

Thirsty landscapes - Investigating growing irrigation water consumption and potential conservation measures within Utah's largest master-planned community: Daybreak.

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**Thirsty landscapes - Investigating growing irrigation water
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Abstract

The demand for more water in the southwestern parts of the United States of America is growing due to an increasing population, while climate conditions are becoming more unfavorable with higher temperatures and less precipitation.

This study explores current culinary and secondary water consumptions used for irrigation purposes in the Daybreak neighborhood, located in South Jordan, Utah. Additionally, it examines the role of park strips and their impact on residential outdoor water usage, as well as their overall water conservation potential, and aims to deliver an estimate of the community's future irrigation water consumption once completed around the year 2025.

Based on over 6,500 manually digitized and classified features, detailed water meter readings, as well as several other GIS processes and statistical analyses, Daybreak, in its current state of being 35% developed, is using close to 1 million cubic meters of water annually to irrigate its public open spaces. The results also indicate that Daybreak's single family residence (SFR) irrigation consumption is significantly different compared to non-Daybreak units, and that a positive relation exists between park strip area and SFR irrigation water usage. Furthermore, the conservation potential by converting turf-covered park strips to xeriscapes can theoretically reach over 1.2 million cubic meters of culinary water per year once Daybreak is fully developed, while the future irrigation volume for SFR units and public areas is estimated to surpass 9 million cubic meters per year.

Overall, the results and findings of this research will advance the understanding of current and future irrigation consumption patterns within the Daybreak community and can be used as the basis for further research. Moreover, they assist South Jordan's decision makers with water related challenges and can serve as justification for potential future city ordinances regarding water conserving landscaping.

Keywords: Geography, GIS, Utah, South Jordan, Daybreak, Irrigation, Water, Park Strips

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List of Acronyms

HOA	Home Owner Association
min1	minimum use month irrigation consumption
min3	minimum 3-month average irrigation consumption
MPC	Master Planned Community
SFR	Single-Family Residence
NAIP	National Agriculture Imagery Program
NRG	Near-Infrared, Red, Green

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1. Introduction

Water consumption in the southwestern parts of the United States of America is a very current and important issue. The demand for water is growing due to an increasing population, while climate conditions in the western states are becoming more unfavorable with higher temperatures and less precipitation.

1.1 Water consumption in the United States of America

According to the United States Geological Survey (USGS) and its latest 5-year report on the nation's water usage from 2010, the total daily fresh and saline water consumption was at about 1.344 trillion liters per day (355 billion gallons), with freshwater withdrawals accounting for 86% of the total, or 1.158 trillion liters per day (306 billion gallons) (Maupin et al., 2014). This number represents a decrease in total water consumption of 13% compared to the year 2005, and the first decline since the report was first published in 1950 - a trend that can mainly be attributed to conservation efforts and increased efficiency, specifically within the industrial sector.

However, even though total water usage levels this low were last reported over 40 years ago, the nationwide consumption still has increased over 10-fold during the twentieth century and remains very high to this date, putting significant stress on many freshwater systems due to over usage (Donnelly & Cooley, 2015). Furthermore, a constantly growing population puts additional pressure on the demand for more water, while climate change related effects will further the stress on the availability of fresh water in many areas, due to rising temperatures and evapotranspiration rates as well as reduced precipitation. Brown et al., (2013) assess that, while the nationwide water withdrawals from 2005 to 2090 would only rise by 13% with a population increase of 70%, the projection will significantly increase when taking the effects of future climate change into consideration. Their research estimates that the water withdrawals in the United States from 2005 to 2090 will increase between 35% and 52%, depending on the used climate change model.

