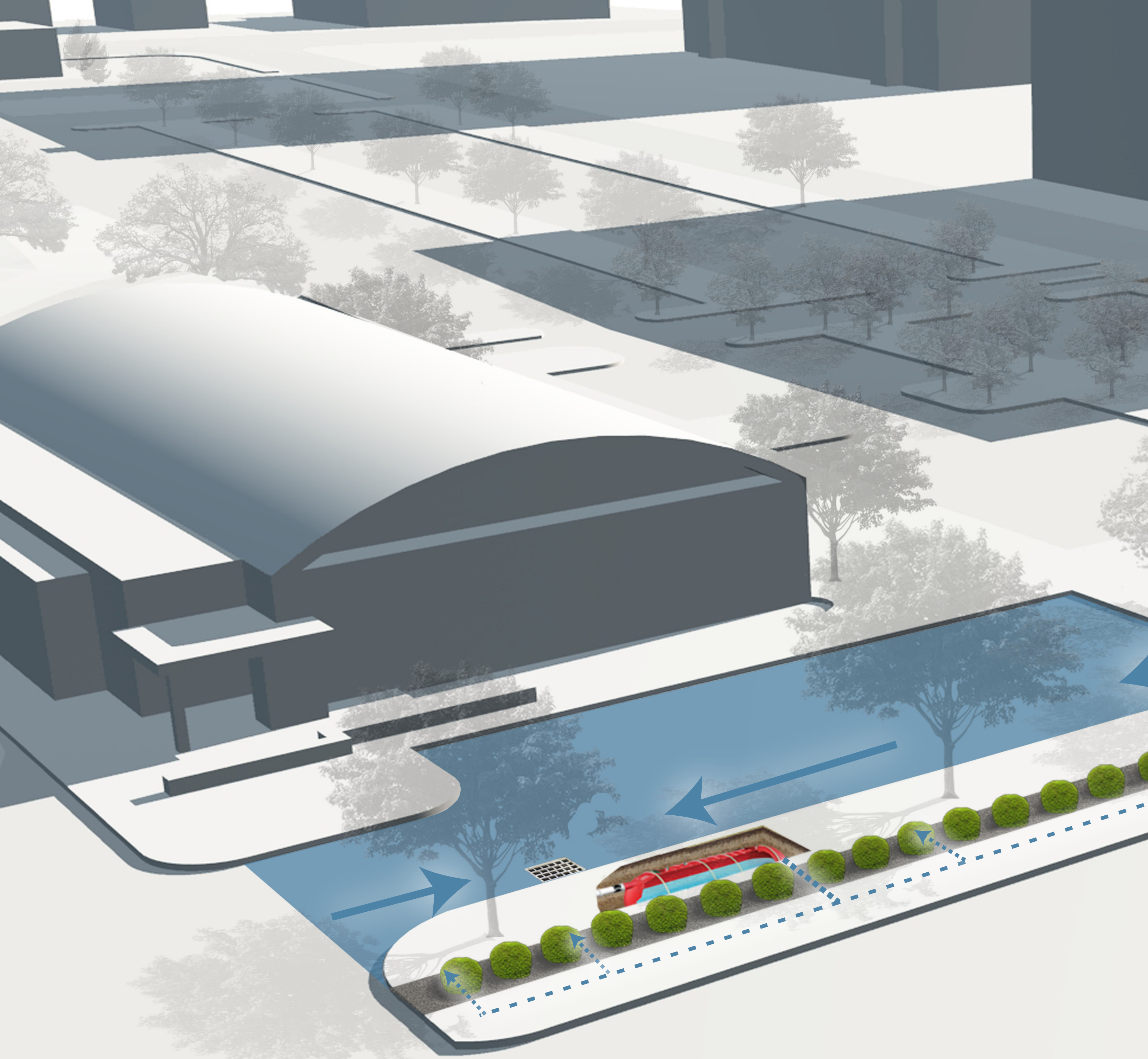
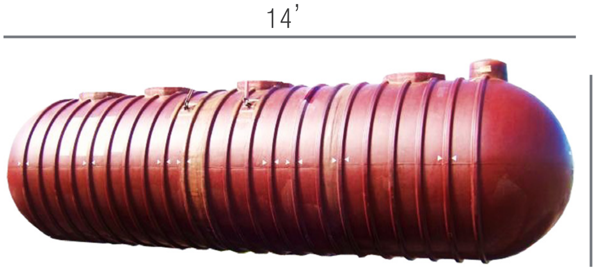
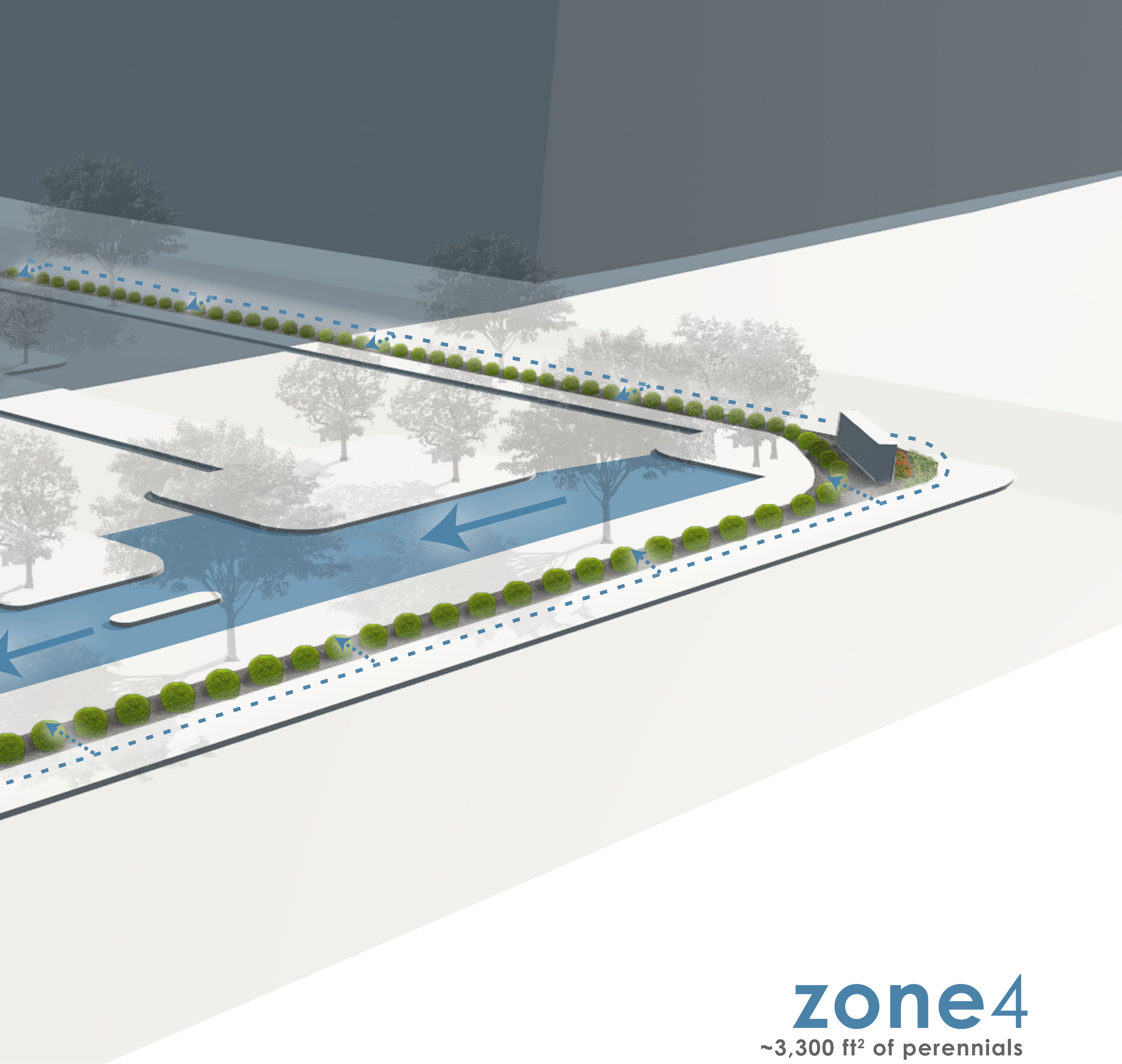


Figure 5.10 Irrigation Zone 4 Functional Diagram

All of the irrigation for Zone 4 is fed by 9,257 ft^2 of parking lot surface. Surface runoff flows into the existing drain inlet to a 100 gallon first flush diverter to remove all suspended solids, pollutants, and debris from the stormwater. From the first flush diverter, water flows into the 2,000 underground fiberglass cistern where it is then pumped to a drip irrigation system within the bed of Arborvitae shrubs.



2,000 Gallon Fiberglass Cistern



zone4

~3,300 ft² of perennials

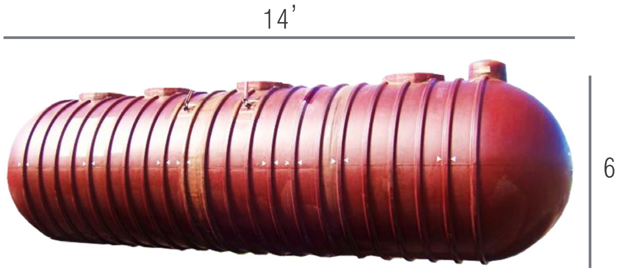
watersource

9,257 ft² of Parking Lot Surface

storagecontainer

(1) 2,000 Gallon Underground Fiberglass Cistern

All of the irrigation for Zone 5 is fed by 7,476 ft^2 of parking lot surface. Surface runoff flows into the existing drain inlet to a 100 gallon first flush diverter to remove all suspended solids, pollutants, and debris from the stormwater. From the first flush diverter, water flows into the 2,000 underground fiberglass cistern where it is then pumped to a drip irrigation system within the bed of Arborvitae shrubs.



2,000 Gallon Fiberglass Cistern

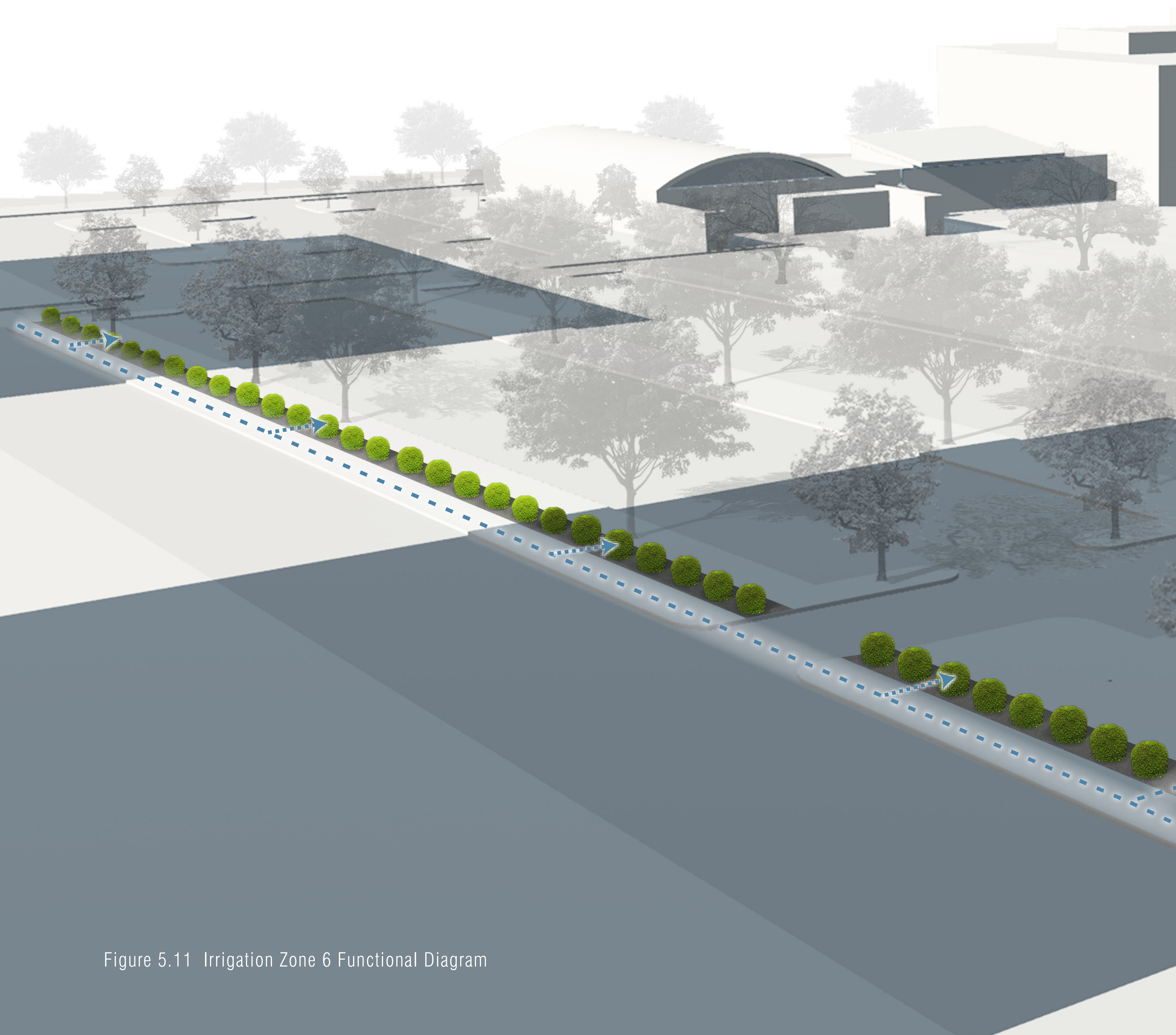
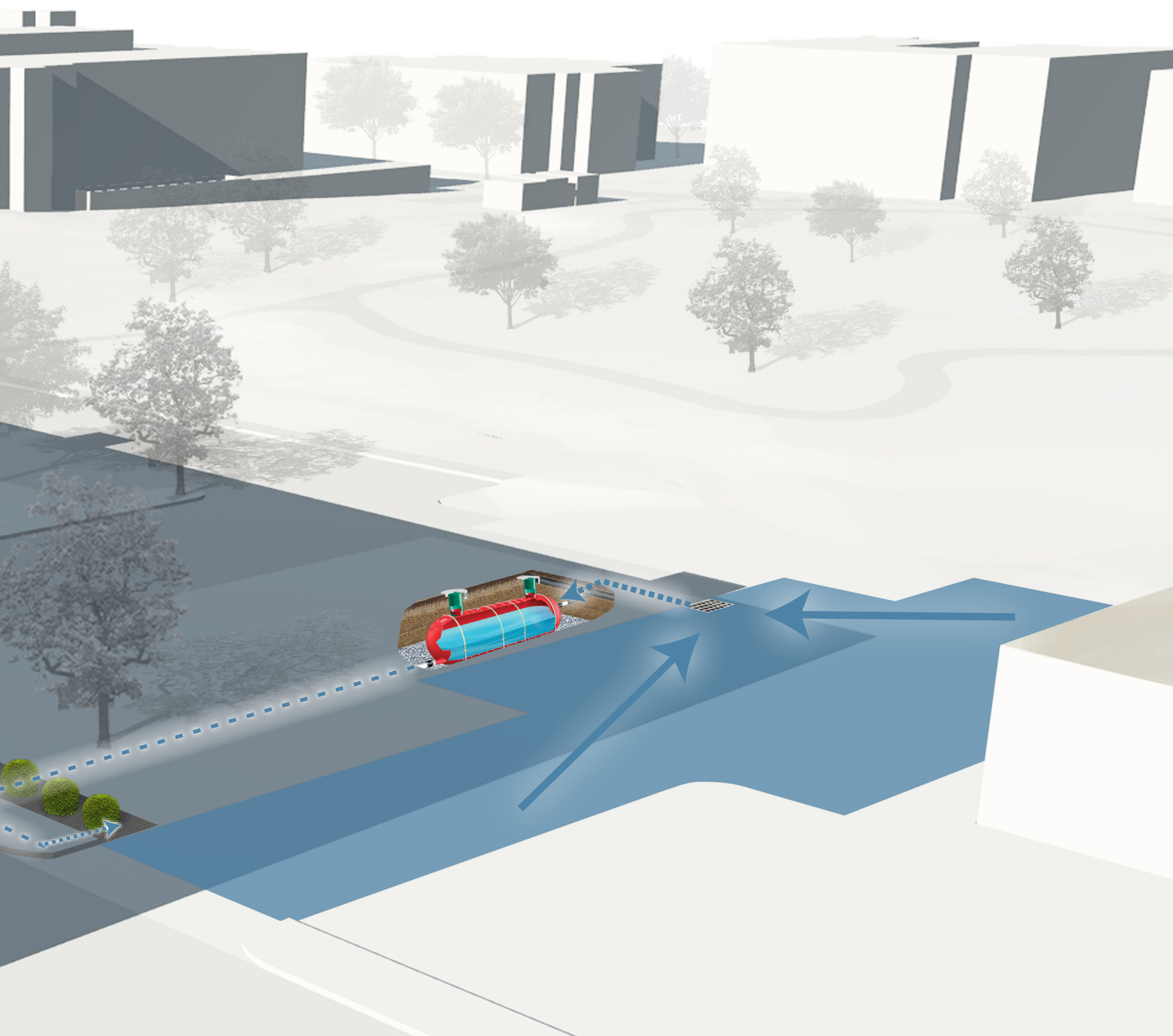


Figure 5.11 Irrigation Zone 6 Functional Diagram

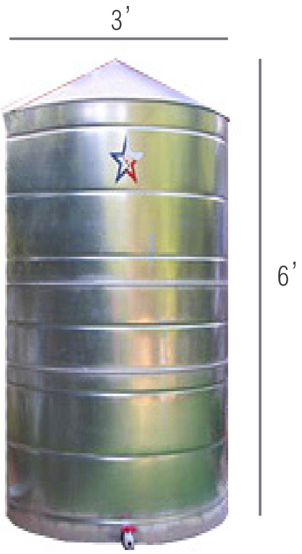
watersource
7,476 ft^2 of Parking Lot Surface

zone5
~2,700 ft^2 of perennials

storagecontainers
(1) 2,000 Gallon Underground Fiberglass Cistern



All of the Irrigation for Zone 6 is provided by 3,602 ft^2 of rooftop surface. As rainfall hits the roof, it is directed into the gutter system where it is fed to a downspout connected to a 35 gallon first flush diverter. When the diverter is filled to capacity, overflow enters the 300 gallons cistern. Water for irrigation is pumped underground from the cistern through a submersible pump located within the cistern. Irrigation flows through a drip system to provide water to the perennial planting beds.