1.2 Climatic conditions and water consumption in Utah

Current and future water usage estimates are important information for water managers, especially in the dry and hot southwestern states of the U.S., including the state of Utah. Utah is the second driest state in the nation and receives an average annual precipitation of only 330 mm

(13 in) that is distributed very unevenly throughout the state due to extreme variations in elevation. While the state's mountain ranges can receive up to 1,524 mm (60 in) annually, mostly as snow, the lower elevation basins usually only receive between 127 and 254 mm (5-10 in) of rain per year (Office of Legislative Research and General Counsel (OLRGC), 2012). Only the state of Nevada experiences less precipitation on average, and in addition to already having a dry, continental climate, multiple studies taking emission scenarios generated by the Intergovernmental Panel on Climate Change (IPCC) into account to estimate future climate conditions, predict rising temperatures and declining precipitation for the American Southwest (Garfin et al., 2014). The National Oceanic and Atmospheric Administration (NOAA), for example, predicts an annual mean temperature increase for the state of Utah of up to 5.28 degrees Celsius (9.5 °F) by the year 2099, based on multi-model means for the IPCC scenarios A2 and B1 (Kunkel et al., 2013). In addition to that, the Department of Atmospheric Sciences of the University of Utah expects a noticeable decline in snowpack depth due to warming temperatures over the next decades (Strong, 2013).

The thinning of the snowpack can be especially troublesome, since Utah heavily relies on the accumulation and storage of snow in the Wasatch Mountain watersheds for its water supply. Research conducted by Bardsley et al., (2013) indicates that warming temperatures in the state of Utah will lead to earlier snowmelt runoff and an overall decrease in total runoff volume that can cause severe long and short term droughts. Furthermore, the most significant flow reductions will occur during the summer months where the demand for water peaks.

But climatic influences aren't the only factor that will affect the state's water supply, since Utah also ranks amongst the highest in net immigration and overall population growth compared to the other states in the nation. With the rising demand for more residential housing, industrial and commercial developments, municipal as well as statewide consumption rates will only increase, which could put the beehive state in a precarious situation. As of 2010, Utah has the country's second highest domestic per capita water consumption with an average daily use of 618 liters (167 gallons) of culinary water per person. Culinary water typically refers to treated, or potable water of sufficient quality that is suitable for human consumption. Utah's daily per capita water uptake rate is almost twice as much as the national average of 337 liters (89 gal) (Maupin et al., 2014), and the state's high water usage can be attributed to several factors. One reason is that

water in Utah is cheap, which undermines the population’s willingness to participate in necessary conservation efforts. According to the Utah Division of Water Resources, the cost of culinary water per 1,000 gallons (3,785 liter) is over 40% less compared to the national average (Utah Division of Water Resources, 2010). In addition to that, another important factor that significantly contributes to Utah’s high domestic water usage is residential landscape irrigation.

1.3 City of South Jordan and its Daybreak community

According to the Utah State University, urban landscape irrigation accounts for up to 65% of the total annual municipal water consumption (Utah State University, 2016), and the City of South Jordan (Figure 1) is one of many municipalities in Utah that will face significant challenges regarding its municipal water budget. South Jordan is located about 32 kilometers (20 miles) southwest of Salt Lake City, with a population of almost 67,000 people, according to the latest U.S. Census estimates. As of 2016, the city ranks amongst the top five cities with the highest growth rates in the country, and between 2010 and 2015, South Jordan ranked highest in the country for its overall growth of 32 percent, or 16,175 people (United States Census Bureau, 2015).