300 Gallon
Galvanized Steel Cistern

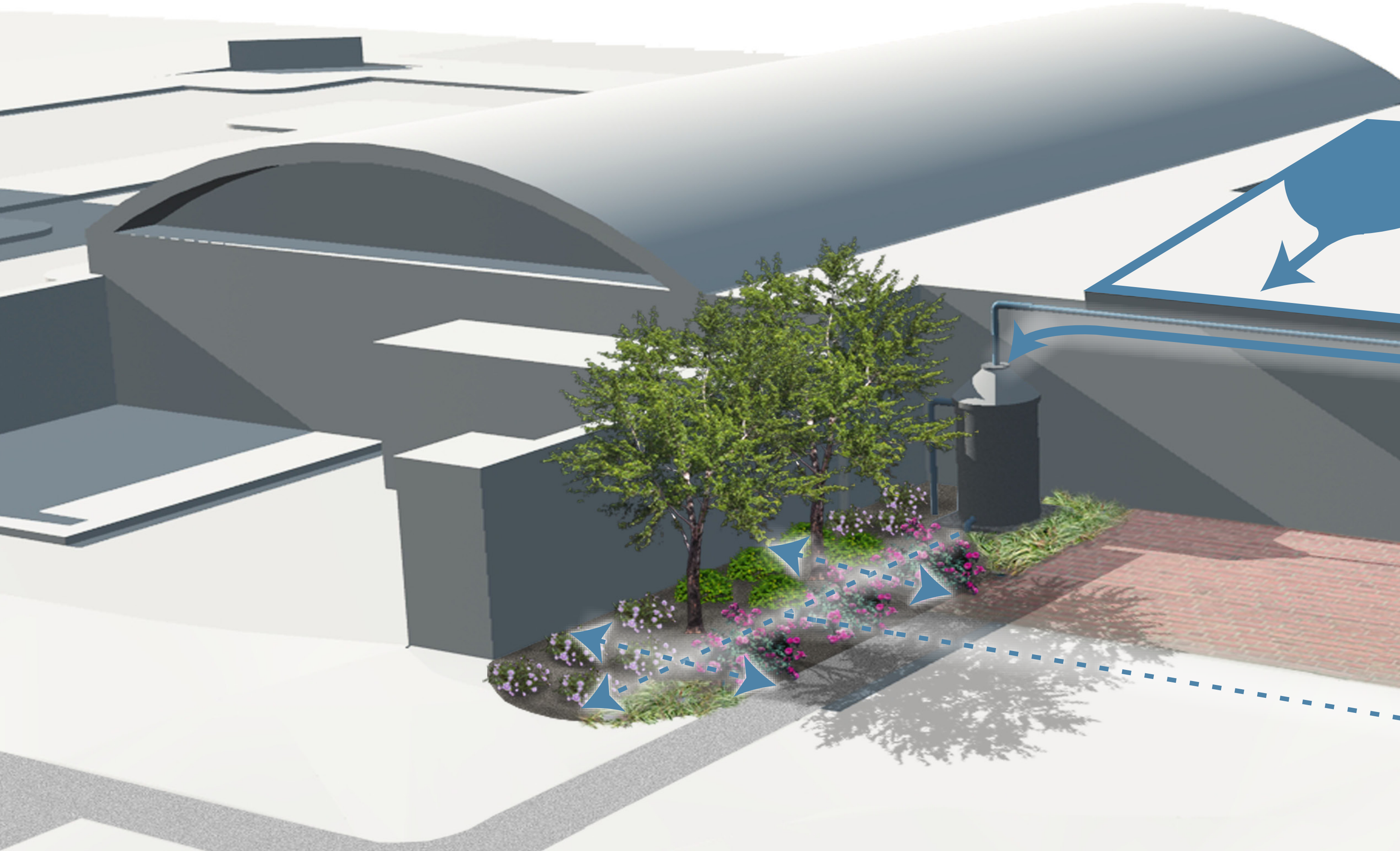
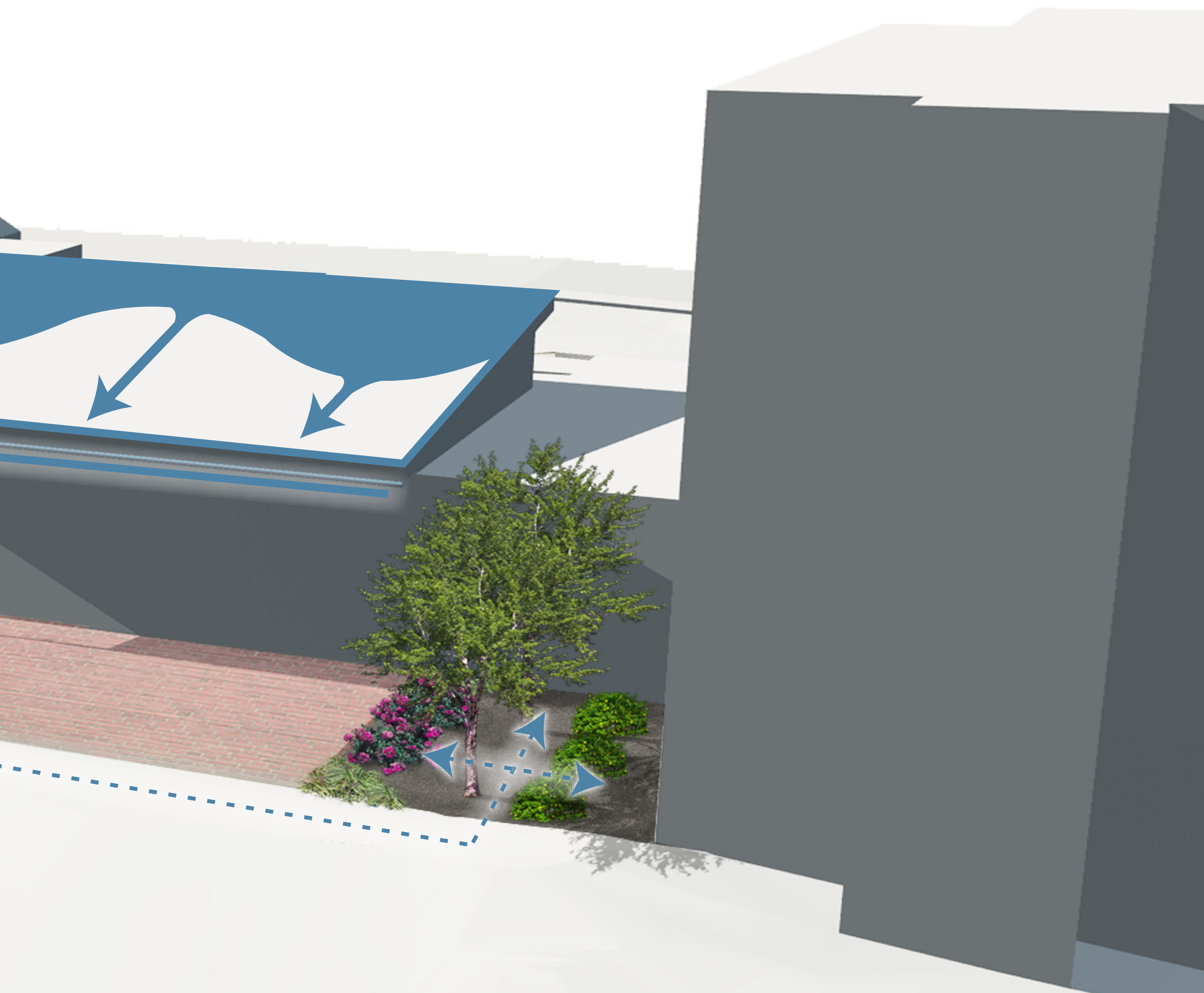


Figure 5.12 Irrigation Zone 6 Functional Diagram

watersource
3,602 ft^2 of Rooftop Surface

zone6
~1,232 ft^2 of perennials

storagecontainers
(1) 300 Gallon Galvanized Steel Above-Ground Cistern



Selecting the Storage Container Materials

Fabricated metal cisterns, the most common above-ground cistern option, have been selected for all of the above-ground water harvesting storage containers in the proposed retrofit. These cisterns use lightweight, thin gage steel for structure and an impermeable liner for containment. The lightweight steel makes the cisterns easily movable and their prefabricated design make installation easier than cisterns which require on-site assembly. Above-ground metal cisterns can last up to 75 years due to the above-ground environment being less corrosive than underground (Kowalsky and Thomason 2011). Another added benefit of a steel cistern is the associated aesthetics. People generally recognize the look of a steel water harvesting cistern, and when placed out in front of a particular building, it can give the perception to onlookers that this company is actively harvesting and recycling water, thus benefitting the image of the corporation.

Underground fiberglass cisterns have been chosen as storage containers for Zones 2, 4, and 5. Fiberglass cisterns are common choices for underground options because they offer high pressure ratings and resist corrosion, often having a lifespan of up to 75 years (Kowalsky and Thomason 2011). These cisterns are relatively lightweight making installation easier than other options. While they are not the most economical choice, the durability of fiberglass tanks has been shown to be the superior choice for underground storage. Figure 5.13 shows an elevation of the underground cistern layout, working elements, and back-up water supply connections

Zone 3 uses the Atlantis Underground Crate System for its storage container needs. This system is a network of stacked crates, with each crate having 95% void space, surrounded by a polypropylene plastic liner wrapped around the crates. Each crate is lightweight, allowing for easy installation, and can be installed in various volumes, shapes, and depths to accommodate the specific needs of any particular project. The crates are structurally sound which allow for normal activities to occur on top of the buried underground cistern. The necessity to install a large, 50,000 gallon storage container within Zone 5 that can be easily installed to fit the tight space between underground utilities is the rationale for this particular type of cistern. Figure 5.14 shows an elevation of the underground crate cistern layout, working elements, and back-up water supply connections.

Table 5.2 shows a comprehensive cost/benefit comparison of various storage containers material options.

	Material	*Cost*	*Installation* (hard - easy)	*Longevity* (short - long)	*Durability* (low - high)	*Maint. Access* (hard - easy)
Underground	*Fiberglass*	$$$$$	●●●	●●●●	●●	●●●●
	Polyethylene	$	●●●●●	●●●	●●●	●●
	Steel Reinforced Polyethylene	$$$	●●●●	●●●●●	●●●●●	●●●●
	Plastic Crates	$$$	●●●	●●	●	●
	Concrete	$$$$$	●●	●●●●	●●	●●●●
	Waterproof Corrugated Metal	$$	●●●●	●●●	●●●●●	●●●●
	Fabricated Steel	$$$$	●●●	●●●	●●●●	●●●●
Above-Ground	*Monolithic*	$$$	●●●●	●●●●●	●●●●	●●●●●
	Plate Assembled On-Site	$$$	●●	●●●●●	●●●●	●●●●●

Table 5.2 Cost/Benefit Comparison of Storage Container Materials. Source: Kowalsky and Thomason 2011

1. Drain inlet collecting surface runoff from parking lot
2. Gutter and downspout collecting runoff from roof
3. Dry well to receive overflow from first flush diverter
4. Release lever to empty first flush diverter after rain events
5. Maintenance access to first flush diverter
6. First flush diverter
7. Maintenance access to cistern
8. Underground fiberglass cistern
9. Cistern overflow
10. Pump and pump shroud
11. Dry well (or storm drain) to receive overflow from cistern
12. Valve/backflow preventor for back-up connection to municipal water source

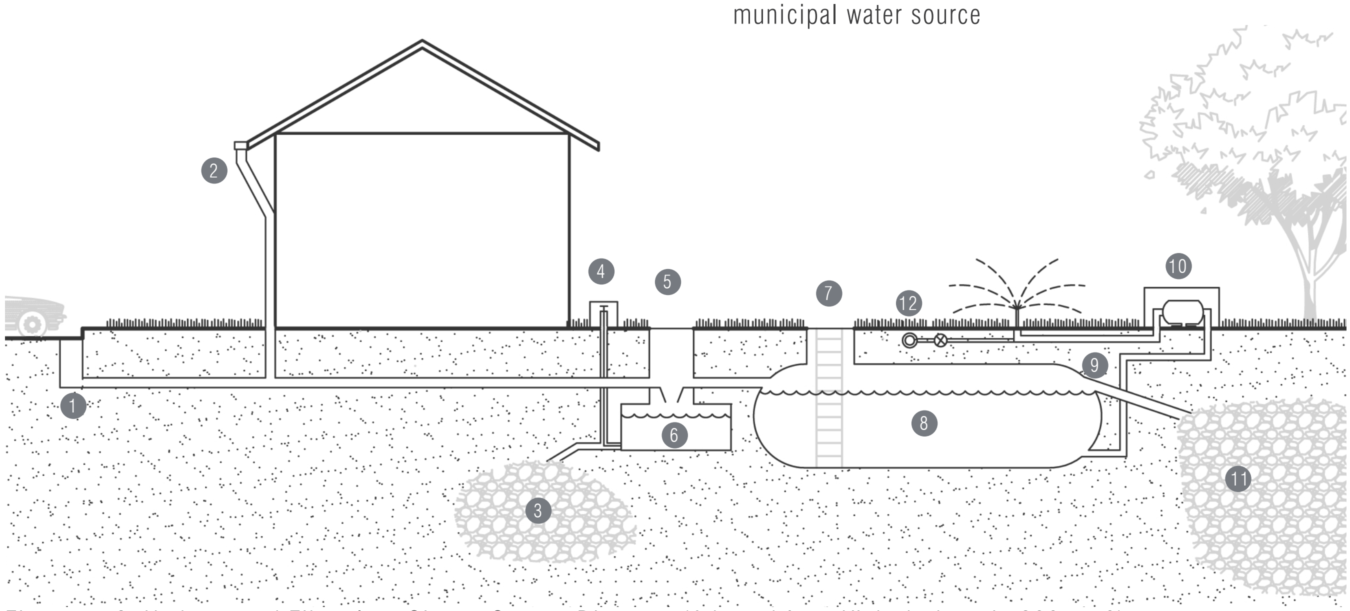


Figure 5.13 Underground Fiberglass Cistern System Diagram. (Adapted from Kinkade-Levario 2007, 16)

1. Drain inlet collecting surface runoff from parking lot
2. Gutter and downspout collecting runoff from roof
3. Dry well to receive overflow from first flush diverter
4. Release lever to empty first flush diverter after rain events
5. Maintenance access to first flush diverter
6. First flush diverter
7. Polypropylene plastic liner surrounding stacked crates
8. Underground stacked crate cistern
9. Cistern overflow
10. Pump and pump shroud
11. Dry well (or storm drain) to receive overflow from cistern
12. Valve/backflow preventor for back-up connection to municipal water source

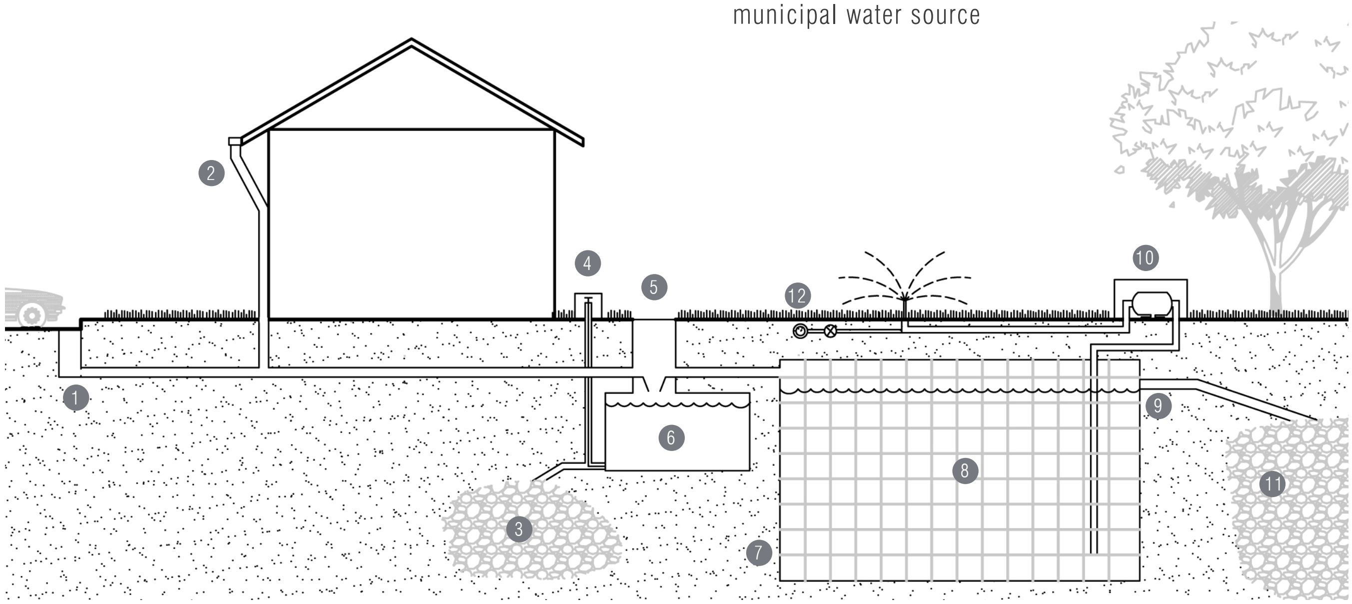


Figure 5.14 Underground Atlantis Crate Cistern System Diagram. (Adapted from Kinkade-Levario 2007, 16)

Sizing the Cisterns

Each cistern was sized based on a method similar to the monthly water budget introduced at the end of Chapter 2 (Table 2.3). However, a daily water budget (Figure 5.3) was used to determine the minimum size each cistern needs to be in order to hold enough water to last 10 days between significant rain events while still allowing an adequate amount of water to be drawn out for irrigation every three days. The month of August was used for the daily water budget due to it being the month with the least rainfall and nearly the highest irrigation demands. Using the month with the lowest rainfall and highest demand allocates enough water for the worst-case scenario in each growing season. Therefore the cistern size should be adequate to provide irrigation during other months when rainfall is greater and irrigation demand is less. Accounting for 10 days between rain events is due to the EPA's prediction of more intense, less frequent storms in the Midwest. St. Louis currently averages eight significant rainfall events for the month of August based on trends over the past 11 years (Figure 3.2). Each daily water budget accounts for only four rainfall events at twice the intensity, thus providing congruency with the EPA's predictions. Table 5.3 shows an example of a daily water budget used to size the cistern for Zone 5. Listed below are basic assumptions inherent with each daily water budget:

- Rainfall events are assumed to be spread evenly throughout the month
- Each rainfall event is assumed to be the same intensity
- Equal volumes of irrigation water are assumed to be applied to the vegetation every 3 days

Daily landscape water demand numbers are based on the monthly water demand numbers for each vegetation area shown in Appendix C. For the example shown in Table 5.3 Daily Water Budget for Zone 5, the monthly water demand for August was divided by the number of days in the month to get the quantities in the Daily Water Demand column. The Water Requirements column reflects the amount of water that needs to be collected to meet the daily water demand after factoring in irrigation inefficiency. The Available Supply column represents the volume of rainfall that is generated from the collection surface that is feeding the cistern, accounting for the runoff coefficient. Loss from first flush represents the volume of water lost due to filtration through the first flush diverter. That volume adheres to the general first flush diverter sizing guidelines in Table 5.1. The Amount Needed for Irrigation column represents the quantity of water that will be drawn from the cistern every three days to irrigate the associated vegetation area. Each number in this column represents the sum of three days' worth of water requirements from the Water Requirements column. The Cumulative Storage column is a running total of the amount of water in each cistern at the end of every day after factoring in water input through surface runoff and water drawn down for irrigation purposes. The Overflow column represents the amount of water drained from the overflow outlet once the cistern has reached its maximum capacity. An example detailing how each cistern was sized to allow three cycles of irrigation to be drawn out between rainfall events is shown below for Table 5.3 Zone 5:

- August 2 – Rainfall event occurs, filling the cistern up to capacity (1,800 gallons)
- August 3 – 570 gallons (3 days' worth of water requirements) are drawn out for irrigation purposes. 1,230 gallons are left in the tank
- August 4 - No rainfall occurs. No irrigation drawn
- August 5 - No rainfall occurs. No irrigation drawn
- August 6 - 570 gallons are drawn out for irrigation purposes. 660 gallons are left in the tank.
- August 7 - No rainfall occurs. No irrigation drawn
- August 8 - No rainfall occurs. No irrigation drawn
- August 9 - 570 gallons are drawn out for irrigation purposes. 90 gallons are left in the tank.
- August 10 – Rainfall event occurs, filling the cistern back up to capacity.

Day	Daily Water Demand	Water Requirements	Available Supply (4 Events @ .62" Each)	Loss to First Flush	Amt. Needed for Irrigation	Cumulative Storage	Overflow
8/1	188	190	0	-	0	0	0
8/2	188	190	2,456	100	0	1,800	556
8/3	188	190	0	-	570	1,230	0
8/4	188	190	0	-	0	1,230	0
8/5	188	190	0	-	0	1,230	0
8/6	188	190	0	-	570	660	0
8/7	188	190	0	-	0	660	0
8/8	188	190	0	-	0	660	0
8/9	188	190	0	-	570	90	0
8/10	188	190	2,456	100	0	1,800	646
8/11	188	190	0	-	0	1800	0
8/12	188	190	0	-	570	1,230	0
8/13	188	190	0	-	0	1,230	0
8/14	188	190	0	-	0	1,230	0
8/15	188	190	0	-	570	660	0
8/16	188	190	0	-	0	660	0
8/17	188	190	0	-	0	660	0
8/18	188	190	2,456	100	570	1,230	1,216
8/19	188	190	0	-	0	1,230	0
8/20	188	190	0	-	0	1,230	0
8/21	188	190	0	-	570	660	0
8/22	188	190	0	-	0	660	0
8/23	188	190	0	-	0	660	0
8/24	188	190	0	-	570	90	0
8/25	188	190	0	-	0	90	0
8/26	188	190	2,456	100	0	1,800	646
8/27	188	190	0	-	570	1,230	0
8/28	188	190	0	-	0	1,230	0
8/29	188	190	0	-	0	1,230	0
8/30	188	190	0	-	570	660	0
8/31	188	190	0	-	0	660	0

Table 5.3 Zone 5 Daily Water Budget For the Month of August for Determining Size of Cistern (In Gallons)

Site Design

After every water generating source (Figure 5.6) has been dedicated to providing irrigation for the highest priority vegetation areas (Figures 5.7 – 5.12), approximately 76.5% (7.38 acres) of the turf landscape is left without a source of water (Figure 5.15). The findings reveal that these 7.38 acres of turf must be replaced with vegetation that can still function and appear healthy without needing much supplemental irrigation. Figures 5.16 and 5.17 show the existing planting plan at Sigma Aldrich and the proposed planting plan that has replaced the 7.38 acres of turf with native drought tolerant wildflowers and tallgrass species. Proposed elements in the newly designed site plan include: a native wildflower and tallgrass meadow, a split-rail fence, dry creek bed, relaxation and seating coves within the native meadow inside the existing walking trail, and native drought tolerant plantings within the existing parking lot islands.

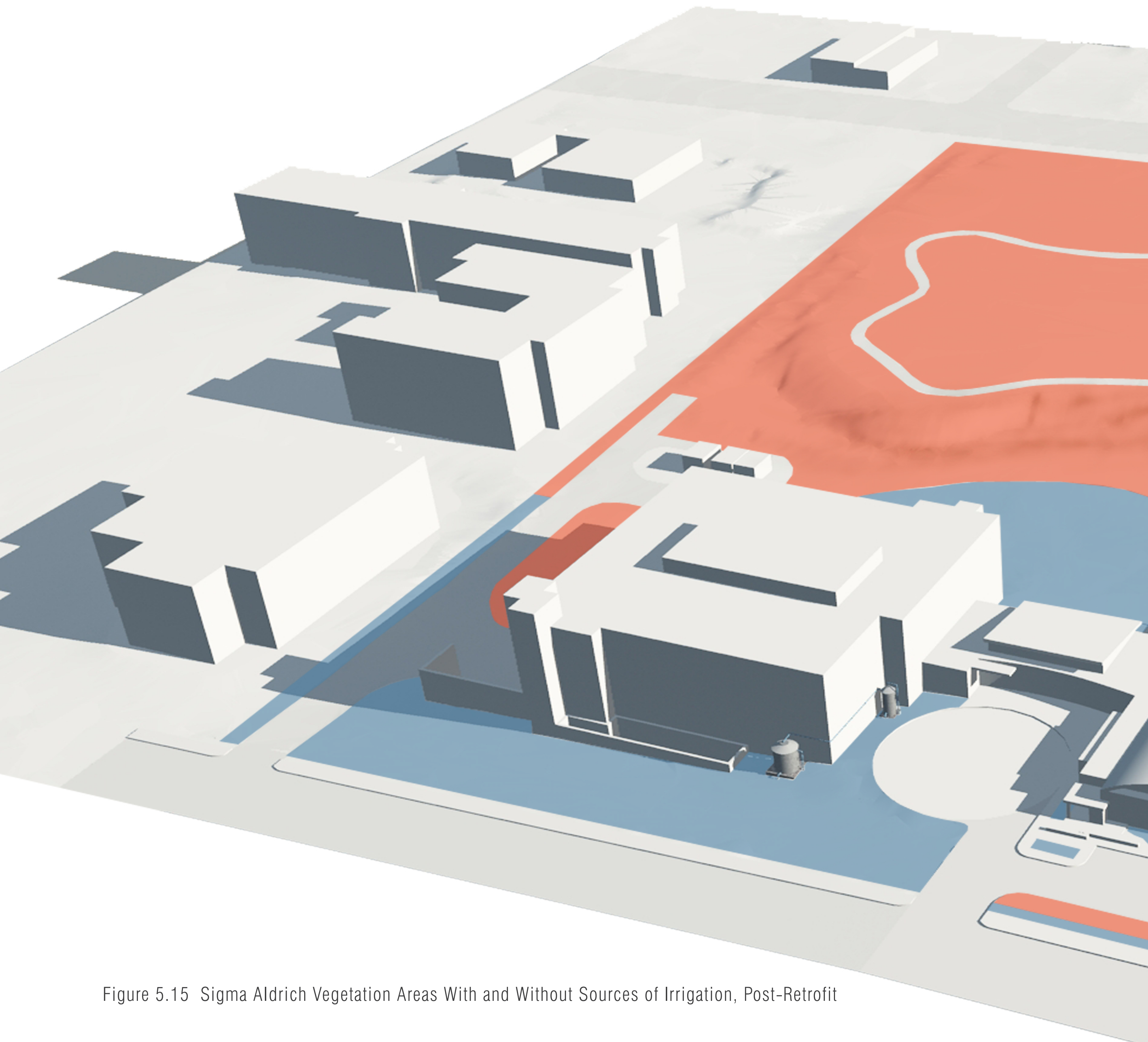
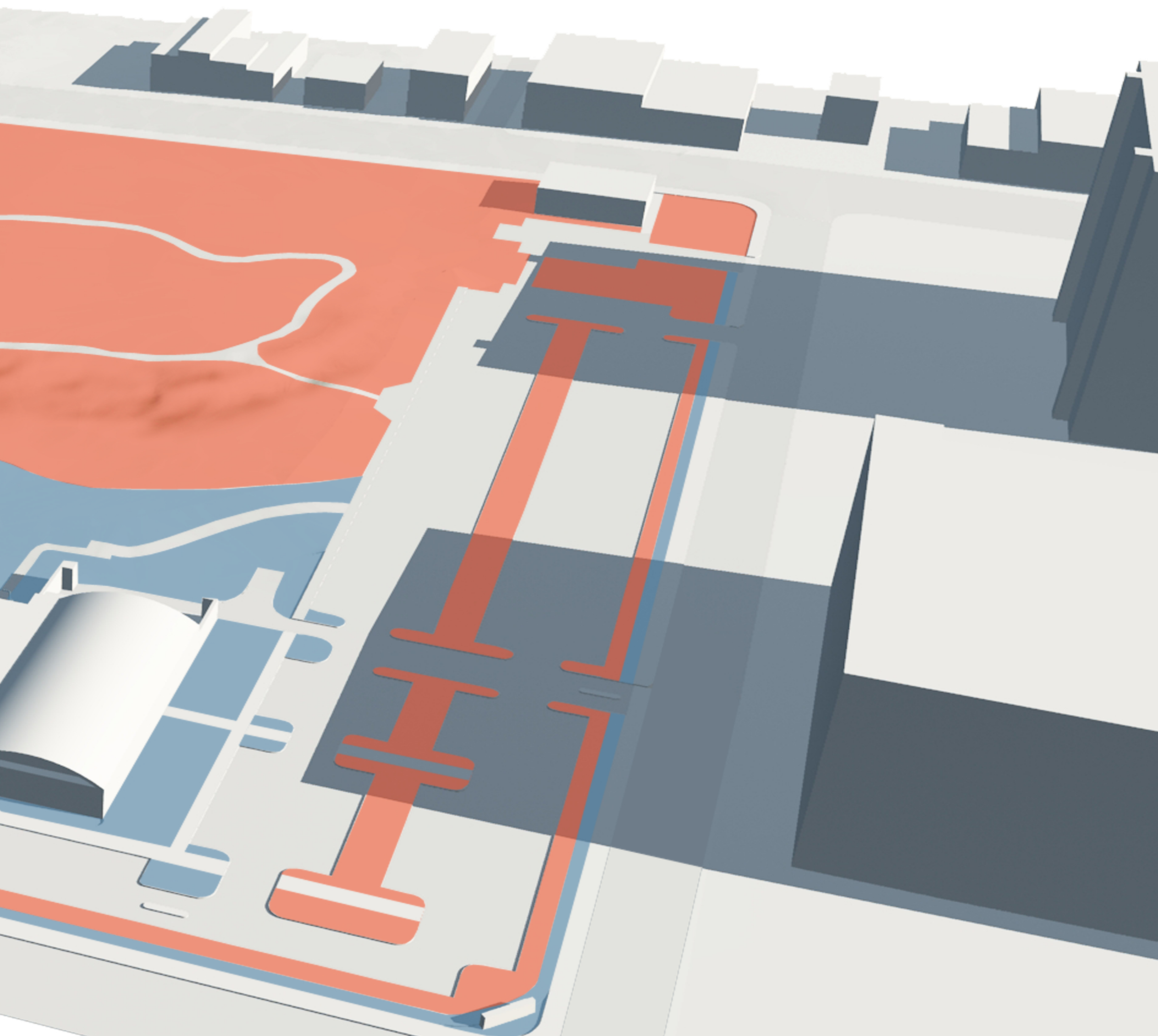


Figure 5.15 Sigma Aldrich Vegetation Areas With and Without Sources of Irrigation, Post-Retrofit

<u>After all the potential water supply is harvested:</u>

23.5% (2.27 acres) of landscape can be irrigated by harvested water

76.5% (7.38 acres) of landscape has no available water supply



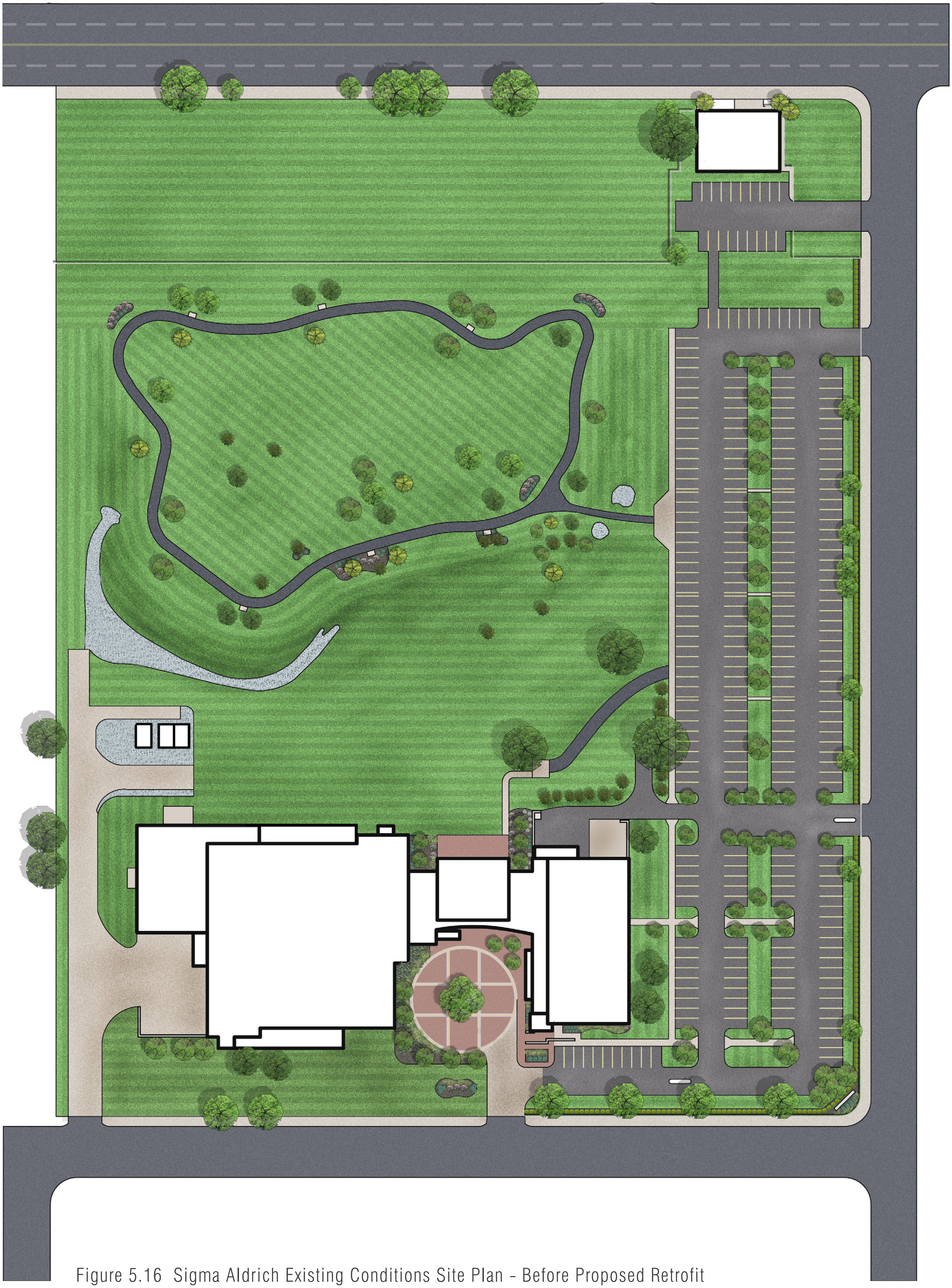


Figure 5.16 Sigma Aldrich Existing Conditions Site Plan - Before Proposed Retrofit

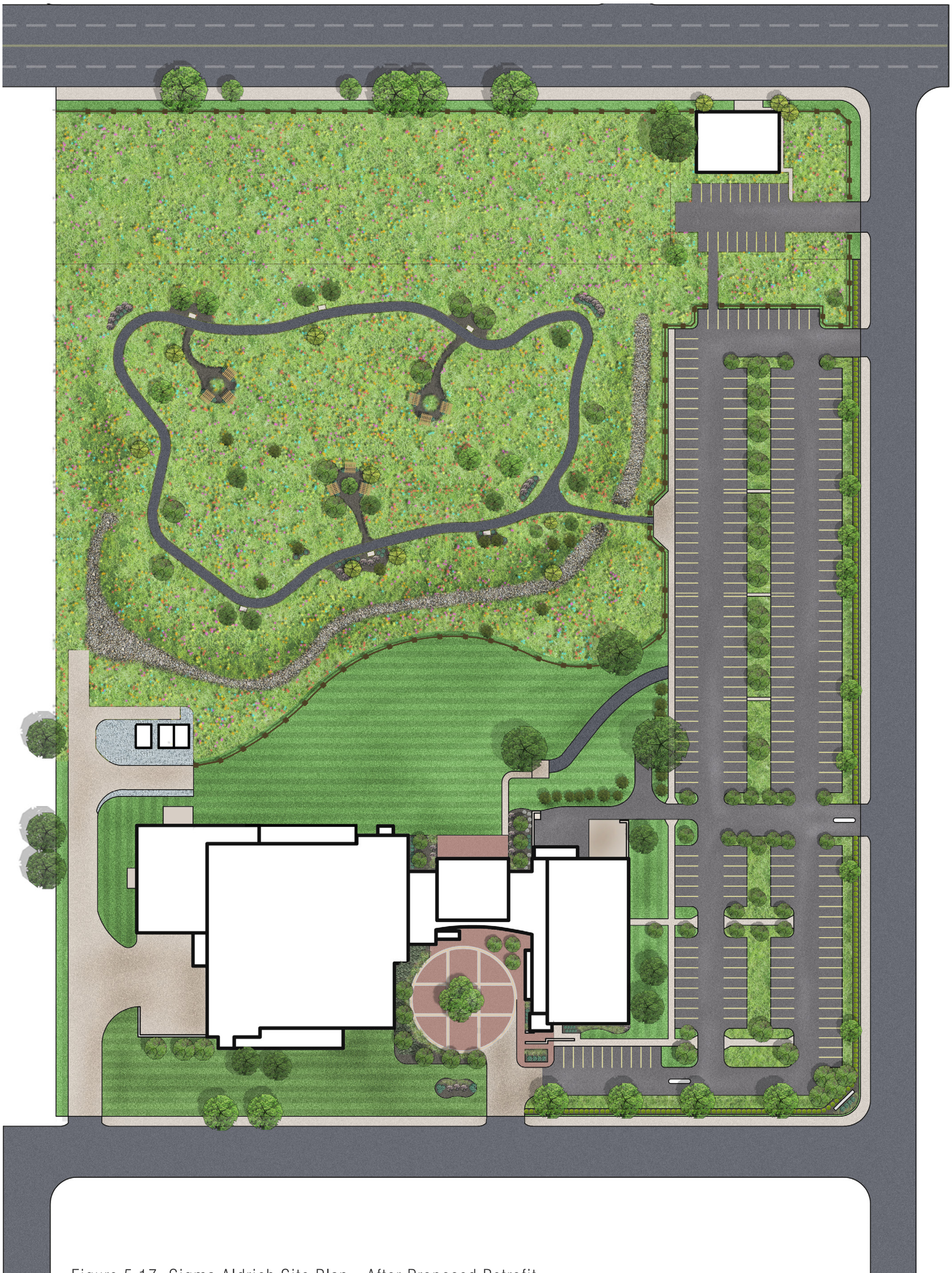


Figure 5.17 Sigma Aldrich Site Plan - After Proposed Retrofit

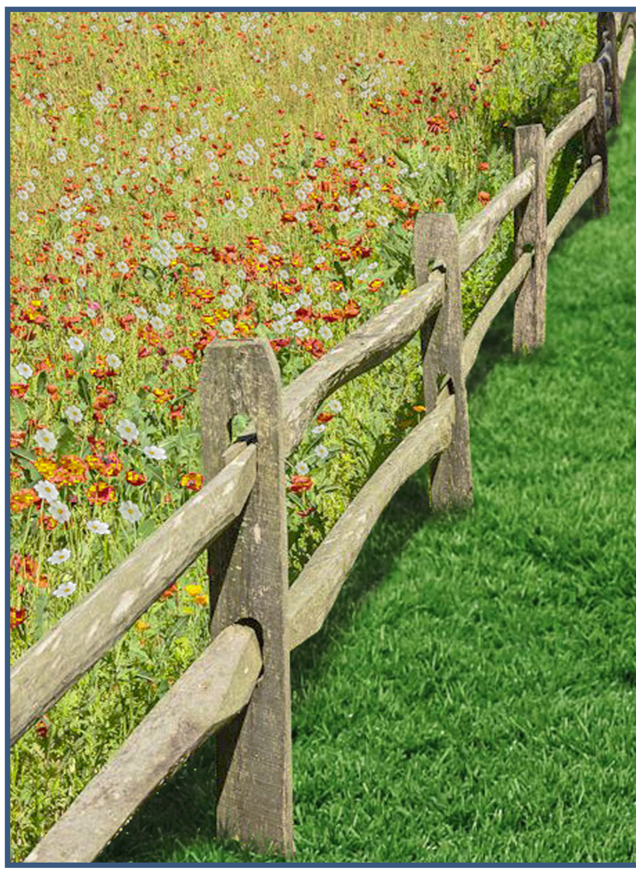
Native Meadow

The native wildflower and tallgrass meadow is made up of a seed mix consisting of the following 24 wildflower and 5 tallgrass species (denoted with asterisk):

Leadplant	Butterflyweed
Sky Blue Aster	Smooth Aster
Frost Aster	White Aster
Canada Milk Vetch	Lanceleaf Coreopsis
Purple Prairie Clover	Pale Purple Coneflower
Showy Sunflower	Downy Sunflower
Roundhead Bushclover	Rough Blazingstar
Lupine	Bergamot
Dotted Mint	Beardtongue
Yellow Coneflower	Black Eyed Susan
Stiff Goldenrod	Showy Goldenrod
Ohio Spiderwort	Hoary Vervain
Big Bluestem*	Sideoats Grama*
Canada Wild Rye*	Little Bluestem*
Indiangrass*	

Wildflower Meadow.
(Image Source: Richard Croft 2007)

These species are drought tolerant and are specifically chosen to maintain their health and natural form in dry soils and harsh conditions. Apart from providing a visually stimulating planting area that can perform with little to no supplemental irrigation, the native meadow provides many other benefits as well. The height and color palette of the meadow adds an aesthetic richness to the site and clearly defines the space of manicured turf between the meadow and the main building. The addition of the split-rail fence acts as a transition from the more formal look of the manicured turf to the rustic, naturalistic look of the tallgrass meadow. As Joan Nassauer states in her 1995 journal article “Messy Ecosystems, Orderly Frames,” often times there is a cultural misinterpretation of a native landscape that lacks cues of human design intention. When there are no signs of human intention in a landscape, such as a clearly mown and maintained edge, people generally view the landscape as an unkempt, overgrown, ignored area. The implementation of the split rail fence and mown perimeter acts as cultural clues of order which tell the onlooker that this landscape



Split-Rail Fence. (Image Source: Adapted from Flickr user Maryann’s****Fotos)

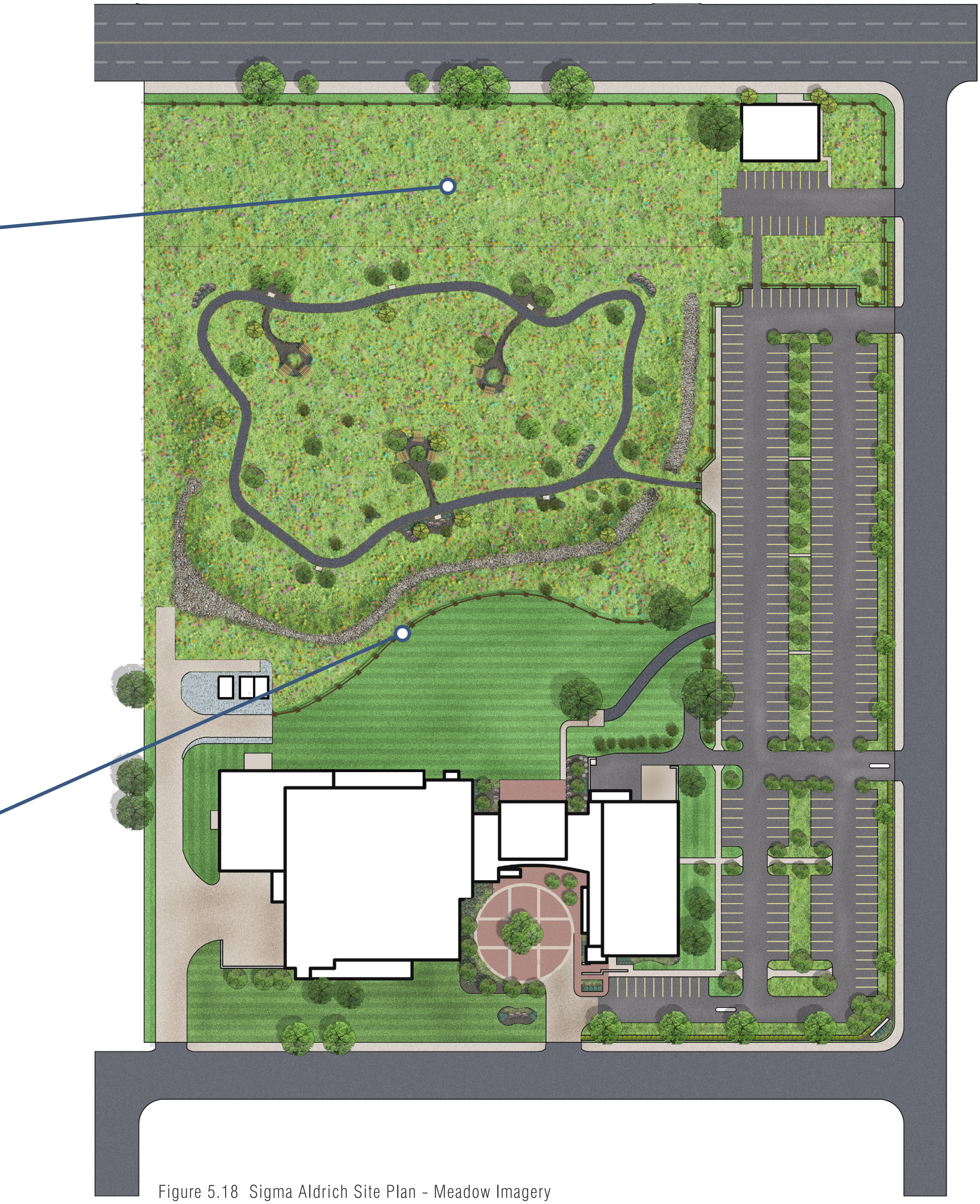


Figure 5.18 Sigma Aldrich Site Plan - Meadow Imagery

has been clearly designed with human intention and is meant to perform an ecological function. This leads to greater aesthetic acceptance. The meadow also transforms the existing trail area from an area where there is an intense feeling of exposure amongst the vast areas of turf into a sheltered destination. The entrance to the trail, as marked by a gap between the split-rail fence, acts as a clearly defined threshold into a different space and invites users to enter and walk amongst the native setting within an urban environment. Along the trail, three intimate relaxation coves have been designed to provide workers with a place to sit and relax underneath a pergola while they enjoy lunch with a friend. This addition adds relief from the intense summer sun while at the same time invites more workers to enjoy the outside environment and gain some exercise at the same time. The dense planting of the meadow also helps mitigate surface runoff from the area due its deep root system, compared to the higher runoff coefficients associated with the existing turf. Once established, this native meadow will significantly reduce maintenance costs currently related to the weekly mowing of 7.38 acres of existing turf, thus adding a financial benefit as well.