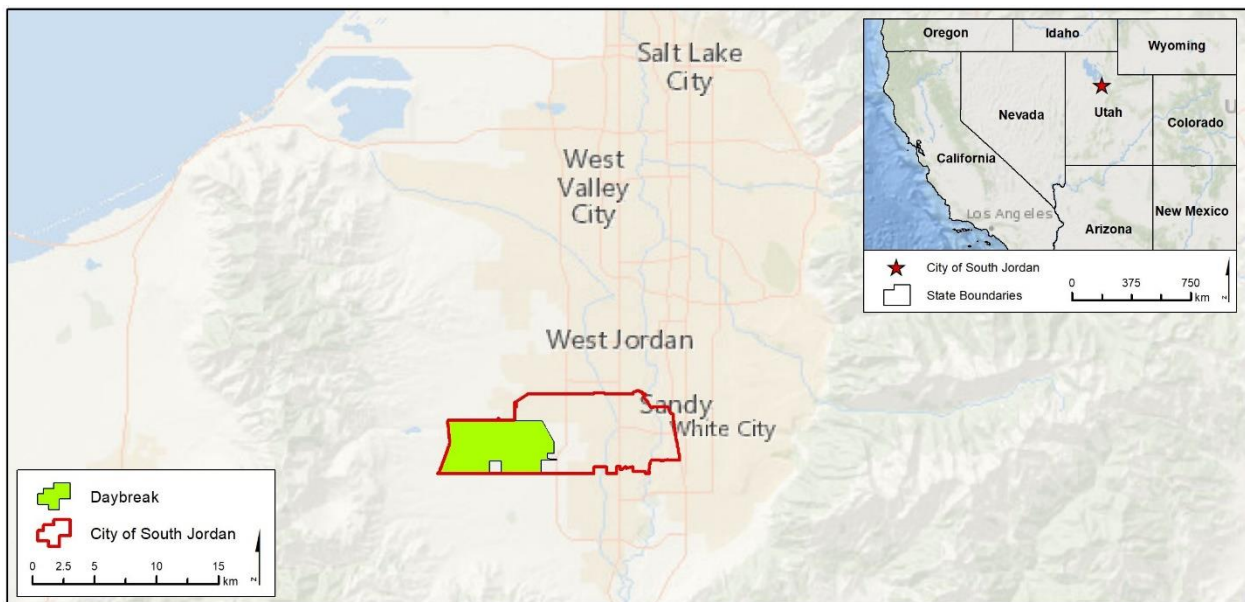


Figure 1: Location of South Jordan and the Daybreak Community

One of the reasons for South Jordan’s significant growth is the Daybreak Community, one of the largest master planned communities in the country, located in the western part of the city. As of

today, over 65% of the land allocated for Daybreak is still undeveloped, and once the project is completed around the year 2025, the community is expected to house over 20,000 residential units (Daybreak, 2015). Not only will the addition of thousands of turf-covered residential yards add substantial stress to South Jordan's municipal water supply, but the amount of turf-covered park strips, which is the area between the sidewalk and the back of the curb of the adjacent street, will also significantly add to that load. On the other hand, park strips also offer a great potential to reduce outdoor irrigation consumption due to the fact that the turf cover can be easily replaced with less water demanding options. However, according to the most recent landscaping guidelines established by Daybreak's home owner association (HOA), artificial turf or a complete replacement of turf with cobble stones, for example, are not permitted in the community, which leaves a replacement with mulch or desert-scapes (xeriscapes) in combination with drought resistant plants and dripline irrigation systems as the only available option (Daybreak, 2017). The potential water savings based on this measure will be assessed in this paper. The Daybreak HOA also heavily influences the irrigation practices of the community's residents, since yellowing turf due to under watering can potentially result in imposed fines for negligence of curb appeal. Potential differences in irrigation consumption between single family residences (SFR) in Daybreak compared to SFRs in South Jordan outside of Daybreak will also be evaluated in this paper.

Another important aspect that can negatively affect South Jordan's water budget is Daybreak's secondary (non-potable) water supply obtained from Utah Lake, located about 20 kilometers to the south, that is used to irrigate the majority of public greenspaces in Daybreak. As has occurred in the past, the community's secondary water supply can be forced to be temporarily shut off and switched to culinary water, due to the occurrence of extensive blooms of toxic cyanobacteria algae, commonly known as blue-green algae, in Utah Lake. The last algae bloom occurred in July of 2016, and caused a four day down time of Daybreak's secondary water system. The average daily culinary water consumption in a scenario like this will also be evaluated in this paper.

A changing climate, in addition to tremendous population growth rates, will put an immense burden on South Jordan's water budget and supply, especially since Daybreak is designed to have mostly single-family residence (SFR) units with turf-covered yards and park strips. The

addition of an estimated 15,000 residential units, as well as numerous recreational areas and open spaces in the form of parks and other greenspaces over the next 10 years, will require extensive irrigation, especially throughout the dry and hot summer months.

Rising water demands for irrigation purposes pose a serious threat to South Jordan's municipal water budget. It is therefore essential to assess the different consumption rates of public and residential areas to understand current usage, as well as to estimate future consumption rates and evaluate various water conservation measures within the study area.

1.4 Research questions and objectives

This thesis aims to increase our understanding about water consumption used for residential and public open space irrigation purposes within the Daybreak community located in South Jordan, Utah, with the specific research objectives and questions being:

1. To map the different types of existing public irrigated areas and estimate their water consumption rates within the Daybreak community.
 - Where are the different types of public irrigated areas (open space, park, park strips) located?
 - What are their water consumption rates?
2. To assess if the park strip area for an existing residential unit has a statistically significant impact on the unit's average water consumption, and to evaluate the water conservation potential for park strips within the community.
 - Does the percentage of park strip area of an existing residential unit with respect to the unit's total irrigated area have a significant impact on the average water consumption?
 - How much culinary water can be saved by implementing irrigation conservation measures approved by the Daybreak Home Owner Association (HOA) for residential and public park strips?
3. To assess if residential units in Daybreak have a significantly higher average irrigation water usage compared to residential units in South Jordan located outside of Daybreak.
 - Is the average residential irrigation usage of a single-family residence (SFR) within Daybreak statistically significantly different compared to non-Daybreak SFRs?

4. To calculate the daily culinary water consumption within the community caused by temporary secondary water shut-offs.
 - How much culinary water will be used per day for public greenspace irrigation within Daybreak, if the secondary water supply has been temporarily shut off?
5. To estimate future residential and open space irrigation volume once Daybreak is completed in 2025.
 - How much culinary water will Daybreak consume for single family residential irrigation purposes once completed in 2025?
 - How much culinary and secondary water will Daybreak consume for open space irrigation purposes once completed in 2025?

2. Literature Review

The main focus of this paper will be on culinary water consumption used for irrigation purposes within the Daybreak community, and an emphasis will be placed on the water usage for residential park strips. Park strips that surround residential homes or run parallel to streets account for significant amounts of grass covered areas within the city that need to be irrigated for aesthetic reasons, while not serving any essential functional purposes. Even though more and more cities in the state, including Salt Lake City, are updating their regulations regarding planting alternatives to turf on park strips, mainly due to a rising awareness concerning water conservation, the vast majority of Daybreak's residential and commercial units still use water intensive turf as their preferred cover.

2.1 Outdoor irrigation consumption

Even though a good amount of research has been conducted on estimating irrigation water usage for urban areas, most of these studies focuses on larger regions and not on comparably small areas such as the Daybreak community in South Jordan. Furthermore, the existing research on outdoor irrigation estimates and demands varies widely regarding their used methods and produced results.

The U.S. Environmental Protection Agency (EPA) estimates that, depending on the region, between 30-60% of all residential water consumption is being used for irrigation purposes (U.S. Environmental Protection Agency (EPA), 2017), which is comparable to a study conducted by Vickers, (1991), that estimated residential outdoor usage between 30-50%. On the other hand, Gleick et al., (2003), calculated that irrigation is responsible for up to 70% of total residential water consumption in California, whereas Kjelgren et al., (2000), concluded upon a 48% landscape water use for Salt Lake City in 2000. The significantly varying results of these studies validate the idea that regional factors relating to water usage, land cover features, as well as climatic conditions and availability of data all play an important role when estimating residential irrigation consumption and conservation potentials as concluded by Gleick et al., (2003).

Few studies actually quantify average residential irrigation usage on a single unit level, but rather focus on estimated water demands or needs and the correlation of factors that drive irrigation usage, such as income, evapotranspiration rates, lot area, plant species, or water rates (DeOreo et al., 2011). This holds true for South Jordan, and its Daybreak community, as well. A short

interview conducted with South Jordan's former water conservation manager indicated that the city is using estimates for residential irrigation consumption ranging from 70-80% of the total municipal water budget, without being able to present concrete numbers regarding water usage for the various features located in Daybreak (single residential homes, open greenspaces, parks, and park strips) (Maloy, 2017).

2.2 Park strip irrigation and conservation potential

References, actual studies, or data that focus on the irrigation of park strips and their conservation potential, as well as their impact on the overall irrigation consumption are very sparse at best.