Parking Lot Plantings

The existing parking lot islands have been proposed to be stripped of turf and replanted with an outside 4' border of Blue Grama (9" – 2' tall) and a center planting of Little Bluestem (2 – 4' tall). Not only do these native grasses provide drought tolerant vegetation that requires no supplemental irrigation once established, but they also complement the naturalistic look of the native wildflower and tallgrass meadow.

Pergola Seating Cove. (Image Source: Old World Garden Farms 2014)

Dry Creek Bed. (Image Source: Invisible Structures 2014)

Native Drought Tolerant Grass Parking Lot Island. (Image Source: Conservation Design Forum 2014)

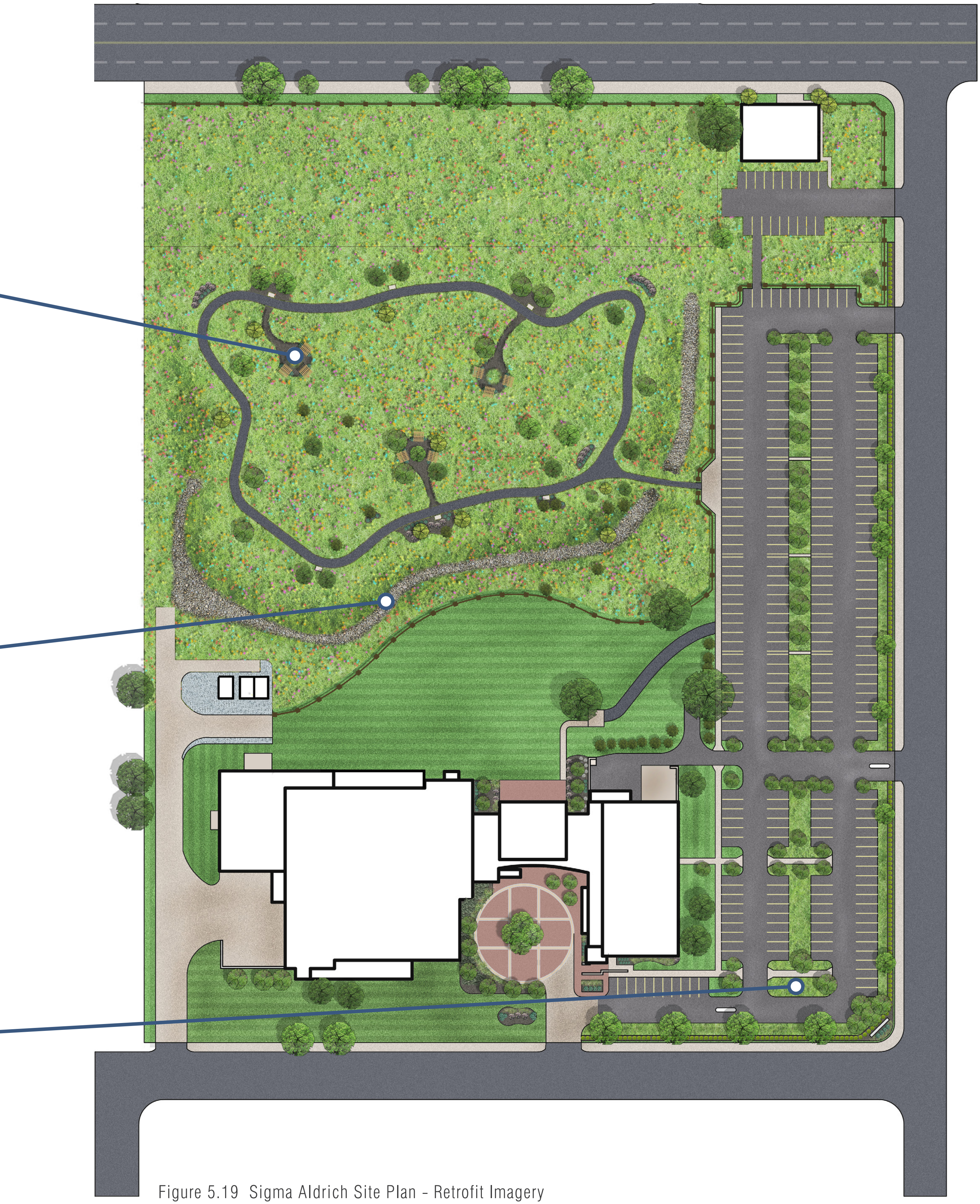


Figure 5.19 Sigma Aldrich Site Plan - Retrofit Imagery

Making a Case for Going Native

Transforming the rear portion of the Sigma Aldrich site will most certainly change the existing character of the site from the vast expanse of turf into a naturalistic, native prairie ecosystem within the urban environment. While this may be a shocking transition to some, it is not a new phenomenon. There has been a trend over the last decade for corporate headquarters throughout the country to go native and incorporate wildflower and tallgrass meadows into their site designs. Three examples of large corporations that have transitioned away from the normal turf planting scheme to a more naturalistic look are presented on page 111. Native plantings at these corporate headquarters can have substantial benefits. First, planting with native species can substantially decrease the amount of money spent on irrigation. As mentioned earlier, too much turf in a large area can create a sense of exposure within the landscape. Installing tallgrass meadows in an area creates lift and adds visual interest and sense of enclosure that makes a space feel more comfortable. Perhaps the most important benefit for corporations going native is the boost in the image of the company. A corporation that takes every measure possible to conserve water resources, provide wildlife habitat, and curtail the negative environmental impacts associated with urban runoff publicly demonstrates greater environmental responsibility.

Design Summary

After the proposed retrofit, the area around the building remains largely unchanged regarding the aesthetics of the site. The addition of two cisterns, one being 12’ x 18’ and one at 3’ x 6’, will be visible upon entry into the drop off area and from passing by on the street. The visibility of the shiny steel cisterns, however, is an intentional design move to reveal to the public that the Sigma Aldrich Corporation is taking measures to become a more sustainable company. The addition of the native tallgrass meadow to the rear portion of the site adds dynamic visual interest throughout the year over the blooming, growing, and dormant seasons compared to monotonous mown turf. This design move not only completely removes the need to irrigate the 7.38 acres of former turf landscape after the meadow has been established, but also creates more comfortable, inviting, clearly defined spaces within the landscape. In the end, this proposed retrofit turns this site into a truly balanced site in which a targeted 100% of the site’s irrigation demands are met from water harvested and recycled on-site.

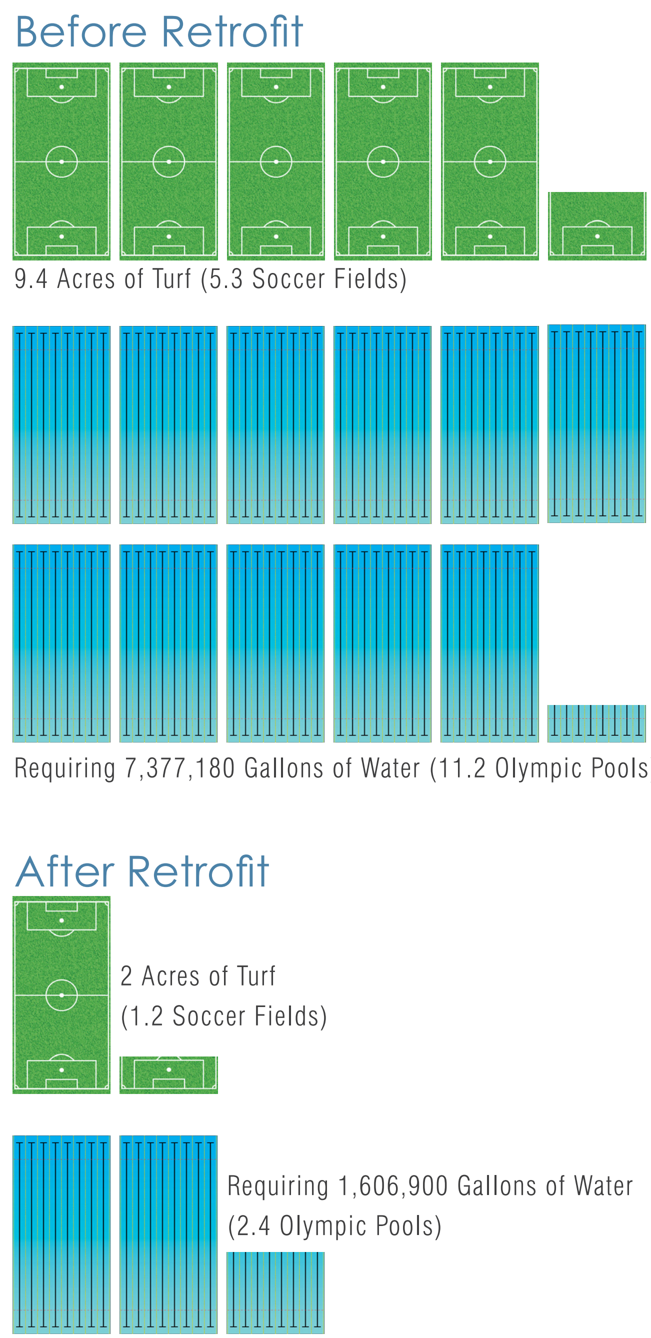


Figure 5.20 Post-Retrofit Water Use Comparison

Figure 5.21 Heifer International Headquarters, Arkansas
(Image Source: Flickr user Paul Barrows 2011)

Heifer International
By Ecological Design Group

"The site design for the Heifer International World Headquarters could not be initiated without consideration of Heifer's unqualified commitment to sustainability. The site design speaks through a series of concentric rings that expand outward from a central commons. One of these rings consists of a constructed wetland which creates an educational conservation experience with a global context. The placement of communities of plants in appropriate habitats represents the diversity and necessity of human communities, as well as good ecology." (Ecological Design Group 2014)

Trump Tower
By Hoer Schaudt

The 92-story Trump Tower along the Chicago River in Chicago, Illinois, features the first native landscape or a major commercial building in the downtown portion of the city. There are "rich layers of wetland grasses, sumac bushes and tall plane trees immerse visitors in an abstraction of a Midwestern riverbank juxtaposed with monumental architecture." (Hoer Schaudt 2014)

Discover Card Campus
By Hoer Schaudt

This 85-acre campus was designed as a four seasons landscape in Riverwoods, Illinois. Meadows of native grasses are planted throughout the buffer and has thousands of bulbs planted to enhance entrances, ponds, and corners of the site. The native meadow eliminates the need to irrigate the area and provides an "inspiring work environment for company employees." (Hoer Schaudt 2014)

chapter V1:

project conclusions

VI Project Conclusions

Is it Worth It?

Chapter 5 introduced the primary considerations, planning process, and design elements for what it would take to completely transform the Sigma Aldrich site into a landscape which has near zero dependency on a municipal water source for irrigation. Is it really worth it though? Figures 6.1 and 6.2 show an initial cost estimate and return on investment calculation for the proposed retrofit to the Sigma Aldrich site. Values for the estimated costs were gathered from a combination of the manufacturer's or dealer's price of products used, consultation with the *2013 RS Means Handbook for Site Construction*, and allowances based on educated inferences. Findings from the cost estimate reveal that the approximate cost for the entire retrofit is around $250,000. When factoring in the current metered water rates for the City of St. Louis and yearly costs associated with reduction in the projected amount of water used for irrigation and turf maintenance post-retrofit, this project could potentially save nearly $29,000 per year. This results in an estimated return on investment of approximately 8.9 years.

From a strictly economic standpoint, an investment of over $250,000 which takes 9 years to yield $29,000 per year could possibly make financial sense. However, there are many more intangible factors that could potentially provide additional incentives. As mentioned in previous chapters, the enhancements to the image of a company which can advertise that nearly 100% of their irrigation needs are met by water harvested and recycled on-site are everlasting. Projects like this show that the corporation is concerned with the environment and are actively striving to reduce their carbon footprint, reduce pressure on local infrastructure, and limit the environmental impacts of urban surface runoff by harvesting water on-site. After considering the intangibles, the question still remains; is it worth it? I believe the answer to that question lies in the hands of the company decision makers and their values regarding the balance between company image versus return on investment.

Figures 6.1 and 6.2 show that retrofitting an existing site with a water conservation design scheme can make environmental and financial sense. However, Figures 6.3 - 6.5 reveal that installing a water conservation design scheme during initial site construction results in considerable lifetime savings when compared to new construction costs and lifetime operation costs associated with a predominately turf landscape. The comparisons for new construction of the typical turf landscape and the water conservation landscape in Figures 6.3-6.5 assume that all costs associated with other site elements (building, parking lot, trails, sidewalks, tree and perennial plantings, etc.) are the same for each scenario. Therefore, the line items for each

Estimated Project Up-Front Retrofit Costs

Storage (7 Total Cisterns)	*$84,150*
(2) Above-Ground Steel - 300 Gallon @ $675 Each (*Manufacturer Price*)	
(1) Above-Ground Steel - 11,500 Gallon @ $1/Gallon (Kinkade-Levario 2007, 94)	
(1) Underground Atlantis Crate System @ $5.15/ft^3 (Kinkade-Levario 2007, 94)	
(3) Underground Fiberglass Tanks @ $2/Gallon (Kinkade-Levario 2007, 94)	
Pumps	*$3,600*
9 Pumps @ $400/Each (Kinkade-Levario 2007, 94)	
First Flush Diverters	*$2,600*
(5) Polyethylene First Flush Containers @ $1.50/Gallon (Kinkade-Levario 2007, 94)	
Installation of Storage Cisterns	*$10,000*
Backhoe Rental @ $500/Day (Bobcat of St. Louis Prices)	
Workers @ $35/hour (RS Means 2013)	
Turf Removal	*$19,000*
321,500 ft^2 @ $57.50 per 1000 ft^2 (RS Means 2013)	
Wildflower Meadow Seed	*$11,200*
7.38 acres @ 10 lbs. per acre (Prairie Nursery 2014)	
73.8 lbs. needed @ $99.50/lb (Prairie Nursery 2014)	
Labor & Equipment @ $12.05 per 1000 ft^2 (RS Means 2013)	
Underground & Building Piping Allowance	*$20,000*
Allowance for unknown costs associated with water conveyance	
Split Rail Fence	*$32,000*
1,760 lf @ $18.00/lf (RS Means 2013)	
Dry Creek Bed	*$11,000*
12,847 ft^2 & 1 cy covers 54 ft^2	
237 cy needed @ $46.15/cy (RS Means 2013)	
Pergola Seating Coves	*$10,000*
Estimate for 10 Structures @ $1,000/structure	
A/C Condensate Collection Expenses	*$10,000*
Allowance for unknown costs associated with water conveyance	
Subtotal	**$213,550**
+ 20% Contingency	*$42,710*
Total	**$256,260**

Figure 6.1 Estimate of Project Up-Front Retrofit Costs.

*All costs presented in this report are estimations and projections by the author and do not reflect actual costs paid by The Missouri History Museum, Sigma Aldrich Corporation, or Bank of America Plaza.

Estimated Return on Investment

Before Retrofit

City of St. Louis Water Rates .... *$1.40 per 100 ft^3*

Current Site Irrigation Demand (per growing season).............. *986,254 ft^3*

Assuming 100% of landscape is currently irrigated and
is coming from City of St. Louis municipal water supply

Current Site Irrigation Costs (per growing season).................... *$13,807*

From municipal water supply

After Retrofit

Up-Front Project Costs... *$256,260*

Projected Water Demand .... *214,827 ft^3*

Projected Irrigation Costs... *$0*

100% of water used from harvested water

Yearly Energy Costs For Running Cistern Pumps.......................... *$450*

(2) 1/2 HP 460 Watt A/C condensate pumps running 24/7 @ $0.07/kWh
(7) 1/2 HP 460 Watt cistern pumps running 10 hrs/month @ $0.07/kWh

Reduction in Lawn Mowing Expenses. *$15,500*

321,500 ft^2 @ $1.30 per 1000 ft^2 (RS Means 2013)
Mowing once a week from March 1 - October 31 (37 Weeks)

Yearly Savings.. *$28,857*

Savings from water costs
Savings from lawn mowing expenses (minus pump energy costs)

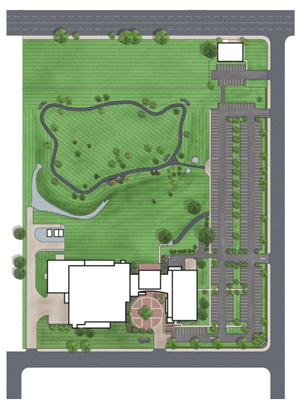
Total Return on Investment (without contingency)......... **7.4 years**

Total Return on Investment (with contingency)............. **8.9 years**

Figure 6.2 Estimated Return on Investment
*All costs presented in this report are estimations and projections by the author and do not reflect actual costs paid by The Missouri History Museum, Sigma Aldrich Corporation, or Bank of America Plaza.

scenario are only those associated with installing and maintaining the areas of turf, the meadow aesthetic, and water harvesting system presented in Chapter 5. Estimated costs for turf installation assume that all areas of turf are seeded by mechanical means at 215 lbs./acre, at a cost of $1,250 per acre (RSMeans 2013). Irrigation installation cost estimations were determined using average costs per square foot of a typical residential underground sprinkler system sourced by a 1.5” supply (RSMeans 2013). It should be noted that costs for installing an irrigation system are very site specific and are affected by many detailed variables outside of the scope of this project. Therefore, the irrigation installation costs in Figures 6.3 - 6.5 are general estimates for comparison and may not reflect actual costs associated with installing an irrigation system at this specific site. The yearly operational costs in each scenario account for prices paid for irrigation from the City of St. Louis’ municipal water source (See Figure 6.1), and maintenance fees associated with weekly turf mowing and weedeating, annual fertilization, and electricity used by pumping water for landscape irrigation. Results show that throughout the estimated 20-year lifespan of the irrigation system, including new construction costs and yearly operational costs, this water conservation landscape has the potential to save approximately $800,000 when compared to a typical large, predominately turf landscape. It should be noted that all costs presented in this report are estimations and projections by the author and do not reflect actual costs paid by Sigma Aldrich.

Figure 6.3
Estimated New Construction Costs
For a Typical Turf Landscape



New Construction - Typical Turf Landscape

Turf Seeding..................*$11,775*

Mechanical Seeding, 215 lbs./acre
$1,250/acre @ 9.42 Acres

Irrigation Installation........*$553,705*

Residential System, 1.5” Supply
$1.35/ft^2 @ 410,152 ft^2 of Turf

Total........................***$565,480***

Yearly Operation Costs - Typical Turf Landscape

Irrigation.....................*$13,800*

Water Source: Municipal Supply

Maintenance................*$22,200*

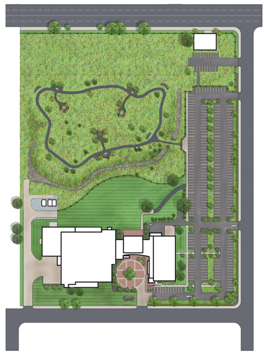
Mowing, Fertilizer,
Weedeating, etc. @ 9.42 acres
Water Harvesting System & Irrigation

Total........................***$36,000***

20-Year Cost....................***$1,285,480***

*All costs presented in this report are estimations and projections by the author and do not reflect actual costs paid by The Missouri History Museum, Sigma Aldrich Corporation, or Bank of America Plaza.

Figure 6.4
Estimated New Construction Costs for a Water Conservation Landscape



New Construction - Water Conservation Landscape

Turf Seeding *$2,550*
Mechanical Seeding, 215 lbs./acre
$1,250/acre @ 2.04 Acres

Irrigation Installation *$119,705*
Residential System, 1.5" Supply
$1.35/ft² @ 88,652 ft² of Turf

Meadow Aesthetic *$54,200*
Seeding, Fence, Dry Creek

Water Harvesting System . . *$183,060*

Total ***$359,515***

Yearly Operation Costs - Water Conservation Landscape

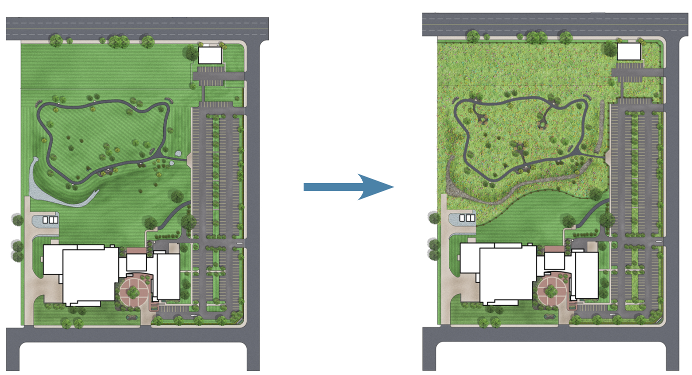
Irrigation *$450*
Water Source: Harvested Water
A/C Condensate
Electricity for Pumps

Maintenance *$4,800*
Turf - Mowing, Fertilizer,
Weedeating, etc. @ 2.04 acres
Meadow - Seasonal Mowing, Occasional
Watering, etc @7.38 acres
Water Harvesting System & Irrigation

Total ***$5,250***

20-Year Cost ***$464,515***

Figure 6.5
Estimated Retrofit Construction Costs



Retrofit Construction - Typical Turf → Conservation

Initial Turf Landscape *$565,480*

Water Harvesting Retrofit .. *$256,260*

Total ***$821,740***

Yearly Operation Costs - Typical Turf → Conservation

Irrigation *$450*

Maintenance *$4,800*

Total ***$5,250***

20-Year Cost ***$926,740***

*All costs presented in this report are estimations and projections by the author and do not reflect actual costs paid by The Missouri History Museum, Sigma Aldrich Corporation, or Bank of America Plaza.