The majority of all studies that include calculations for residential outdoor water usage focus on the entire irrigated area instead of emphasizing park strip areas. Isolating park strips from the entire irrigated area is important, because smaller irrigated areas tend to have a higher water consumption per area unit compared to larger areas (Maheshwari, 2016). Furthermore, most other studies solely rely on remote sensing approaches to differentiate irrigated from non-irrigated areas by analyzing aerial images in different band combinations. Endter-Wada et al., (2008), for example, use false color composite multispectral images to classify irrigated and non-pervious areas, whereas Halper et al., (2015), base their results on irrigated areas derived from normalized difference vegetation index (NDVI) values. Depending on the resolution of the available multispectral imagery, narrow areas such as park strips with a width of 1.2 – 2 meter (4 - 6.5 feet) will usually result in mixed pixels of irrigated and non-irrigated areas or will be ignored completely, which is why all areas for this study were obtained from manual digitization based on 3-inch resolution aerial imagery.

One of the very few articles that actually quantifies potential irrigation water savings for park strips was obtained from the Jordan Valley Water Conservancy District as part of their rebate program "Flip Your Strip", which offers rebates to convert turf covered park strips to more water efficient designs. Their data suggests that a full adaptation could save an estimated 26,498 – 37,854 liters (7,000 – 10,000 gal) per year (Jordan Valley Water Conservancy District, 2017), depending on the size of the park strip. However, these numbers highly underestimate the results obtained from the calculations of this study.

Other studies focus more on a complete conversion of residential landscapes, including all non-park strip areas, to xeriscape landscapes. Sovocool and Morgan, (2005), for example, estimate that the water saving potential that can be achieved by redesigning turf areas to xeriscape landscapes was found to be 76.4%, or an average of 2,273.3 l/m² (55.8 gal/ft²) per year. The results were obtained from a study conducted in Las Vegas, Nevada, and involved the comparing and metering of irrigation volumes for xeriscape areas and traditional turf covered areas. Due to the similar climatic conditions during the summer months between Nevada and the study area for this paper, Sovocool and Morgan's results will serve as the benchmark to assess potential irrigation water savings regarding park strips in the Daybreak neighborhood.

3. Methodology

3.1 Study Area

3.1.1 Location and extent

The study area is the Daybreak Community in South Jordan, Utah, located about 32 kilometers (20 miles) southwest of Salt Lake City at 40.557 degrees latitude north and 111.974 degrees longitude west (Figure 2). Due to its close proximity to the Wasatch Mountain Range, which forms the western edge of the Rocky Mountains, the city's average elevation is approximately 1,420 m (4,658 ft).