Primary Takeaways

The process of researching, analyzing, planning, and designing a comprehensive water harvesting system in St. Louis, Missouri has culminated in the development of multiple lessons learned:

- Large commercial and corporate buildings in the Midwest have an inherent potential to generate substantial quantities of water on-site; especially through A/C condensate recovery.
- Sites with a balanced ratio of vegetation-to-building footprint-to-hardscape, and high A/C needs, have the potential to harvest enough water on-site to meet 100% of irrigation demands.
- Sites in which a majority of the parcel is vegetation do not have the potential to harvest enough water to meet 100% of irrigation demands.
- During the hottest summer months, A/C condensate helps compensate for reduced rainfall in the water budget.
- Turf demands an astonishing amount of water compared to than any other type of vegetation in the landscape. Its long-term sustainability in an era of greater demand on water resources is truly questionable. However, native drought tolerant wildflower and tallgrass species can be effective alternatives to turf in areas where turf is not completely necessary, providing aesthetic richness, wildlife habitat, and low water consumption.
- Irrigation efficiency plays a considerable role in how much water is needed to effectively provide the landscape with its irrigation requirements; initially installing highly efficient systems can result in significant savings in the long run.
- It is most cost effective to install water harvesting systems during initial landscape construction
- In times of extreme drought, a back-up connection to a municipal water supply can still be provided

While water harvesting has emerged out of necessity in the southern and western United States, I believe its use has great potential in the Midwest. Each constructed water harvesting project will serve as a model and catalyst for the rest of the region. When the time comes to harvest water out of necessity in the Midwest, hopefully site-scale water harvesting will already be deeply embedded into the site design mindset.

Stakeholder Involvement

Individuals involved in the process of developing this MP+R include multiple facilities managers with the Sigma Aldrich Corporation. During the planning stages of the project, contact was initiated with the managers to discuss intentions and possible benefits to both parties involved. Each individual went above and beyond their busy schedules to provide me with relevant site data which played an integral role in the development of the project. As a bonus, the findings, results and conclusion of this MP+R are intended to provide the corporation with metrics that they can take forward at their own discretion and continue to actively address and promote sustainable design as they have done in the past and will continue to do in the future.

Additional consultation from professionals with irrigation and water harvesting expertise was instrumental in the research and design portions of this MP+R. Jim Davis, General Manager of Landtech Design, irrigation design consultants and Kim Seay, Director of Client Services for Wahaso - Water Harvesting Solutions, provided generous assistance and professional insight throughout the duration of this investigation.

Future Research

Time constraints limit this project to the predictive modeling stages of planning water harvesting systems. A greater concern within the industry is the actual post-installation performance of implemented systems. More specifically, there is a need to determine how well the predictive measurements correlate to actual field measurements. This idea could possibly be incorporated into the realm of the SITES program, which is an interdisciplinary effort to create voluntary national guidelines and performance benchmarks for sustainable design, led by the American Society of Landscape Architects, the Lady Bird Johnson Wildflower Center at the University of Texas at Austin, and the United States Botanic Garden. In the program, points are awarded to new construction based on metrics associated with estimations. Future research would suggest how to incorporate a post-installation measuring system that requires SITES projects to track landscape performances years after installation and report to a collective database that can be accessed by professionals and those in academia.

A second avenue of investigation would attempt to assess the public's acceptance of the aesthetics associated with zero-dependent landscapes in the Midwest. Future research would address how receptive the public is to the idea of changing the aesthetic of the landscape to incorporate a more ecofriendly way of handling water on-site. As a future landscape architect, social acceptance of new landscape practices and aesthetic preferences will continue to be a challenge. However, as more projects like this become implemented, hopefully these practices will become commonplace within the region and more publicly acceptable.

appendices:

glossary

Glossary

Air Conditioning Condensate –
Water generated as condensation on an air conditioning unit's cooling coils a the result of the difference in relative humidity of the air entering and leaving the unit

Air Handling Unit -
Portion of the heating, ventilating, and air conditioning system used to condition and circulate air (Lawrence, Perry, Alsen 2012)

Brownfield –
Property with the potential presence of hazardous substances, pollutants, or contaminants (Calkins 2012)

Catchment Area –
The collection surface from which rainwater runs off (Krishna 2005)

Change in Omega –
The difference between the specific humidity of the ambient air at a given location and the specific humidity of the conditioned air inside

Cistern –
Reservoir used to store harvested water (Despins 2010)

Comprehensive Water Harvesting System –
Water harvesting system that captures, stores, and reuses multiple sources of water, such as rainwater, air conditioning condensate, or steam.

Conveyance –
Means of transporting water from one area to another

Crop Coefficient –
The amount of water needed by a particular plant to provide optimum growth or yield (Blaney and Criddle 1962)

Effective Rainfall –
The portion of a rain event that is actually usable by plants (The Irrigation Association 2005)

Essential Water Use –
Water use that is necessary for human consumptive uses, i.e. drinking, bathing

Evapotranspiration Rate –
Total water lost from the soil and plant surfaces (evaporation) and water used by the plants (transpiration) over a period of time (The Irrigation Association 2005)

Free Water –
Any water that falls as precipitation on a site or is generated onsite, i.e. steam or air conditioning condensation

Impervious Surface –
Any surface that does not allow water infiltration, or entering into the soil below

Landscape Demand –
The irrigation requirements of a landscape

Municipal Water Source –
Water that is supplied by a city, town, municipality, private water company, irrigation district, or local authoritative body (Adapted from Kinkade-Levario 2007)

Monthly Water Budget -
Analyzation used to calculate the amount of water that can be collected in the project area and determine if that amount will meet the projects water demands (Kinkade-Levario 2007)

Non-Essential Water Use –
Any water use that is not considered essential, i.e. irrigation, car washing. See Essential Water Use.

Non-potable Water –
Water that is not fit for human consumption

Performance-based Design –
Method of designing which focuses on metrics associated with landscape dynamics, i.e. amount of stormwater filtered, amount of carbon sequestered, percentage of contaminates filtered through a bioswale.

Pervious Surface –
Any surface that allows water infiltrate, or enter the soil below

Plant Factor –
The amount of water needed by a particular plant to provide minimally acceptable performance and function (The University of California 2013)

Post-Installation –
After a project has been constructed.

Potable Water –
Water that is fit for human consumption (Kinkade-Levario 2007)

Potential Water Supply –
Any "free water" that can be collected, stored, and reused on-site. See Free Water

Predictive Modeling –
Utilizing estimation calculations to predict the actual performance of a built system

Retrofit –
Adding a component to something that did not have it when it was first built. In this case, design adjustments made to an existing built landscape.

Runoff –
Drainage that leaves an area as surface flow

Runoff Coefficient –
A coefficient relating to the percentage of water that leaves a particular surface as runoff.

Site-Scale –
Small scale project typically between 0 – 20 acres

SITES –
Interdisciplinary effort to create voluntary guidelines and performance benchmarks for sustainable land design, construction, and maintenance practices (Calkins 2012)

Water Harvesting –
The practice of collecting water and storing it for later use (Despins 2010)

Zero-Dependent Landscape –
Designed landscape that does not depend on a municipal water source for its irrigation demands

appendix A:
climate data

Day	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average Mean Daily Temp (°F)
1-May	68	55	51	64	75	69	58	67	56	73	71	64.3
2-May	58	53	49	64	67	68	59	65	51	81	58	61.2
3-May	57	50	50	68	67	55	60	67	53	79	43	59.0
4-May	58	60	55	64	65	57	61	69	50	77	46	60.2
5-May	70	66	61	58	71	63	64	71	59	82	55	65.5
6-May	68	78	67	54	72	66	65	65	61	82	62	67.3
7-May	68	76	71	62	73	67	71	67	70	69	70	69.5
8-May	60	76	74	61	75	58	68	53	71	66	71	66.6
9-May	79	78	75	65	76	56	62	52	77	62	70	68.4
10-May	72	76	76	62	77	57	58	58	78	64	61	67.2
11-May	58	76	76	54	75	55	64	68	81	65	61	66.6
12-May	62	73	71	56	71	55	62	67	78	70	53	65.3
13-May	65	68	77	49	67	62	74	71	68	67	59	66.1
14-May	67	60	63	49	73	62	68	61	54	67	76	63.6
15-May	68	59	55	56	71	54	75	58	51	69	82	63.5
16-May	62	62	57	60	62	58	57	61	53	70	76	61.6
17-May	64	74	64	63	58	71	56	59	54	67	72	63.8
18-May	70	75	69	62	58	64	59	64	63	72	73	66.3
19-May	72	74	78	68	64	64	68	61	63	78	81	70.1
20-May	64	80	63	63	69	61	69	62	72	80	73	68.7
21-May	58	81	66	68	71	62	73	67	76	66	74	69.3
22-May	59	80	74	64	73	60	76	71	76	66	71	70.0
23-May	60	76	73	66	76	65	77	82	73	71	60	70.8
24-May	60	74	68	77	77	63	77	82	74	79	58	71.7
25-May	62	71	66	82	70	69	71	79	74	83	62	71.7
26-May	62	62	69	78	76	73	76	80	58	85	71	71.8
27-May	67	74	69	82	74	65	76	78	59	85	76	73.2
28-May	72	73	67	82	75	62	64	75	68	85	78	72.8
29-May	68	74	71	82	77	66	69	77	80	80	78	74.7
30-May	72	79	69	80	75	79	75	80	84	75	75	76.6
31-May	67	68	74	78	73	78	69	80	81	61	74	73.0

Average Daily Temperatures for St. Louis, MO, May 2003 - 2013. Used to Determine Humidity Ratio for A/C Condensate Estimation. Source: Weather Underground 2014

Day	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average Mean Daily Humidity (%)
1-May	85	91	54	85	66	63	83	70	64	70	57	71.6
2-May	92	84	50	69	91	47	65	70	72	53	72	69.5
3-May	59	76	56	72	86	53	62	63	58	65	86	66.9
4-May	93	70	49	65	94	50	60	56	55	71	80	67.5
5-May	74	69	50	61	81	50	61	58	65	67	84	65.5
6-May	84	52	46	59	71	54	76	49	61	66	70	62.5
7-May	86	57	46	61	49	80	65	59	63	79	61	64.2
8-May	97	53	52	65	62	81	79	49	68	58	55	65.4
9-May	85	59	59	80	61	76	66	56	73	59	67	67.4
10-May	92	64	59	90	66	71	60	66	75	59	79	71.0
11-May	62	68	65	71	66	74	59	67	64	51	57	64.0
12-May	58	82	76	55	63	56	59	83	58	51	47	62.5
13-May	65	91	61	75	50	68	73	72	67	56	48	66.0
14-May	83	93	66	81	47	66	60	77	88	46	45	68.4
15-May	79	72	55	87	64	78	71	83	85	48	45	69.7
16-May	90	84	54	85	56	63	66	89	54	44	61	67.8
17-May	95	72	51	65	52	46	45	92	56	38	77	62.6
18-May	96	82	58	49	53	47	52	64	56	46	74	61.5
19-May	92	89	58	53	42	53	42	75	73	54	61	62.9
20-May	79	76	80	63	43	63	52	86	69	55	71	67.0
21-May	62	70	70	58	41	49	53	80	66	57	72	61.6
22-May	66	66	66	43	51	66	57	72	70	56	67	61.8
23-May	70	80	48	47	49	72	58	67	65	48	78	62.0
24-May	83	74	53	60	48	77	63	68	65	40	59	62.7
25-May	83	92	52	55	72	76	91	67	74	54	59	70.5
26-May	74	93	54	56	67	78	74	68	83	54	62	69.4
27-May	68	90	54	61	77	85	73	70	76	46	70	70.0
28-May	66	79	58	58	67	59	85	42	82	46	71	64.8
29-May	58	77	45	59	61	65	69	58	61	43	62	59.8
30-May	79	87	72	63	72	69	59	65	55	45	66	66.5
31-May	79	65	52	75	76	70	49	67	59	69	78	67.2

Average Daily Relative Huimidity (as %) for St. Louis, MO, May 2003 - 2013. Used to Determine Humidity Ratio for A/C Condensate Estimation. Source: Weather Underground 2014

Day	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average Mean Daily Temp (^{o}F)
1-Jun	59	71	73	72	76	77	80	80	79	60	73	72.7
2-Jun	58	68	71	72	73	75	78	75	79	68	65	71.1
3-Jun	55	68	75	76	71	80	64	77	86	74	64	71.8
4-Jun	63	68	82	72	72	78	63	71	89	80	65	73.0
5-Jun	64	72	84	70	70	82	66	84	83	73	71	74.5
6-Jun	63	74	78	74	73	78	72	75	85	70	72	74.0
7-Jun	68	79	82	79	84	85	73	75	87	71	68	77.4
8-Jun	68	82	81	78	72	85	77	74	88	75	70	77.3
9-Jun	71	73	79	80	70	76	69	78	85	77	73	75.5
10-Jun	72	80	80	78	68	76	78	79	82	81	73	77.0
11-Jun	70	84	76	68	75	79	75	81	74	75	78	75.9
12-Jun	74	80	77	66	76	84	69	84	69	73	86	76.2
13-Jun	73	78	80	70	76	74	75	84	70	70	78	75.3
14-Jun	74	82	75	74	79	76	73	82	73	75	74	76.1
15-Jun	75	80	76	80	82	80	72	80	77	80	80	78.4
16-Jun	75	80	73	82	82	73	75	80	78	84	78	78.2
17-Jun	76	80	72	81	84	69	82	80	74	81	77	77.8
18-Jun	78	76	70	77	80	72	86	85	78	86	77	78.6
19-Jun	74	69	71	80	79	75	85	81	79	85	77	77.7
20-Jun	66	66	73	85	75	74	83	85	85	85	80	77.9
21-Jun	70	73	76	86	81	77	85	87	79	79	84	79.7
22-Jun	74	68	82	81	83	74	89	85	78	77	82	79.4
23-Jun	78	70	85	80	80	74	88	88	72	77	80	79.3
24-Jun	82	78	86	75	79	74	85	78	73	85	81	79.6
25-Jun	80	64	86	76	81	83	88	81	73	80	86	79.8
26-Jun	70	67	84	70	83	78	86	88	76	74	83	78.1
27-Jun	70	72	84	71	81	81	86	85	75	83	84	79.3
28-Jun	82	74	84	76	77	76	78	81	77	94	82	80.1
29-Jun	79	71	88	78	68	72	79	75	76	92	74	77.5
30-Jun	78	75	87	76	70	73	77	74	81	92	71	77.6

Average Daily Temperatures for St. Louis, MO, June 2003 - 2013. Used to Determine Humidity Ratio for A/C Condensate Estimation. Source: Weather Underground 2014

Day	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average Mean Daily Humidity (%)
1-Jun	66	60	50	88	74	59	52	69	48	57	75	63.5
2-Jun	93	65	71	62	72	64	62	78	55	54	74	68.2
3-Jun	99	61	64	54	72	74	80	72	57	56	64	68.5
4-Jun	80	61	62	52	62	70	57	63	54	59	65	62.3
5-Jun	59	63	51	49	66	67	59	65	57	55	66	59.7
6-Jun	86	74	58	51	63	71	51	57	59	49	67	62.4
7-Jun	79	78	59	58	54	66	66	59	53	48	68	62.5
8-Jun	54	72	64	54	56	58	73	71	51	46	63	60.2
9-Jun	54	89	77	57	60	68	74	65	55	50	71	65.5
10-Jun	80	81	70	67	67	59	74	68	54	56	72	68.0
11-Jun	87	72	83	89	62	57	71	74	76	73	67	73.7
12-Jun	88	74	76	67	57	58	77	70	74	58	58	68.8
13-Jun	85	70	69	54	50	73	69	75	65	50	62	65.6
14-Jun	78	68	65	55	54	65	71	77	73	52	58	65.1
15-Jun	64	79	59	49	54	58	81	74	64	50	60	62.9
16-Jun	64	92	63	50	52	61	76	67	54	63	73	65.0
17-Jun	60	81	58	64	52	55	73	74	77	66	77	67.0
18-Jun	63	88	58	70	67	51	66	67	69	52	67	65.3
19-Jun	73	71	60	60	60	53	64	73	67	54	64	63.5
20-Jun	54	62	62	58	51	71	73	60	62	43	63	59.9
21-Jun	53	83	58	55	56	59	66	60	61	55	64	60.9
22-Jun	54	85	60	70	62	62	62	68	55	56	71	64.1
23-Jun	55	67	55	65	73	59	67	56	61	50	73	61.9
24-Jun	59	63	51	62	74	58	64	64	59	43	67	60.4
25-Jun	77	70	61	64	73	59	69	63	69	45	62	64.7
26-Jun	85	62	56	69	62	63	66	64	79	47	69	65.6
27-Jun	68	62	55	64	72	67	56	68	73	39	63	62.5
28-Jun	51	73	64	52	79	64	58	68	67	26	61	60.3
29-Jun	58	64	54	60	80	68	48	63	66	38	67	60.5
30-Jun	74	66	49	60	71	56	57	60	63	48	74	61.6

Average Daily Relative Huimidity (as %) for St. Louis, MO, June 2003 - 2013. Used to Determine Humidity Ratio for A/C Condensate Estimation. Source: Weather Underground 2014

Day	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average Mean Daily Temp (^oF)
1-Jul	78	78	76	84	73	76	74	73	86	91	73	78.4
2-Jul	78	80	73	86	73	79	75	74	88	89	66	78.3
3-Jul	83	76	79	86	75	74	75	78	81	89	74	79.1
4-Jul	88	82	79	81	82	72	73	85	78	94	74	80.7
5-Jul	86	78	78	75	82	72	72	86	80	94	76	79.9
6-Jul	86	76	77	72	81	78	75	86	83	95	79	80.7
7-Jul	86	74	78	74	82	87	78	85	79	95	81	81.7
8-Jul	86	78	79	76	83	83	80	82	78	87	86	81.6
9-Jul	84	83	81	82	85	80	81	80	80	83	88	82.5
10-Jul	78	83	81	78	79	79	81	79	87	83	81	80.8
11-Jul	78	83	76	80	76	85	84	80	93	83	76	81.3
12-Jul	77	83	71	80	77	80	74	80	90	84	75	79.2
13-Jul	75	87	75	84	79	75	75	83	84	85	76	79.8
14-Jul	78	80	80	80	78	78	75	88	80	84	79	80.0
15-Jul	84	76	79	84	80	81	80	87	82	85	83	81.9
16-Jul	78	80	82	86	81	83	80	84	83	89	85	82.8
17-Jul	84	76	84	88	78	83	71	87	87	92	86	83.3
18-Jul	76	74	84	89	87	84	68	82	88	95	86	83.0
19-Jul	78	76	82	86	82	85	72	82	90	93	88	83.1
20-Jul	81	82	86	86	72	89	72	82	91	81	88	82.7
21-Jul	81	88	88	78	70	85	73	84	93	82	85	82.5
22-Jul	74	87	88	76	72	76	72	86	93	89	79	81.1
23-Jul	72	78	86	80	74	76	75	89	92	94	83	81.7
24-Jul	72	70	91	80	74	70	79	86	85	96	83	80.5
25-Jul	75	63	91	84	77	76	80	81	85	97	73	80.2
26-Jul	81	71	84	86	82	81	76	82	89	89	73	81.3
27-Jul	86	70	73	83	84	80	78	84	90	88	70	80.5
28-Jul	76	72	74	86	81	79	82	87	92	82	70	80.1
29-Jul	75	76	76	85	80	86	75	83	90	80	71	79.7
30-Jul	75	66	78	89	78	75	76	79	82	81	72	77.4
31-Jul	80	76	79	92	80	79	73	81	87	88	76	81.0

Average Daily Temperatures for St. Louis, MO, July 2003 - 2013. Used to Determine Humidity Ratio for A/C Condensate Estimation. Source: Weather Underground 2014

Day	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average Mean Daily Humidity (%)
1-Jul	77	85	56	42	69	58	63	56	66	45	55	61.1
2-Jul	71	90	53	42	56	63	67	56	62	51	70	61.9
3-Jul	65	96	55	48	54	75	62	54	76	49	65	63.5
4-Jul	65	76	70	68	70	62	79	60	73	39	62	65.8
5-Jul	64	91	62	56	64	66	83	52	65	37	67	64.3
6-Jul	69	91	61	48	60	65	65	59	64	42	64	62.5
7-Jul	65	75	58	51	57	60	65	63	75	44	62	61.4
8-Jul	61	83	59	47	56	68	60	77	74	62	58	64.1
9-Jul	62	75	51	45	62	64	64	72	66	61	59	61.9
10-Jul	76	78	51	67	73	62	70	66	67	48	70	66.2
11-Jul	60	81	74	79	58	68	72	69	57	45	62	65.9
12-Jul	64	68	94	76	54	69	76	76	60	49	55	67.4
13-Jul	60	70	84	70	54	59	72	71	71	60	57	66.2
14-Jul	63	62	74	75	57	57	73	69	65	61	66	65.6
15-Jul	65	66	78	62	57	60	71	69	65	57	70	65.5
16-Jul	65	71	69	52	55	55	72	58	59	56	63	61.4
17-Jul	61	83	66	49	67	50	62	60	63	46	63	60.9
18-Jul	88	74	70	59	57	54	59	76	60	44	63	64.0
19-Jul	85	67	73	70	73	59	62	71	60	44	58	65.6
20-Jul	73	68	67	65	68	57	62	72	55	65	62	64.9
21-Jul	66	69	61	77	57	55	60	71	54	55	70	63.2
22-Jul	73	73	63	64	60	79	68	68	51	40	66	64.1
23-Jul	70	78	73	57	58	67	69	58	60	43	59	62.9
24-Jul	60	69	59	51	62	78	68	71	65	38	57	61.6
25-Jul	56	92	54	45	58	79	61	74	66	36	59	61.8
26-Jul	58	70	65	53	53	76	62	71	62	51	69	62.7
27-Jul	68	66	69	70	70	68	61	75	57	53	64	65.5
28-Jul	84	63	62	63	72	76	69	69	51	49	53	64.6
29-Jul	74	71	59	65	74	68	70	63	60	69	65	67.1
30-Jul	69	98	59	60	61	85	65	84	78	70	77	73.3
31-Jul	66	84	62	54	55	81	65	79	70	55	78	68.1

Average Daily Relative Huimidity (as %) for St. Louis, MO, July 2003 - 2013. Used to Determine Humidity Ratio for A/C Condensate Estimation. Source: Weather Underground 2014

Day	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average Mean Daily Temp (°F)
1-Aug	80	80	82	91	80	84	73	80	90	89	78	82.5
2-Aug	78	80	84	91	85	82	74	81	91	87	78	82.8
3-Aug	77	84	86	84	85	79	80	92	89	86	78	83.6
4-Aug	78	78	83	81	85	87	81	91	84	87	73	82.5
5-Aug	77	72	75	80	89	86	80	83	81	84	73	80.0
6-Aug	76	68	79	86	90	81	76	80	86	82	81	80.5
7-Aug	79	70	80	86	91	77	80	80	89	85	83	81.8
8-Aug	77	72	83	82	89	75	87	84	83	85	77	81.3
9-Aug	75	75	86	88	88	74	89	90	82	82	75	82.2
10-Aug	75	75	89	86	85	75	80	90	75	74	77	80.1
11-Aug	76	67	88	81	86	70	80	90	75	74	75	78.4
12-Aug	74	62	87	78	89	74	77	90	78	75	77	78.3
13-Aug	76	64	81	80	83	75	76	89	81	74	73	77.5
14-Aug	82	67	75	82	89	75	78	85	75	72	67	77.0
15-Aug	84	67	71	76	92	75	82	82	73	78	68	77.1
16-Aug	86	70	76	77	87	72	83	78	73	84	69	77.7
17-Aug	87	78	76	81	81	73	81	77	83	72	71	78.2
18-Aug	82	82	84	83	83	73	76	80	83	72	75	79.4
19-Aug	82	76	87	82	85	73	83	85	83	74	78	80.7
20-Aug	86	67	85	78	80	77	74	83	83	74	80	78.8
21-Aug	91	70	83	77	85	76	73	81	82	76	83	79.7
22-Aug	84	74	81	76	88	80	68	82	79	79	84	79.5
23-Aug	78	76	72	78	90	83	69	78	87	83	82	79.6
24-Aug	80	78	74	80	82	76	70	80	91	85	81	79.7
25-Aug	86	78	74	77	79	71	75	74	78	82	82	77.8
26-Aug	88	82	76	81	75	75	79	72	79	79	87	79.4
27-Aug	84	83	80	81	80	76	81	74	82	80	87	80.7
28-Aug	83	76	78	80	86	80	73	77	77	80	86	79.6
29-Aug	80	64	78	68	87	77	70	84	77	79	87	77.4
30-Aug	76	68	74	67	79	76	61	80	79	83	91	75.8
31-Aug	76	74	77	72	73	77	66	83	90	79	91	78.0

Average Daily Temperatures for St. Louis, MO, August 2003 - 2013. Used to Determine Humidity Ratio for A/C Condensate Estimation. Source: Weather Underground 2014

Day	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average Mean Daily Humidity (%)
1-Aug	71	73	60	53	58	71	71	72	60	49	63	63.7
2-Aug	79	78	50	49	56	69	67	68	57	61	76	64.5
3-Aug	76	83	58	63	63	67	58	60	65	69	74	66.9
4-Aug	71	91	65	58	67	71	69	54	60	60	60	66.0
5-Aug	68	64	72	56	55	65	70	69	72	58	75	65.8
6-Aug	73	60	64	49	50	74	61	58	70	50	70	61.7
7-Aug	72	63	61	54	48	73	62	61	65	45	66	60.9
8-Aug	70	63	67	69	55	66	63	60	64	53	84	64.9
9-Aug	71	68	57	63	59	64	55	61	65	61	74	63.5
10-Aug	65	69	51	69	59	72	69	64	68	62	65	64.8
11-Aug	67	67	55	70	53	60	67	64	65	51	59	61.6
12-Aug	75	72	63	65	49	59	61	67	65	54	76	64.2
13-Aug	78	67	69	64	66	64	56	62	64	68	71	66.3
14-Aug	77	69	88	67	46	72	59	70	64	66	61	67.2
15-Aug	67	65	92	59	51	68	59	70	63	59	58	64.6
16-Aug	62	58	79	56	57	59	70	58	67	67	64	63.4
17-Aug	63	65	78	52	62	63	75	59	65	50	68	63.6
18-Aug	77	66	73	69	59	61	76	68	66	50	63	66.2
19-Aug	67	80	64	75	62	59	69	65	63	44	65	64.8
20-Aug	69	98	62	75	78	67	71	72	65	51	61	69.9
21-Aug	65	82	61	61	63	84	66	77	67	53	59	67.1
22-Aug	66	71	68	62	55	77	67	72	61	48	61	64.4
23-Aug	64	91	64	60	48	70	68	58	60	44	64	62.8
24-Aug	61	92	66	51	71	65	69	66	54	37	64	63.3
25-Aug	55	93	84	68	71	66	64	55	51	60	53	65.5
26-Aug	63	88	85	72	61	68	61	60	57	78	58	68.3
27-Aug	75	83	70	73	50	69	60	62	59	69	55	65.9
28-Aug	75	88	67	82	44	75	83	58	53	60	54	67.2
29-Aug	92	94	66	85	54	71	69	60	52	55	59	68.8
30-Aug	86	89	72	83	59	64	73	76	51	50	55	68.9
31-Aug	96	74	62	76	54	70	58	71	43	77	51	66.5

Average Daily Relative Huimidity (as %) for St. Louis, MO, August 2003 - 2013. Used to Determine Humidity Ratio for A/C Condensate Estimation. Source: Weather Underground 2014

Day	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average Mean Daily Temp (^oF)
1-Sep	72	75	77	72	74	83	64	78	93	78	82	77.1
2-Sep	68	73	76	70	76	83	67	79	91	79	77	76.3
3-Sep	72	75	77	70	80	74	70	70	88	81	73	75.5
4-Sep	69	78	76	73	83	69	73	65	71	83	75	74.1
5-Sep	68	79	76	69	82	61	70	69	66	78	77	72.3
6-Sep	68	72	77	71	78	64	72	78	64	80	79	73.0
7-Sep	70	70	80	74	78	70	74	71	65	79	82	73.9
8-Sep	72	69	81	76	76	71	73	72	67	67	79	73.0
9-Sep	72	67	81	75	78	64	73	68	65	67	88	72.5
10-Sep	74	72	83	76	76	66	74	66	70	68	89	74.0
11-Sep	77	73	81	75	69	74	74	72	72	73	85	75.0
12-Sep	74	73	81	67	64	78	74	72	77	75	77	73.8
13-Sep	73	76	82	65	69	83	72	77	82	75	67	74.6
14-Sep	68	76	71	66	62	69	71	77	61	64	65	68.2
15-Sep	68	78	68	69	55	61	75	74	55	63	72	67.1
16-Sep	71	76	64	74	64	65	74	69	61	69	68	68.6
17-Sep	70	70	67	72	76	68	70	68	64	68	66	69.0
18-Sep	73	70	73	66	79	70	67	77	66	60	78	70.8
19-Sep	60	73	81	59	80	73	72	73	64	64	84	71.2
20-Sep	62	68	76	56	81	68	65	79	65	68	68	68.7
21-Sep	66	68	74	62	79	70	74	83	70	71	63	70.9
22-Sep	70	70	84	71	78	72	74	75	59	59	64	70.5
23-Sep	64	72	74	68	79	74	73	82	66	56	65	70.3
24-Sep	76	74	76	60	81	74	71	72	57	60	70	70.1
25-Sep	62	72	72	63	77	74	71	66	57	71	75	69.1
26-Sep	68	70	68	66	66	70	65	57	61	73	74	67.1
27-Sep	62	66	67	68	72	68	69	59	64	68	74	67.0
28-Sep	55	65	66	58	72	72	62	65	67	64	76	65.6
29-Sep	54	58	56	57	70	67	58	68	75	64	67	63.1
30-Sep	50	62	59	65	74	60	58	68	64	65	67	62.9

Average Daily Temperatures for St. Louis, MO, September 2003 - 2013. Used to Determine Humidity Ratio for A/C Condensate Estimation. Source: Weather Underground 2014

Day	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average Mean Daily Humidity (%)
1-Sep	100	72	53	78	50	60	64	80	47	82	70	68.7
2-Sep	96	74	60	70	51	70	62	74	42	79	61	67.2
3-Sep	89	80	60	66	51	87	65	60	50	71	62	67.4
4-Sep	69	78	53	68	51	94	69	58	62	63	58	65.7
5-Sep	70	78	62	71	68	86	83	60	54	75	58	69.5
6-Sep	69	81	62	61	80	77	81	43	53	70	57	66.7
7-Sep	73	64	57	55	79	74	76	57	55	65	55	64.5
8-Sep	74	70	55	54	86	76	70	60	49	63	74	66.5
9-Sep	78	76	61	52	62	68	67	73	78	59	61	66.8
10-Sep	75	74	58	63	64	63	72	90	74	61	49	67.5
11-Sep	73	71	59	73	61	79	69	69	70	58	52	66.7
12-Sep	93	73	49	83	45	81	64	58	58	54	59	65.2
13-Sep	94	84	61	71	56	68	65	51	46	56	53	64.1
14-Sep	88	88	81	68	54	81	67	62	89	73	46	72.5
15-Sep	68	84	91	64	50	77	61	70	58	60	53	66.9
16-Sep	61	84	87	63	47	70	63	74	55	71	67	67.5
17-Sep	66	65	73	75	50	66	55	68	58	81	78	66.8
18-Sep	76	67	74	63	58	68	62	68	85	60	73	68.5
19-Sep	82	63	73	63	60	68	50	80	80	57	63	67.2
20-Sep	71	59	77	64	62	77	82	74	74	41	85	69.6
21-Sep	83	61	68	55	56	77	78	59	61	49	70	65.2
22-Sep	78	70	63	73	60	72	74	74	83	50	69	69.6
23-Sep	54	72	79	73	60	63	78	62	82	52	61	66.9
24-Sep	59	77	71	68	65	68	85	66	62	55	68	67.6
25-Sep	48	67	91	60	70	61	66	63	69	72	70	67.0
26-Sep	83	66	84	57	77	62	79	77	61	74	65	71.4
27-Sep	68	63	75	55	59	66	66	64	61	82	59	65.3
28-Sep	64	54	81	56	52	67	47	61	62	59	62	60.5
29-Sep	60	62	59	55	50	85	62	65	54	62	60	61.3
30-Sep	80	60	60	55	49	71	70	62	44	58	66	61.4

Average Daily Relative Huimidity (as %) for St. Louis, MO, September 2003 - 2013. Used to Determine Humidity Ratio for A/C Condensate Estimation. Source: Weather Underground 2014

Day	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average Mean Daily Temp (^oF)
1-Oct	52	67	68	70	72	59	65	63	56	60	74	64.2
2-Oct	46	52	73	80	72	56	59	56	57	61	77	62.6
3-Oct	57	60	79	83	70	62	55	52	63	69	79	66.3
4-Oct	60	58	80	77	75	63	57	52	65	69	80	66.9
5-Oct	65	52	86	62	80	68	58	56	68	47	68	64.5
6-Oct	68	60	54	57	80	69	61	62	69	45	55	61.8
7-Oct	68	68	51	58	81	64	55	68	72	47	61	63.0
8-Oct	69	68	52	61	77	61	56	67	70	50	63	63.1
9-Oct	66	66	54	65	70	63	49	72	69	57	62	63.0
10-Oct	68	62	57	61	57	65	48	73	68	50	68	61.5
11-Oct	66	60	60	50	53	71	46	72	71	55	69	61.2
12-Oct	61	56	65	44	56	73	50	71	68	58	68	60.9
13-Oct	60	57	65	48	59	72	47	62	67	68	61	60.5
14-Oct	60	50	66	48	67	67	46	60	63	65	58	59.1
15-Oct	59	52	62	51	64	65	48	60	59	60	62	58.4
16-Oct	59	50	59	55	66	54	45	62	68	68	54	58.2
17-Oct	52	52	67	60	62	53	45	67	55	61	58	57.5
18-Oct	58	56	67	56	72	54	47	66	51	56	53	57.8
19-Oct	66	52	66	42	62	54	60	56	48	51	51	55.3
20-Oct	72	54	57	50	67	59	65	61	49	57	61	59.3
21-Oct	68	58	52	55	74	55	60	58	51	64	49	58.5
22-Oct	62	65	54	43	57	56	60	61	57	70	50	57.7
23-Oct	62	70	47	40	53	50	54	76	65	72	44	57.5
24-Oct	62	60	45	39	51	49	52	71	64	75	41	55.4
25-Oct	58	66	48	43	46	51	59	69	69	64	43	56.0
26-Oct	44	64	46	50	54	53	53	67	61	45	52	53.5
27-Oct	48	63	50	47	55	42	51	62	51	43	47	50.8
28-Oct	53	68	48	51	47	40	55	46	50	44	53	50.5
29-Oct	50	76	52	56	49	50	59	47	50	45	53	53.4
30-Oct	63	66	55	65	56	56	60	57	56	47	65	58.7
31-Oct	64	60	54	53	57	62	48	54	53	46	59	55.5

Average Daily Temperatures for St. Louis, MO, October 2003 - 2013. Used to Determine Humidity Ratio for A/C Condensate Estimation. Source: Weather Underground 2014

Day	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average Mean Daily Humidity (%)
1-Oct	77	61	57	54	60	66	73	57	56	60	73	63.1
2-Oct	50	61	79	47	70	63	54	61	53	64	71	61.2
3-Oct	77	47	74	52	61	61	57	56	50	58	69	60.2
4-Oct	67	49	71	56	60	67	63	60	52	56	65	60.5
5-Oct	64	47	65	59	65	61	65	58	53	76	76	62.6
6-Oct	72	48	62	52	69	65	65	56	59	63	63	61.3
7-Oct	63	54	62	56	61	77	57	56	53	59	59	59.7
8-Oct	66	90	68	57	61	65	89	58	57	57	58	66.0
9-Oct	94	84	71	57	55	61	87	58	59	57	62	67.7
10-Oct	85	41	75	72	54	66	72	53	64	57	65	64.0
11-Oct	91	59	80	71	66	69	63	53	68	60	62	67.5
12-Oct	72	94	70	50	63	70	68	66	77	67	66	69.4
13-Oct	63	88	70	39	64	74	82	56	64	72	47	65.4
14-Oct	80	95	62	37	55	80	90	47	45	68	53	64.7
15-Oct	65	65	56	44	70	81	90	49	46	58	80	64.0
16-Oct	78	48	57	72	66	70	82	50	44	52	62	61.9
17-Oct	73	52	59	83	80	70	70	57	56	63	59	65.6
18-Oct	66	94	56	89	61	65	61	55	75	56	63	67.4
19-Oct	72	98	67	77	58	63	56	50	71	72	64	68.0
20-Oct	59	95	88	63	39	65	59	49	58	61	44	61.8
21-Oct	59	92	89	65	39	66	67	44	52	66	56	63.2
22-Oct	64	85	72	62	79	40	88	47	55	72	65	66.3
23-Oct	63	76	65	56	63	66	86	36	59	70	62	63.8
24-Oct	60	64	72	60	57	82	61	61	58	61	62	63.5
25-Oct	92	62	60	77	79	68	71	74	49	67	57	68.7
26-Oct	77	96	68	93	48	52	84	49	77	56	45	67.7
27-Oct	70	98	63	91	66	49	91	29	65	59	54	66.8
28-Oct	77	91	66	63	51	54	84	59	59	63	59	66.0
29-Oct	65	72	59	60	57	54	90	53	48	52	74	62.2
30-Oct	71	54	58	54	52	58	70	44	41	50	87	58.1
31-Oct	78	64	84	53	56	62	60	56	44	49	86	62.9

Average Daily Relative Huimidity (as %) for St. Louis, MO, October 2003 - 2013. Used to Determine Humidity Ratio for A/C Condensate Estimation. Source: Weather Underground 2014

Day	Humidity Ratio ($lb_{water}/lb_{dry\ air}$)
1-May	0.0091
2-May	0.0080
3-May	0.0071
4-May	0.0075
5-May	0.0085
6-May	0.0089
7-May	0.0097
8-May	0.0091
9-May	0.0098
10-May	0.0100
11-May	0.0090
12-May	0.0083
13-May	0.0090
14-May	0.0086
15-May	0.0086
16-May	0.0080
17-May	0.0080
18-May	0.0084
19-May	0.0098
20-May	0.0101
21-May	0.0093
22-May	0.0097
23-May	0.0100
24-May	0.0105
25-May	0.0117
26-May	0.0116
27-May	0.0121
28-May	0.0113
29-May	0.0111
30-May	0.0133
31-May	0.0116

May Daily Outside Humidity Ratio for St. Louis, MO. Based on 11-year (2003 - 2013) Mean Daily Average Temperature and Mean Daily Average Relative Humidity.

Day	Humidity Ratio ($lb_{water}/lb_{dry\ air}$)
1-Jun	0.0109
2-Jun	0.0110
3-Jun	0.0114
4-Jun	0.0107
5-Jun	0.0107
6-Jun	0.0111
7-Jun	0.0125
8-Jun	0.0119
9-Jun	0.0125
10-Jun	0.0135
11-Jun	0.0142
12-Jun	0.0133
13-Jun	0.0122
14-Jun	0.0125
15-Jun	0.0129
16-Jun	0.0133
17-Jun	0.0138
18-Jun	0.0138
19-Jun	0.0131
20-Jun	0.0123
21-Jun	0.0134
22-Jun	0.0136
23-Jun	0.0132
24-Jun	0.0132
25-Jun	0.0143
26-Jun	0.0136
27-Jun	0.0132
28-Jun	0.0132
29-Jun	0.0121
30-Jun	0.0127

June Daily Outside Humidity Ratio for St. Louis, MO. Based on 11-year (2003 - 2013) Mean Daily Average Temperature and Mean Daily Average Relative Humidity.

Day	Humidity Ratio ($lb_{water}/lb_{dry\ air}$)
1-Jul	0.0125
2-Jul	0.0127
3-Jul	0.0136
4-Jul	0.0150
5-Jul	0.0140
6-Jul	0.0143
7-Jul	0.0143
8-Jul	0.0150
9-Jul	0.0145
10-Jul	0.0150
11-Jul	0.0150
12-Jul	0.0142
13-Jul	0.0145
14-Jul	0.0145
15-Jul	0.0153
16-Jul	0.0148
17-Jul	0.0148
18-Jul	0.0155
19-Jul	0.0160
20-Jul	0.0158
21-Jul	0.0148
22-Jul	0.0145
23-Jul	0.0148
24-Jul	0.0141
25-Jul	0.0136
26-Jul	0.0143
27-Jul	0.0150
28-Jul	0.0143
29-Jul	0.0147
30-Jul	0.0145
31-Jul	0.0155

July Daily Outside Humidity Ratio for St. Louis, MO. Based on 11-year (2003 - 2013) Mean Daily Average Temperature and Mean Daily Average Relative Humidity.

Day	Humidity Ratio ($lb_{water}/lb_{dry\ air}$)
1-Aug	0.0150
2-Aug	0.0158
3-Aug	0.0168
4-Aug	0.0160
5-Aug	0.0145
6-Aug	0.0136
7-Aug	0.0143
8-Aug	0.0148
9-Aug	0.0148
10-Aug	0.0143
11-Aug	0.0127
12-Aug	0.0131
13-Aug	0.0131
14-Aug	0.0133
15-Aug	0.0129
16-Aug	0.0129
17-Aug	0.0131
18-Aug	0.0140
19-Aug	0.0148
20-Aug	0.0149
21-Aug	0.0147
22-Aug	0.0140
23-Aug	0.0138
24-Aug	0.0138
25-Aug	0.0133
26-Aug	0.0145
27-Aug	0.0150
28-Aug	0.0147
29-Aug	0.0137
30-Aug	0.0133
31-Aug	0.0138

August Daily Outside Humidity Ratio for St. Louis, MO. Based on 11-year (2003 - 2013) Mean Daily Average Temperature and Mean Daily Average Relative Humidity.