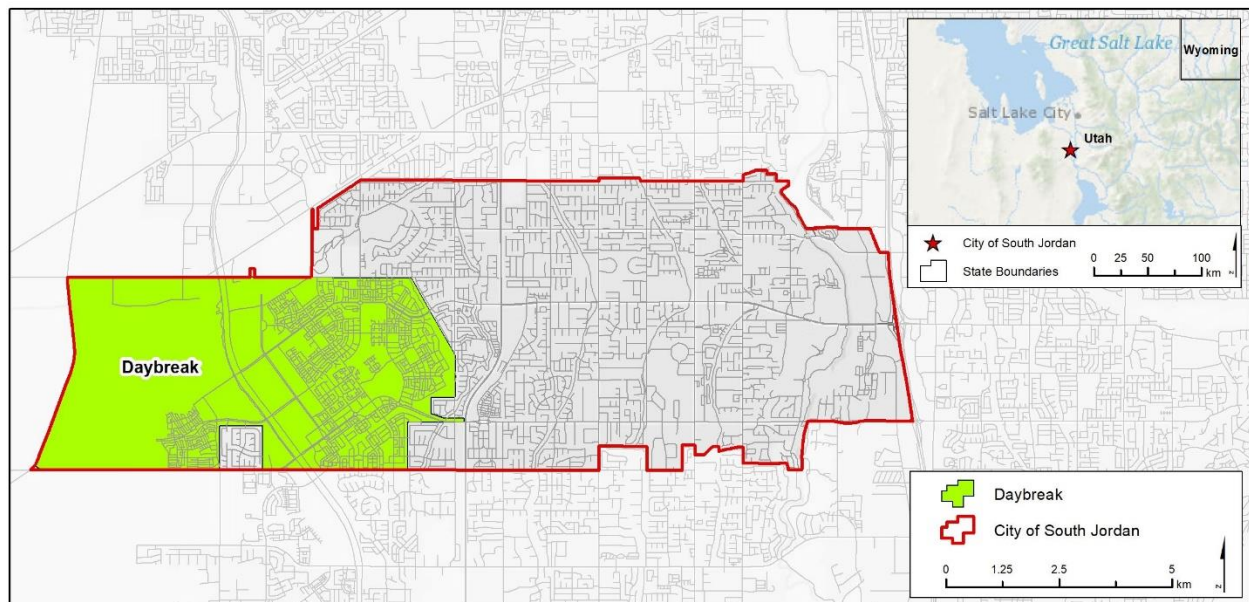


Figure 2: Study area - South Jordan's Daybreak Community

With an area covering over 4,800 acres (19.55 km²) in the western part of South Jordan, Daybreak is the largest master planned community (MPC) in Utah, and ranks among the top 20 selling MPCs in the nation (Burns, 2017).

Construction for Daybreak began in 2004, and as of today, the community is approximately 35% developed with over 4,200, mostly residential, units. By the time Daybreak is expected to be completed around the year 2025, it will eventually house an estimated 20,000 residential units as well as offer about 850,000 m² of commercial and retail space (Daybreak, 2015)

3.1.2 Climate

South Jordan experiences a very hot and dry summer climate. According to historic weather data for Salt lake City (Figure 3), located 32km north-east of South Jordan, the average high temperature over the last six years for the area ranges between

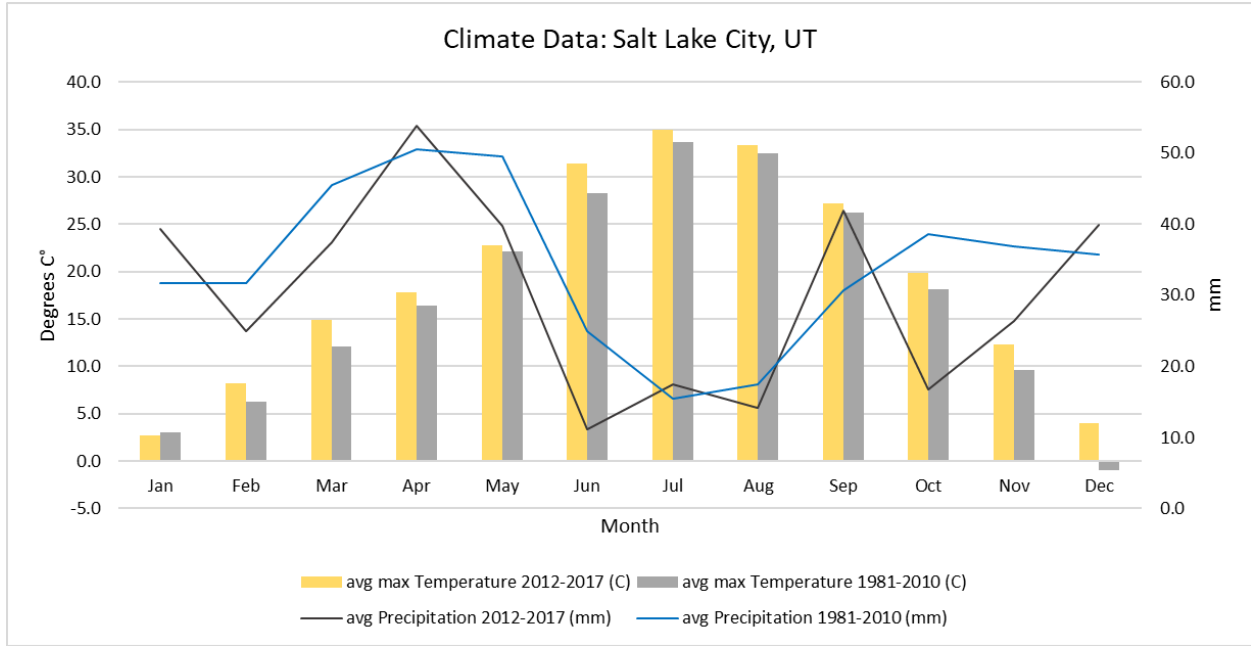


Figure 3: Average climate data for Salt Lake City, UT. Data obtained from “National Oceanic and Atmospheric Administration (NOAA)”. Retrieved March 28th, 2018, from <https://www.wrh.noaa.gov/slc/localtab.php>

31.4 °C (88.5°F) in June, 34.9 °C (94.9°F) in July, and 33.3 °C (92°F) in August, with July being the hottest month of the year. The mean summer precipitation for the same time span ranges between 11.1 mm (0.44 in) and 17.4 mm (0.69in) ((NOAA), 2018).

3.2 Data sets and sources

The data for this project was obtained from South Jordan’s GIS and utility billing department, private entities, as well as publicly available sources (Table 1). The following table shows a detailed compilation of the gathered information:

Table 1: Obtained and collected data

Description	Type	Source
2017 aerial image	Raster file	South Jordan City - GIS
<i>Resolution:</i> 7.62 cm (3 in) per pixel		
<i>Bands:</i> 3 bands, Red Green Blue (RGB)		

<p><i>Date taken:</i> March 2017</p> <p><i>Projected Coordinate System:</i> NAD 1983 StatePlane Utah Central FIPS 4302 Feet</p> <p><i>Datum:</i> D North American 1983</p>		
<p>2016 aerial image</p> <p><i>Resolution:</i> 15.24 cm (6 in) per pixel</p> <p><i>Bands:</i> 3 bands, Red Green Blue (RGB)</p> <p><i>Date taken:</i> October 2016</p> <p><i>Projected Coordinate System:</i> NAD 1983 StatePlane Utah Central FIPS 4302 Feet</p> <p><i>Datum:</i> D North American 1983</p>	Raster file	South Jordan City - GIS
<p>2016 NRG NAIP (National Agricultural Imagery Program) aerial image</p> <p><i>Resolution:</i> 1m per pixel</p> <p><i>Bands:</i> 3 bands, Near Infrared Red Green (NRG)</p> <p><i>Date taken:</i> July 2016</p> <p><i>Coordinate System:</i> WGS 1984 Web Mercator Auxiliary Sphere</p> <p><i>Datum:</i> D WGS 1984</p>	Image Service	Utah AGRC (Automated Geographic Reference Center)
<p>South Jordan City Boundary</p> <p><i>Geometry Type:</i> Polygon</p> <p><i>Projected Coordinate System:</i> NAD 1983 StatePlane Utah Central FIPS 4302 Feet</p>	Shapefile/Feature Class	South Jordan City - GIS
<p>Daybreak Boundary</p> <p><i>Geometry Type:</i> Polygon</p> <p><i>Projected Coordinate System:</i> NAD 1983 StatePlane Utah Central FIPS 4302 Feet</p>	Shapefile/Feature Class	South Jordan City - GIS
<p>Parcel Data</p> <p><i>Geometry Type:</i> Polygon</p> <p><i>Projected Coordinate System:</i> NAD 1983 StatePlane Utah Central FIPS 4302 Feet</p> <p><i>Includes:</i> Parcel ID, address, area (acres & square feet)</p>	Shapefile/Feature Class	South Jordan City - GIS

<p>South Jordan City Zoning Data</p> <p><i>Geometry Type:</i> Polygon</p> <p><i>Projected Coordinate System:</i> NAD 1983 StatePlane Utah Central FIPS 4302 Feet</p> <p><i>Includes:</i> Zone ID, Zone Description</p>	Shapefile/Feature Class	South Jordan City - GIS
<p>2016 Water Meter Data (culinary water only)</p> <p><i>Includes:</i> meter type (residential, landscape), meter account, customer billing address, monthly consumption data in thousand gallon increments</p>	Excel file (xlsx)	South Jordan City – Utility Billing
<p>Building Footprints</p> <p><i>Geometry Type:</i> Polygon</p> <p><i>Projected Coordinate System:</i> NAD 1983 StatePlane Utah Central FIPS 4302 Feet</p> <p><i>Includes:</i> citywide building footprints, building type, tax identification number (Parcel ID)</p>	Shapefile/Feature Class	South Jordan City - GIS
<p>South Jordan City Composite Address Locator</p> <p><i>Projected Coordinate System:</i> NAD 1983 StatePlane Utah Central FIPS 4302 Feet</p> <p><i>Composed of:</i> Address points, street centerlines (Street Name), street centerlines (Alias Name)</p>	Address Locator	South Jordan City - GIS
<p>Daybreak Areas irrigated with Secondary Water 2016</p> <p><i>Includes:</i> 2016 consumption data and rough outline of areas within Daybreak irrigated with secondary water only</p>	Print-out, PDF	Daybreak Water Company (DWC)