Day	Humidity Ratio ($lb_{water}/lb_{dry\ air}$)
1-Sep	0.0137
2-Sep	0.0129
3-Sep	0.0124
4-Sep	0.0118
5-Sep	0.0117
6-Sep	0.0116
7-Sep	0.0117
8-Sep	0.0114
9-Sep	0.0116
10-Sep	0.0122
11-Sep	0.0124
12-Sep	0.0117
13-Sep	0.0119
14-Sep	0.0105
15-Sep	0.0094
16-Sep	0.0101
17-Sep	0.0101
18-Sep	0.0112
19-Sep	0.0108
20-Sep	0.0106
21-Sep	0.0105
22-Sep	0.0113
23-Sep	0.0105
24-Sep	0.0106
25-Sep	0.0101
26-Sep	0.0100
27-Sep	0.0091
28-Sep	0.0081
29-Sep	0.0074
30-Sep	0.0074

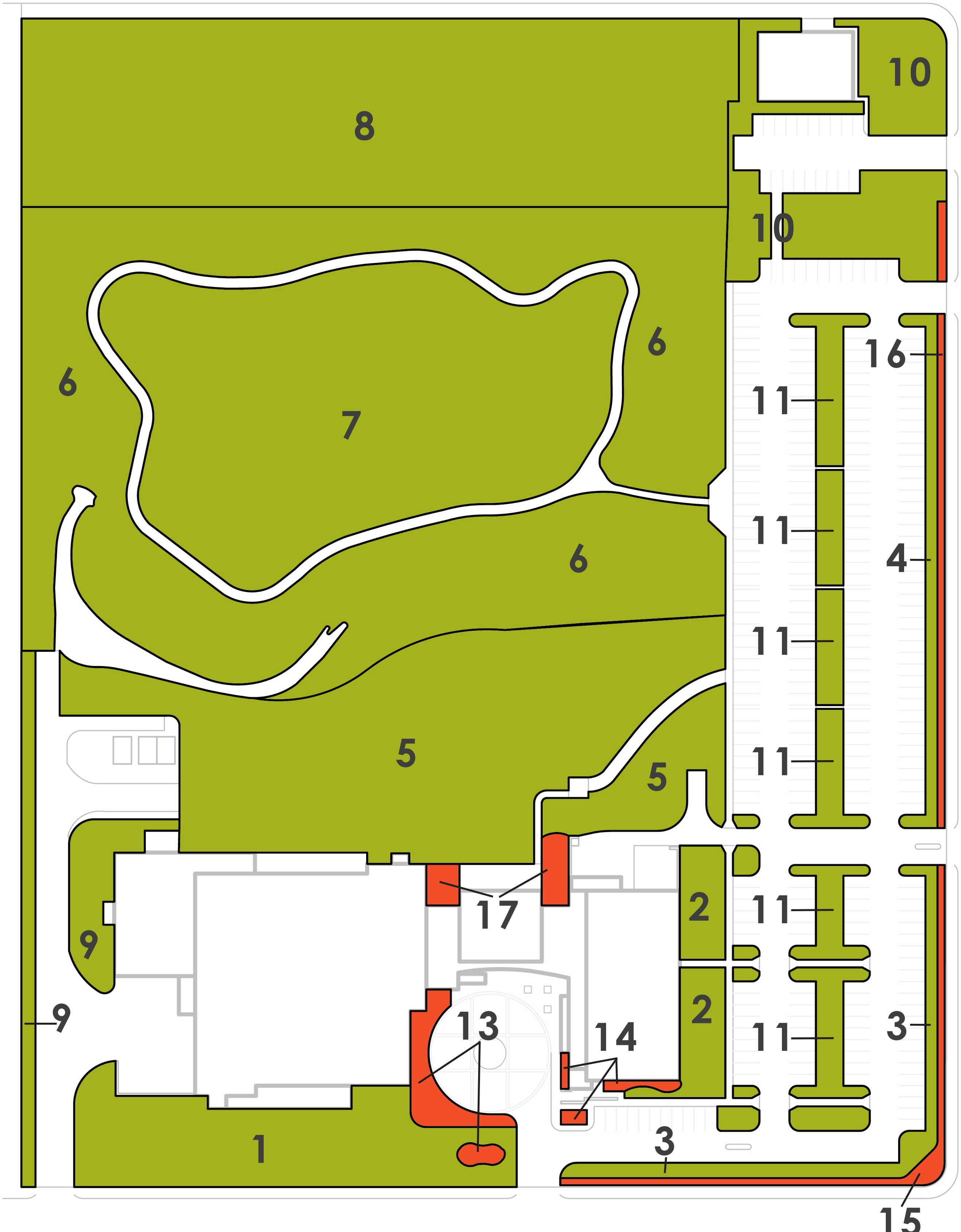
Septeber Daily Outside Humidity Ratio for St. Louis, MO. Based on 11-year (2003 - 2013) Mean Daily Average Temperature and Mean Daily Average Relative Humidity.

Day	Humidity Ratio ($lb_{water}/lb_{dry\ air}$)
1-Oct	0.0080
2-Oct	0.0074
3-Oct	0.0081
4-Oct	0.0086
5-Oct	0.0083
6-Oct	0.0072
7-Oct	0.0073
8-Oct	0.0081
9-Oct	0.0083
10-Oct	0.0075
11-Oct	0.0076
12-Oct	0.0079
13-Oct	0.0074
14-Oct	0.0069
15-Oct	0.0065
16-Oct	0.0063
17-Oct	0.0065
18-Oct	0.0068
19-Oct	0.0062
20-Oct	0.0066
21-Oct	0.0067
22-Oct	0.0067
23-Oct	0.0065
24-Oct	0.0058
25-Oct	0.0065
26-Oct	0.0060
27-Oct	0.0053
28-Oct	0.0050
29-Oct	0.0053
30-Oct	0.0061
31-Oct	0.0058

October Daily Outside Humidity Ratio for St. Louis, MO. Based on 11-year (2003 - 2013) Mean Daily Average Temperature and Mean Daily Average Relative Humidity.

appendix b:

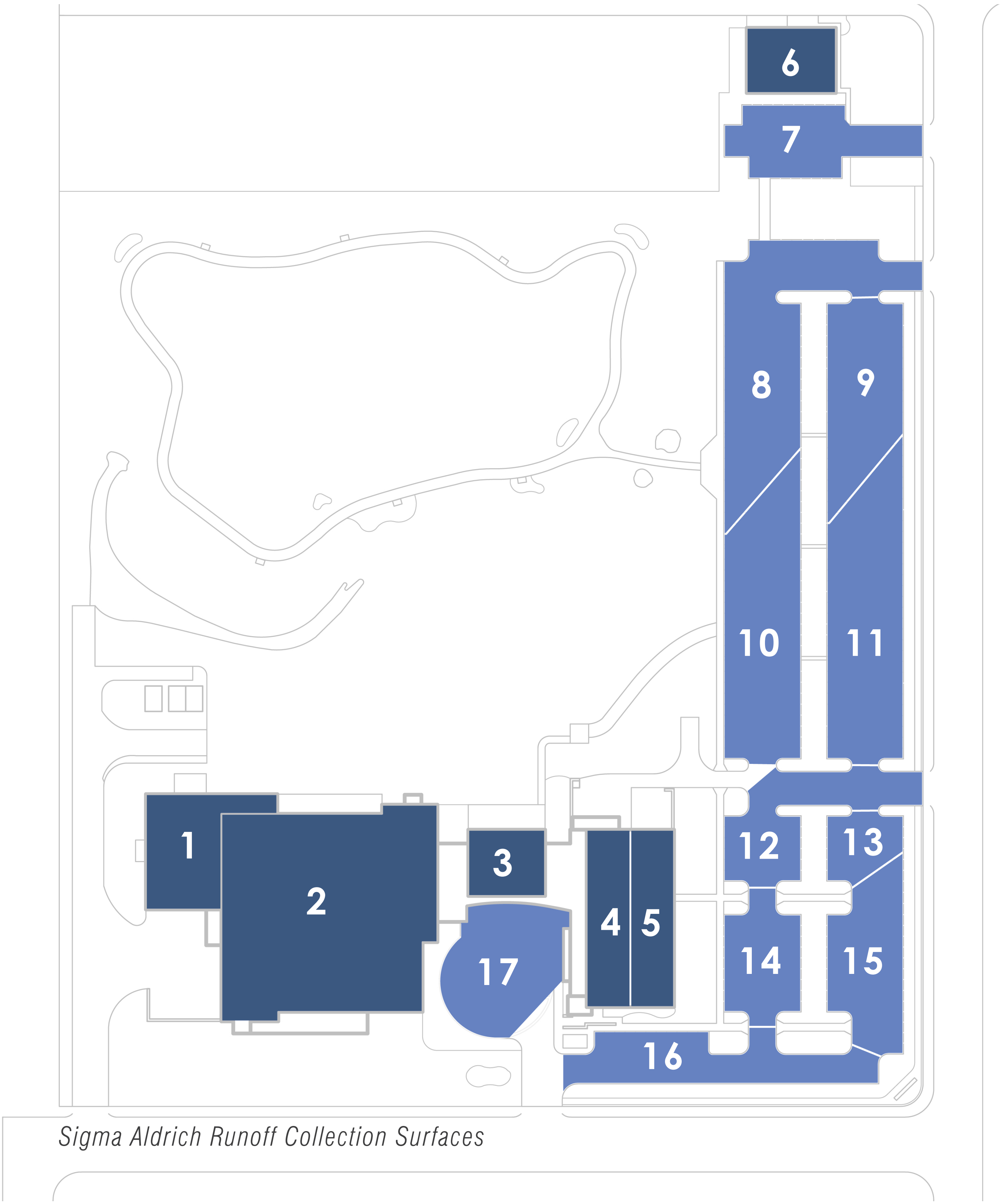
sigma aldrich: **estimated monthly water demand & potential supply**



Sigma Aldrich Vegetation Areas

Sigma Aldrich Estimated Landscape Water Demand by Vegetation Area (in gallons)								
Veg. Area	March	April	May	June	July	August	September	October
1	0	3,208	21,703	48,179	67,704	65,393	29,679	8,794
2	0	1,033	8,209	18,568	26,257	25,415	11,406	3,266
3	0	1,648	7,312	15,147	20,771	19,893	9,434	3,152
4	0	1,145	5,077	10,517	14,422	13,813	6,550	2,188
5	0	8,045	54,305	120,519	169,345	16,3560	74,245	22,011
6	0	16,309	110,345	244,959	344,233	33,2484	150,899	44,714
7	0	10,657	72,105	160,069	224,940	217,262	98,605	29,218
8	0	11,960	80,918	179,632	252,431	243,815	110,656	32,789
9	0	1,414	9,568	21,241	29,849	28,830	13,085	3,877
10	0	2,845	19,246	42,725	60,040	57,991	26,319	7,799
11	0	2,537	11,254	23,313	31,969	30,617	14,520	4,851
12	0	1,773	7,866	16,295	22,345	21,400	10,149	3,391
13	0	0	0	570	1,963	2,303	275	0
14	0	0	0	166	646	761	70	0
15	0	0	1,006	3,840	6,235	6,299	2,199	132
16	0	0	853	3,271	5,250	5,286	1,884	105
17	0	0	0	111	590	804	11	0

Sigma Aldrich Estimated Landscape Water Demand by Vegetation Area Factoring Irrigation Inefficiencies (in gallons)								
Veg. Area	March	April	May	June	July	August	September	October
1	0	5,132	34,724	77,086	108,326	104,629	47,486	14,071
2	0	1,652	13,134	29,710	42,012	40,664	18,249	5,226
3	0	2,638	11,699	24,235	33,233	31,828	15,094	5,043
4	0	1,831	8,123	16,827	23,076	22,100	10,481	3,502
5	0	12,872	86,888	192,831	270,952	261,696	118,792	35,218
6	0	26,095	176,553	391,935	550,773	531,974	241,439	71,542
7	0	17,052	115,369	256,111	359,904	347,620	157,769	46,749
8	0	19,136	129,469	287,411	403,890	390,104	177,050	52,463
9	0	2,263	15,309	33,986	47,759	46,129	20,936	6,204
10	0	4,551	30,794	68,360	96,064	92,785	42,111	12,478
11	0	4,060	18,006	37,301	51,151	48,988	23,232	7,762
12	0	2,837	12,585	26,072	35,752	34,241	16,238	5,425
13	0	0	0	634	2,181	2,559	306	0
14	0	0	0	185	717	845	78	0
15	0	0	1,118	4,267	6,928	6,999	2,444	147
16	0	0	947	3,634	5,834	5,874	2,093	117
17	0	0	0	124	655	893	13	0



Sigma Aldrich Runoff Collection Surfaces

Sigma Aldrich Estimated Monthly Runoff From Each Collection Surface (in gallons)								
Water Source	March	April	May	June	July	August	September	October
1 - 6,943 ft^2	14,440	15,743	19,312	18,250	13,973	9,653	13,587	12,117
2 - 30,274 ft^2	62,963	68,645	84,208	79,576	60,925	42,089	59,242	52,835
3 - 3,602 ft^2	7,491	8,167	10,019	9,468	7,249	5,008	7,049	6,286
4 - 5,478 ft^2	11,393	12,421	15,237	14,399	11,024	7,616	10,720	9,560
5 - 5,478 ft^2	11,393	12,421	15,237	14,399	11,024	7,616	10,720	9,560
6 - 4,107 ft^2	8,542	9,312	11,424	10,795	8,265	5,710	8,037	7,168
7 - 7,476 ft^2	14,685	16,010	19,640	18,559	14,209	9,816	13,817	12,322
8 - 17,196 ft^2	33,777	36,825	45,174	42,689	32,684	22,579	31,781	28,344
9 - 9,725 ft^2	19,102	20,826	25,548	24,142	18,484	12,769	17,973	16,029
10 - 14,751 ft^2	28,974	31,589	38,751	36,620	28,037	19,368	27,262	24,314
11 - 15,295 ft^2	30,043	32,754	40,180	37,970	29,071	20,083	28,268	25,210
12 - 8,334 ft^2	16,370	17,847	21,894	20,689	15,840	10,943	15,403	13,737
13 - 3,260 ft^2	6,403	6,981	8,564	8,093	6,196	4,280	6,025	5,373
14 - 6,207 ft^2	12,192	13,292	16,306	15,409	11,797	8,150	11,471	10,231
15 - 8,443 ft^2	16,564	18,059	22,154	20,935	16,028	11,073	15,585	13,900
16 - 9,257 ft^2	18,183	19,824	24,318	22,981	17,594	12,155	17,108	15,258
17 - 9,000 ft^2	17,678	19,273	23,643	22,343	17,106	11,817	16,633	14,834
Sigma Aldrich Estimated Monthly A/C Condensate Production (in gallons)								
9 Total Units	n/a	n/a	105,631	270,903	388,899	366,746	170,296	4,769

appendix c:

daily water budgets for sizing cisterns

Day	Daily Water Demand	Water Requirements	Available Supply (From A/C Condensate)	Loss to First Flush	Amt. Needed for Irrigation	Cumulative Storage	Overflow to Cistern 2
7/1	84	94	3,711	-	0	300	3,411
7/2	84	94	3,876	-	0	300	3,876
7/3	84	94	4,561	-	282	18	4,561
7/4	84	94	5,668	-	0	300	5,386
7/5	84	94	4,925	-	0	300	4,925
7/6	84	94	5,118	-	282	18	5,118
7/7	84	94	5,121	-	0	300	4,839
7/8	84	94	5,689	-	0	300	5,689
7/9	84	94	5,310	-	282	18	5,310
7/10	84	94	5,668	-	0	300	5,386
7/11	84	94	5,668	-	0	300	5,668
7/12	84	94	5,074	-	282	18	5,074
7/13	84	94	5,280	-	0	300	4,998
7/14	84	94	5,280	-	0	300	5,280
7/15	84	94	5,878	-	282	18	5,878
7/16	84	94	5,501	-	0	300	5,219
7/17	84	94	5,501	-	0	300	5,501
7/18	84	94	6,088	-	282	18	6,088
7/19	84	94	6,480	-	0	300	6,198
7/20	84	94	6,284	-	0	300	6,284
7/21	84	94	5,499	-	282	18	5,499
7/22	84	94	5,301	-	0	300	5,019
7/23	84	94	5,499	-	0	300	5,499
7/24	84	94	4,936	-	282	18	4,936
7/25	84	94	4,572	-	0	300	4,290
7/26	84	94	5,118	-	0	300	5,118
7/27	84	94	5,668	-	282	18	5,668
7/28	84	94	5,102	-	0	300	4,820
7/29	84	94	5,457	-	0	300	5,457
7/30	84	94	5,304	-	282	18	5,304
7/31	84	94	6,035	-	0	300	5,753

Zone 1 (Cistern #1) Daily Water Budget (July) for Determining Size of Cistern (In Gallons). Water Source: A/C Condensate

Day	Daily Water Demand	Water Requirements	Available Supply (overflow from cistern 2)	Loss to First Flush	Amt. Needed for Irrigation	Cumulative Storage	Overflow
7/1	2,384	3,815	3,411	-	0	3,411	0
7/2	2,384	3,815	3,876	-	0	7,287	0
7/3	2,384	3,815	4,561	-	11,445	55	348
7/4	2,384	3,815	5,386	-	0	5,441	0
7/5	2,384	3,815	4,925	-	0	10,366	0
7/6	2,384	3,815	5,118	-	11,445	55	3,984
7/7	2,384	3,815	4,839	-	0	4,894	0
7/8	2,384	3,815	5,689	-	0	10,583	0
7/9	2,384	3,815	5,310	-	11,445	55	4,393
7/10	2,384	3,815	5,386	-	0	5,441	0
7/11	2,384	3,815	5,668	-	0	11,109	0
7/12	2,384	3,815	5,074	-	11,445	55	4,638
7/13	2,384	3,815	4,998	-	0	5,053	0
7/14	2,384	3,815	5,280	-	0	10,333	0
7/15	2,384	3,815	5,878	-	11,445	55	4,711
7/16	2,384	3,815	5,219	-	0	6,253	0
7/17	2,384	3,815	5,501	-	0	11,500	0
7/18	2,384	3,815	6,088	-	11,445	55	5,363
7/19	2,384	3,815	6,198	-	0	5,074	0
7/20	2,384	3,815	6,284	-	0	10,573	1,037
7/21	2,384	3,815	5,499	-	11,445	55	5,499
7/22	2,384	3,815	5,019	-	0	5,074	0
7/23	2,384	3,815	5,499	-	0	10,573	0
7/24	2,384	3,815	4,936	-	11,445	55	4,009
7/25	2,384	3,815	4,290	-	0	4,345	0
7/26	2,384	3,815	5,118	-	0	9,463	0
7/27	2,384	3,815	5,668	-	11,445	55	3,613
7/28	2,384	3,815	4,820	-	0	4,875	0
7/29	2,384	3,815	5,457	-	0	10,332	0
7/30	2,384	3,815	5,304	-	11,445	55	4,136
7/31	2,384	3,815	5,753	-	0	5,808	0

Zone 1 (Cistern #2) Daily Water Budget (July) for Determining Size of Cistern (In Gallons). Water Source: A/C Condensate

Day	Daily Water Demand	Water Requirements	Available Supply (4 Events @ .62" Each)	Loss to First Flush	Amt. Needed for Irrigation	Cumulative Storage	Overflow
8/1	820	1,312	0	-	0	0	
8/2	820	1,312	12,428	500	0	11,928	
8/3	820	1,312	0	-	3,936	7,992	
8/4	820	1,312	0	-	0	7,992	
8/5	820	1,312	0	-	0	7,992	
8/6	820	1,312	0	-	3,936	4,056	
8/7	820	1,312	0	-	0	4,056	
8/8	820	1,312	0	-	0	4,056	
8/9	820	1,312	0	-	3,936	120	
8/10	820	1,312	12,428	500	0	11,798	
8/11	820	1,312	0	-	0	11,798	
8/12	820	1,312	0	-	3,936	7,862	
8/13	820	1,312	0	-	0	7,862	
8/14	820	1,312	0	-	0	7,862	
8/15	820	1,312	0	-	3,936	3,926	
8/16	820	1,312	0	-	0	3,926	
8/17	820	1,312	0	-	0	3,926	
8/18	820	1,312	12,428	500	3,936	8,064	3,604
8/19	820	1,312	0	-	0	8,064	
8/20	820	1,312	0	-	0	8,064	
8/21	820	1,312	0	-	3,936	4,128	
8/22	820	1,312	0	-	0	4,128	
8/23	820	1,312	0	-	0	4,128	
8/24	820	1,312	0	-	3,936	192	
8/25	820	1,312	0	-	0	192	
8/26	820	1,312	12,428	500	0	11,870	
8/27	820	1,312	0	-	3,936	7,934	
8/28	820	1,312	0	-	0	7,934	
8/29	820	1,312	0	-	0	7,934	
8/30	820	1,312	0	-	3,936	3,998	
8/31	820	1,312	0	-	0	3,998	

Zone 2 (Cistern #3) Daily Water Budget (August) for Determining Size of Cistern (In Gallons). Water Source: Runoff

Day	Daily Water Demand	Water Requirements	Available Supply (4 Events @ .62" Each & A/C Condensate)	Loss to First Flush	Amt. Needed for Irrigation	Cumulative Storage	Overflow
8/1	5,276	8,442	5,689	-	0	5,689	
8/2	5,276	8,442	37,942	1000	0	42,631	
8/3	5,276	8,442	7,108	-	25,326	24,413	
8/4	5,276	8,442	6,480	-	0	30,893	
8/5	5,276	8,442	5,280	-	0	36,173	
8/6	5,276	8,442	4,572	-	25,326	15,419	
8/7	5,276	8,442	5,121	-	0	20,540	
8/8	5,276	8,442	5,485	-	0	26,025	
8/9	5,276	8,442	5,499	-	25,326	6,198	
8/10	5,276	8,442	36,760	1000	0	41,958	
8/11	5,276	8,442	3,876	-	0	45,834	
8/12	5,276	8,442	4,207	-	25,326	24,674	41
8/13	5,276	8,442	4,183	-	0	28,857	
8/14	5,276	8,442	4,342	-	0	33,199	
8/15	5,276	8,442	4,023	-	25,326	11,896	
8/16	5,276	8,442	4,041	-	0	15,937	
8/17	5,276	8,442	4,207	-	0	20,144	
8/18	5,276	8,442	36,561	1000	25,326	24,674	5,705
8/19	5,276	8,442	5,485	-	0	30,159	
8/20	5,276	8,442	5,589	-	0	35,748	
8/21	5,276	8,442	5,457	-	25,326	15,879	
8/22	5,276	8,442	4,925	-	0	20,804	
8/23	5,276	8,442	4,749	-	0	25,553	
8/24	5,276	8,442	4,749	-	25,326	4,976	
8/25	5,276	8,442	4,372	-	0	9,348	
8/26	5,276	8,442	36,904	1000	0	45,252	
8/27	5,276	8,442	5,668	-	25,326	24,674	920
8/28	5,276	8,442	5,457	-	0	30,131	
8/29	5,276	8,442	4,663	-	0	34,794	
8/30	5,276	8,442	4,302	-	25,326	13,770	
8/31	5,276	8,442	4,703	-	0	18,473	

Zone 3 (Cistern #4) Daily Water Budget (August) for Determining Size of Cistern (In Gallons). Water Source: A/C Condensate and Runoff

Day	Daily Water Demand	Water Requirements	Available Supply (4 Events @ .62" Each)	Loss to First Flush	Amt. Needed for Irrigation	Cumulative Storage	Overflow
8/1	223	226	0	-	0	0	0
8/2	223	226	3,041	100	0	2,100	556
8/3	223	226	0	-	678	1,422	0
8/4	223	226	0	-	0	1,422	0
8/5	223	226	0	-	0	1,422	0
8/6	223	226	0	-	678	744	0
8/7	223	226	0	-	0	744	0
8/8	223	226	0	-	0	744	0
8/9	223	226	0	-	678	66	0
8/10	223	226	3,041	100	0	2,100	907
8/11	223	226	0	-	0	2,100	0
8/12	223	226	0	-	678	1,422	0
8/13	223	226	0	-	0	1,422	0
8/14	223	226	0	-	0	1,422	0
8/15	223	226	0	-	678	744	0
8/16	223	226	0	-	0	744	0
8/17	223	226	0	-	0	744	0
8/18	223	226	3,041	100	678	1,422	1,585
8/19	223	226	0	-	0	1,422	0
8/20	223	226	0	-	0	1,422	0
8/21	223	226	0	-	678	744	0
8/22	223	226	0	-	0	744	0
8/23	223	226	0	-	0	744	0
8/24	223	226	0	-	678	66	0
8/25	223	226	0	-	0	66	0
8/26	223	226	3,041	100	0	2,100	907
8/27	223	226	0	-	678	1,422	0
8/28	223	226	0	-	0	1,422	0
8/29	223	226	0	-	0	1,422	0
8/30	223	226	0	-	678	744	0
8/31	223	226	0	-	0	744	0

Zone 4 (Cistern #5)Daily Water Budget (August) for Determining Size of Cistern (In Gallons). Water Source: Runoff

Day	Daily Water Demand	Water Requirements	Available Supply (4 Events @ .62" Each)	Loss to First Flush	Amt. Needed for Irrigation	Cumulative Storage	Overflow
8/1	188	190	0	-	0	0	0
8/2	188	190	2,456	100	0	1,800	556
8/3	188	190	0	-	570	1,230	0
8/4	188	190	0	-	0	1,230	0
8/5	188	190	0	-	0	1,230	0
8/6	188	190	0	-	570	660	0
8/7	188	190	0	-	0	660	0
8/8	188	190	0	-	0	660	0
8/9	188	190	0	-	570	90	0
8/10	188	190	2,456	100	0	1,800	646
8/11	188	190	0	-	0	1800	0
8/12	188	190	0	-	570	1,230	0
8/13	188	190	0	-	0	1,230	0
8/14	188	190	0	-	0	1,230	0
8/15	188	190	0	-	570	660	0
8/16	188	190	0	-	0	660	0
8/17	188	190	0	-	0	660	0
8/18	188	190	2,456	100	570	1,230	1,216
8/19	188	190	0	-	0	1,230	0
8/20	188	190	0	-	0	1,230	0
8/21	188	190	0	-	570	660	0
8/22	188	190	0	-	0	660	0
8/23	188	190	0	-	0	660	0
8/24	188	190	0	-	570	90	0
8/25	188	190	0	-	0	90	0
8/26	188	190	2,456	100	0	1,800	646
8/27	188	190	0	-	570	1,230	0
8/28	188	190	0	-	0	1,230	0
8/29	188	190	0	-	0	1,230	0
8/30	188	190	0	-	570	660	0
8/31	188	190	0	-	0	660	0

Zone 5 (Cistern #6) Daily Water Budget (August) for Determining Size of Cistern (In Gallons). Water Source: Runoff

Day	Daily Water Demand	Water Requirements	Available Supply (4 Events @ .62" Each)	Loss to First Flush	Amt. Needed for Irrigation	Cumulative Storage	Overflow
8/1	26	29	0	-	0	0	0
8/2	26	29	1,252	35	0	300	917
8/3	26	29	0	-	87	213	0
8/4	26	29	0	-	0	213	0
8/5	26	29	0	-	0	213	0
8/6	26	29	0	-	87	126	0
8/7	26	29	0	-	0	126	0
8/8	26	29	0	-	0	126	0
8/9	26	29	0	-	87	39	0
8/10	26	29	1,252	35	0	300	956
8/11	26	29	0	-	0	300	0
8/12	26	29	0	-	87	213	0
8/13	26	29	0	-	0	213	0
8/14	26	29	0	-	0	213	0
8/15	26	29	0	-	87	126	0
8/16	26	29	0	-	0	126	0
8/17	26	29	0	-	0	126	0
8/18	26	29	1,252	35	87	213	1,043
8/19	26	29	0	-	0	213	0
8/20	26	29	0	-	0	213	0
8/21	26	29	0	-	87	126	0
8/22	26	29	0	-	0	126	0
8/23	26	29	0	-	0	126	0
8/24	26	29	0	-	87	39	0
8/25	26	29	0	-	0	39	0
8/26	26	29	1,252	35	0	300	956
8/27	26	29	0	-	87	213	0
8/28	26	29	0	-	0	213	0
8/29	26	29	0	-	0	213	0
8/30	26	29	0	-	87	126	0
8/31	26	29	0	-	0	126	0

Zone 6 (Cistern #7) Daily Water Budget (August) for Determining Size of Cistern (In Gallons). Water Source: Runoff

appendix d:

literature map

Sources of "Free Water"

Briggs, Socha, Terry 2009
Bauer, Coopersmith, Davis 2011

Benefits / Risks

Krishna 2005
Cabell Brand Center 2009
Kloss 2008

System Componenets

Krishna 2005
Kinkade-Levario 2007

Design Considerations

Graffam, Holmes, Kinkade 2010
Jones, Hunt, Wright 2009
Kinkade and Bock 2011
Lawrence, Perry, Dempsey 2010a
Lawrence, Perry Alsen 2012
Guz 2005

search

Is it possible to retrofit an existing landscape in St. Louis with a harvsted water irrigation system that has zero dependency on a municipal water supply?

Performance-Based Design

Precedent Analysis

Phoenix Convention Center
T.C. Williams High School

Extracted Literature Design Considerations

Graffam, Holmes, Kinkade 2010
Jones, Hunt, Wright 2009
Kinkade and Bock 2011
Lawrence, Perry, Dempsey 2010a

Predictive Modeling

Estimated Demand Results
Estimated Supply Results
Storage Sizing Results

Base Knowledge

Estimating Demand

Blaney and Criddell 1962
Cabell Brand Center 2009
Waterfall 2004
Pittenger 2012
Kinkade and Bock 2011
The Irrigation Association 2005
Calkins 2012
The University of California 2013

Estimating Supply

Calkins 2012
Harris and Dines 1998
Krishna 2005
Kinkade and Bock 2011
Waterfall 2004
Lawrence, Perry, Dempsey 2010b
Guz 2005
Painter 2009

Determining Storage

Kinkade-Levario 2007

extract

Predictive Modeling Application

Estimating Demand

The Irrigation Association 2005
Davis 2013

Estimating Supply-Surface Runoff

Krishna 2005
Kinkade and Bock 2011
Waterall 2004

Estimating Supply-A/C Condensate

Lawrence, Perry, Dempsey 2010b
Loveless, Farooq, Ghaffour 2012

Determining Storage

Kinkade-Levario 2007

inform

references

References

ASHRAE. 2003. “ASHRAE Standard 62-2001 - Ventilation for Acceptable Indoor Air Quality.” American Society of Heating, Refigerating and Air-Conditioning Engineers, Inc. Accessed December 7, 2013. Retrieved from https://www.ashrae.org/standards-research--technology/standards-addenda/Addenda-to-Standard-62-2001

Bauer, John R., Mark Coopersmith, and Jim Davis. 2011. “SUN A7: Harvesting On-Site Water Sources for Sustainable Irrigation.” Presentation at the American Society of Landscape Architects National Conference, San Diego, CA, October 30-November 2. Accessed August 29, 2013. Retrieved from http://www.asla.org/search.aspx?q=rainwater%20harvesting

Blaney, Harry French, and Wayne D. Criddle. 1962. Determining Consumptive Use and Irrigation Water Requirements. U.S. Department of Agriculture.

Briggs, Todd, Judeen Terrey, and Roger Socha. 2009. “Gutters to Green: Innovative Water Harvesting.” Presentation at the American Society of Landscape Architects Annual Meeting Education Session B1, Chicago, IL, September 18. Accessed August 29, 2013. Retrieved from http://www.asla.org/search.aspx?q=rainwater%20harvesting

Cabell Brand Center. 2009. “Virginia Rainwater Harvesting Manual, 2nd Edition.” Accessed October 18, 2013 Retrieved from http://www.cabellbrandcenter.org/Downloads/RWH_Manual2009.pdf.

Calkins, Meg. 2011. The Sustainable Sites Handbook. Hoboken, N.J.: Wiley.

City of San Antonio. 2009. “Information Bulletin 13.” Accessed November 4, 2013. Retrieved from https://webapps1.sanantonio.gov/dsddocumentcentral/upload/IB163.pdf

City of St. Louis. 2012. “Water Rates.” Accessed March 31, 2014. Retrieved from http://www.stlwater.com/waterrates.php

Davis, Jim. 2014. Personal Correspondence. November 2013

Despins, C. 2010. “Ontario Guidelines for Residential Rainwater Harvesting Systems Handbook”. Accessed September 29. 2013. Retrieved from Sustainable Technologies Evaluation Program Web site: http://www.sustainabletechnologies.ca/Portals/_Rainbow/Documents/ONTARIO_RWH_HANDBOOK_2010.pdf

Ecological Design Group. 2014. “Heifer International World Headquarters, Little Rock, AR.” Accessed March 27, 2013. Retrieved from http://www.ecologicaldg.com/Projects/ArkansasRiverValley/HeiferInternationalWorldHeadquarters.aspx

Environmental Protection Agency. 2013. “Climate Change in the Midwest.” Accessed October 1, 2013. Retrieved from http://www.epa.gov/climatechange/impacts-adaptation/midwest.html

Farahbakhsh, Khosrow, Christopher Despins, and Chantelle Leidl. 2009. “Developing Capacity for Large-scale Rainwater Harvesting in Canada.” Water Quality Research Journal of Canada 44 (1): 92.

Francis, Mark. 2013. “Community Design (re) Examined.” Hou, J*., et Al*: 18–24.

Guz, Karen. 2005. “Condensate Water Recovery.” ASHRAE Journal 47 (6): 54–56.

Graffam, Skip, Nicole Holmes, and Heather Kinkade. 2010. “Rainwater Harvesting for Landscape Irrigation.” Presentation at the American Society of Landscape Architects National Conference, Washington, D.C., September 10-13. Accessed August 29, 2013.
Retrieved from http://www.asla.org/search.aspx?q=rainwater%20harvesting

Harris, Charles W., and Nicholas T. Dines. 1998. Time Saver Standards for Landscape Architecture: Second Edition. New York, New York: McGraw-Hill.

Hoer Schaudt. 2014. “Discover Card.” Accessed March 30, 2014.
Retrieved from http://www.hoerrschaudt.com/commercial/discover-card.php

----. 2014. “Trump Tower.” Accessed March 30, 2014.
Retrieved from http://www.hoerrschaudt.com/commercial/trump-tower.php#

Jones, Matthew P., and William F. Hunt. 2010. “Performance of Rainwater Harvesting Systems in the Southeastern United States.” Resources, Conservation and Recycling 54 (10) (August): 623–629. doi:10.1016/j.resconrec.2009.11.002.

Jones, Matthew P., William F. Hunt, and Jason Wright. 2009. “Rainwater Harvesting Experiences in the Humid Southeast USA.”Accessed October 10, 2013.
Retrieved from http://link.aip.org/link/ascecp/v342/i41036/p209/s1.

Kafin and Van Ooyen. 2008. “Rainwater Harvesting 101.” Accessed November 4, 2013.
Retrieved from http://www.grownyc.org/files/osg/RWH.how.to.pdf

Kinkade, Heather, and Sandra A. Brock. 2011 “From Catchment to Reuse: Designing and Implementing Rainwater Harvesting Systems.” Presentation at the American Society of Landscape Architects National Conference, San Diego, CA, October 30-November 2. Accessed August 29, 2013. Retrieved from http://www.asla.org/search.aspx?q=rainwater%20harvesting

Kindade-Levario, Heather. 2007. Design for Water. British Columbia, Canada: New Society Publishers.

Kloss, Christopher. 2008. “Managing Wet Weather with Green Infrastructure Municipal Handbook: Rainwater Harvesting Policies”. US Environmental Protection Agency.

Kowalsky, Greg and Kathryn Thomason. 2011. “Cistern Design Considerations for Large Rainwater Harvesting Systems.” Accessed March 18, 2014. Retrieved from http://www.conteches.com/DesktopModules/Bring2mind/DMX/Download.aspx?Command=Core_Download&EntryId=9614&PortalId=0&TabId=144

Krishna, J. H. 2005. “The Texas Manual on Rainwater Harvesting, 3rd Edition”. Texas Water Development board.

Lawrence, Thomas. 2013. Personal E-mail Correspondence. November 2013

Lawrence, Thomas, Jason Perry, and Tyler Alsen. 2012. “A Study of 47 U.S. Cities: AHU Condensate Collection economics. (TECHNICAL FEATURE)(Cover Story): An Article from: ASHRAE Journal.” ASHRAE Journal 54 (5) (May).

Lawrence, Thomas, Jason Perry, and Peter Dempsey. 2010a. “Capturing Condensate by Retrofitting AHUs.” ASHRAE Journal 52 (1) (January):48–54.

Lawrence Thomas, Jason Perry, and Peter Dempsey. 2010b. “Predicting Condensate Collection from HVAC Air Handling Units.” ASHRAE Trans 116(2):3–15

Loveless, Kolin J., Aamir Farooq, and Noreddine Ghaffour. 2012. “Collection of Condensate Water: Global Potential and Water Quality Impacts.” Water Resources Management (December 28). Accessed October 18, 2013. Retrieved from http://link.springer.com/article/10.1007%2Fs11269-012-0241-8/fulltext.html.

McCoy, Kevin. 2012. “USA TODAY analysis: Water costs gush higher.” USA Today. Accessed February 26, 2014. Retrieved from http://www.usatoday.com/story/money/business/2012/09/27/rising-water-rates/1595651/

Painter, Fred. 2009. “Condensate Harvesting from Large Dedicated Outside Air-Handling Units with Heat Recovery”, ASHRAE Transactions 2009, 115(2):

Pittenger, Dennis. 2012. “How Much Water Does a Landscape Really Need?” Presentation at the 2012 Landscape Industry Show Workshop, Los Angeles, CA. Accessed September 29, 2013. Retrieved from http://ucanr.org/sites/UrbanHort/files/136134.pdf

Prairie Nursery. 2014. “Tall Prairie for Dry Soils.” Accessed March 9, 2014. Retrieved from http://www.prairienursery.com/store/seed-mixes/classic-prairie-seed-mixes/tall-prairie-for-dry-soils#.Uz9kmPIdUg1

RS Means. 2013. RS Means Site Work & Landscape Cost Data: 32nd Annual Edition. Reed Construction Data, LLC, Norwell, MA

Seay, Kim. 2013. Personal Telephone Correspondence. December 2013

The Irrigation Association. 2005. "Landscape Irrigation Scheduling and Water Management." Water Management Committee of The Irrigation association. Accessed November 4, 2013. Retrieved from http://www.asla.org/uploadedFiles/PPN/Water%20Conservation/Documents/LISWM%20Draft.pdf

University of California. 2013. "Estimating Water Needs of Landscape Plants and Entire Landscapes." Center for Landscape and Urban Horticulture, Department of Agriculture and Natural Resources. Accessed September 29, 2013. Retrieved from http://ucanr.edu/sites/UrbanHort/Water_Use_of_Turfgrass_and_Landscape_Plant_Materials/Plant_Water_Needs/Estimating_Water_Needs_of_Landscape_Plants_and_Entire_Landscapes/

Waterfall, Patricia. 2004. "Harvesting Rainwater for Landscape Use" Accessed October 8, 2013. Retrieved from http://ag.arizona.edu/pubs/water/az1052/harvest.html

Images and Figures

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Brewer, Michael. 2013. "US Drought Monitor - August 13, 2013." USDA. http://droughtmonitor.unl.edu. Accessed November 8, 2013.

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Brewer, Michael. 2013. "US Drought Monitor - August 14, 2012." USDA. http://droughtmonitor.unl.edu. Accessed November 8, 2013.

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Edwards, Laura. 2013. "US Drought Monitor - August 16, 2011." USDA. http://droughtmonitor.unl.edu. Accessed November 8, 2013.

Figure 1.4

Kepple, Kevin A, Denny Gainer, Joan Murphey, Dough Carroll, Kevin McCoy, Oliver St. John, and Tom McGarrit. "Increase in Water Costs from 2000 - 2012." USA TODAY. http://www.usatoday.com/story/money/business/2012/09/27/rising-water-rates/1595651/. Accessed February 26, 2014.

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Haid, Wes. 2014. "Study Site Locations." Source: Adapted from Google Earth, St. Louis Missouri. Accessed February 18, 2014.

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Muller, Bob. 2007. “Modern Water Harvesting System Storage Container.” Photograph by Flickr user Bob Muller. May 5, 2007. Accessed April 21, 2014. Retrieved from https://www.flickr.com/photos/bobx-nc/491406937/in/photolist-KqAap-8aszwq-diEYmV-7tHzj8-4D71BY-76vuzy-fj9Eg1-db86DT-7wQPfo 9k2yGL-fQ6htS-9nmLcG-9nbMDR-9nbMAZ-btf2Xh-9neQ8b-82y2Gg-82y7Xt-dEdyWg-dD2zxF-dEdy4P-bjFJbm-dD2uRg-dD2Cv4-dUdXeW-8fJDbD-9q6PMV-8HX6kf-8fJDop-dEdxTv-8fJDCR-57ZywL-dEiWCL dEiWEA-63VFsf-dGtmri-dEiWJS-dEiWrj-dEdwkB-dEiX7C-dEdxq4-dEdysM-83ytqk-83ysUt-7KM8jy-7KM8ZE-dDtJzp-8A9qzX-aLn7Kt-aLnuXz. Image Use Authorization: Creative Commons Attribution General 2.0 License

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Rouvin, Axel. 2007“Ancient Portuguese Underground Cistern in El Jadida, Morocco.” Photograph. February 28, 2007. Accessed April 1, 2014. Retrieved from http://en.wikipedia.org/wiki/File:El_Jadida_cistern.jpg Image Use Authorization: Creative Commons Attribution General 2.0 License

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Haid, Wes. “Water Harvesting System Components.” Adobe InDesign.

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Haid, Wes. “Average Number of Significant Rainfall Events (0.1”>) for St. Louis (2003 - 2013).” Microsoft Excel. Data Source: “Weather History for St. Louis, Missouri.” Accessed November 19, 2013. Retrieved from http://www.wunderground.com/history/airport/

Figure 3.3

Haid, Wes. “Average Amount (inches) of Rainfall per Significant Rainfall Event for St. Louis (2003 - 2013)” Microsoft Excel. Data Source: “Weather History for St. Louis, Missouri.” Accessed November 19, 2013. Retrieved from http://www.wunderground.com/history/airport/

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Haid, Wes. “30-Year Average Monthly Evapotranspiration Quantities (inches) for St. Louis.” Microsoft Excel. Data Source: Davis 2014.

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ASHRAE. 1963. “Psychometric Chart.” Accessed March 13. 2014. Retrieved from http://www.buildingcontrolworkbench.com/BCWInfo/GrayBook/Gpsycash.htm

Figure 3.6

Haid, Wes. 2014. “Mean Daily Average Temperature and Relative Humidity for St. Louis (2003 - 2013).” Microsoft Excel. Data Source: “Weather History for St. Louis, Missouri.” Accessed November 19, 2013. Retrieved from http://www.wunderground.com/history/airport/

Figure 3.7

Haid, Wes. 2014. “Average Daily Humidity Ratio for St. Louis Missouri (2003 - 2013).” Microsoft Excel. Data Source: “Weather History for St. Louis, Missouri.” Accessed November 19, 2013. Retrieved from http://www.wunderground.com/history/airport/

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Haid, Wes. 2014. “Post-Water Use Comparison.” Adobe Photoshop and InDesign. Soccer Field Image Source: Wikimedia User SeLarin. 2005. Accessed March 25, 2014. Retrieved from http://commons.wikimedia.org/wiki/File:Football_field.jpg. Swimming Pool Image Source: “Olympic-size swimming pool.” 2014 Wikipedia. Accessed March 25, 2014. Retrieved from http://en.wikipedia.org/wiki/Olympic-size_swimming_pool

Figure 5.21

Barrows, Paul. 2011. “Heifer International Headquarters, Little Rock, Arkansas.” Photography by Flickr User paul barows. Accessed March 29, 2014. Retrieved from https://www.flickr.com/photos/naildriver/6246535976/in/photolist-avZ8w9-avZ8pN-avZ8Bq-gkKosw-avZ8kh-g3Xovd-i5ywZs-i5yqbX-dSVD1n-kRF4M9-kRF4bQ-9GPfT4-kRDTUV-kRDVvv-8CYwPc-8CYwTg-4ztupp-4Tf8fs-4Tf1zy-4VBkEr-dcQDgP-dcQFqh-9Vpwnk-8jWb1p-bxD8xm-cRC4iu-fAr27o-4TeYmb-4VBkF2-9vNdvk-dLragG-8ipuSo-9zJ6At-8pvjZj-7aZgVy-7aV9sH-9LtJiq-4ZDLTp-7KpEKQ-7KpEDA-7KpEN5-7KpEFo-bmLEYW-bzFx2e-bzFx7a-6tx9Xw-6txaeq-bmLMFC-bmLMxq-bzF63a. Image Use Authorization: Written permission from image source.

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