3.3 GIS processes

Several steps were employed in this study to address the research objectives and answer the proposed research questions. All of the following steps and non-statistical methods were conducted using ESRI’s ArcMap software version 10.5.

3.3.1 Data preparation

This section describes the necessary steps to obtain the relevant data for this study that results in two separate datasets: the first contains the geocoded meters with assigned parcel identification numbers (*geocoded Meters with parcel_ID*), and the second one all citywide building footprints including monthly water consumption rates (*Building Footprints incl. consumption rates*).

With the help of the city-wide address locator, the meter data obtained from South Jordan's Utility billing department are geocoded based on the included billing address and then assigned the parcel identification number (parcel_ID) of the corresponding parcel (output *geocoded Meters with parcel_ID*). Due to the fact that the composite address locator contains address points in addition to centerlines, the geocoded (residential) meters are placed on the parcel centroid, which ensures that the meters will be assigned the correct parcel_ID number (Figure 4Error! Reference source not found.).



Figure 4: Geocoded residential water meters

Landscape meters (*type = 'Landscape'*), if they cannot be assigned to a specific parcel, will be placed along the street centerline. Figure 5 illustrates the successful geocoding of 19,489 residential and landscape meters.

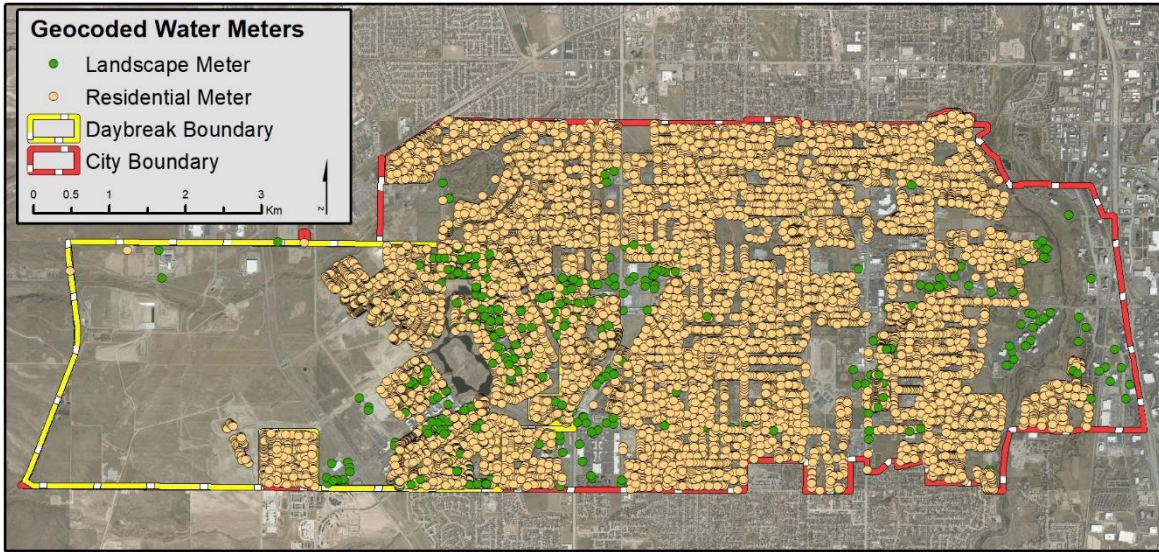


Figure 5: Geocoding results of 19,489 residential and landscape meters

Since the building footprints already contain the parcel_ID of the lot they are located in, the meters can simply be joined to the building footprints based on the parcel_ID, which results in the second output dataset (**Building Footprints incl. consumption rates**).

The flowchart depicted in Figure 6 outlines the described processes.

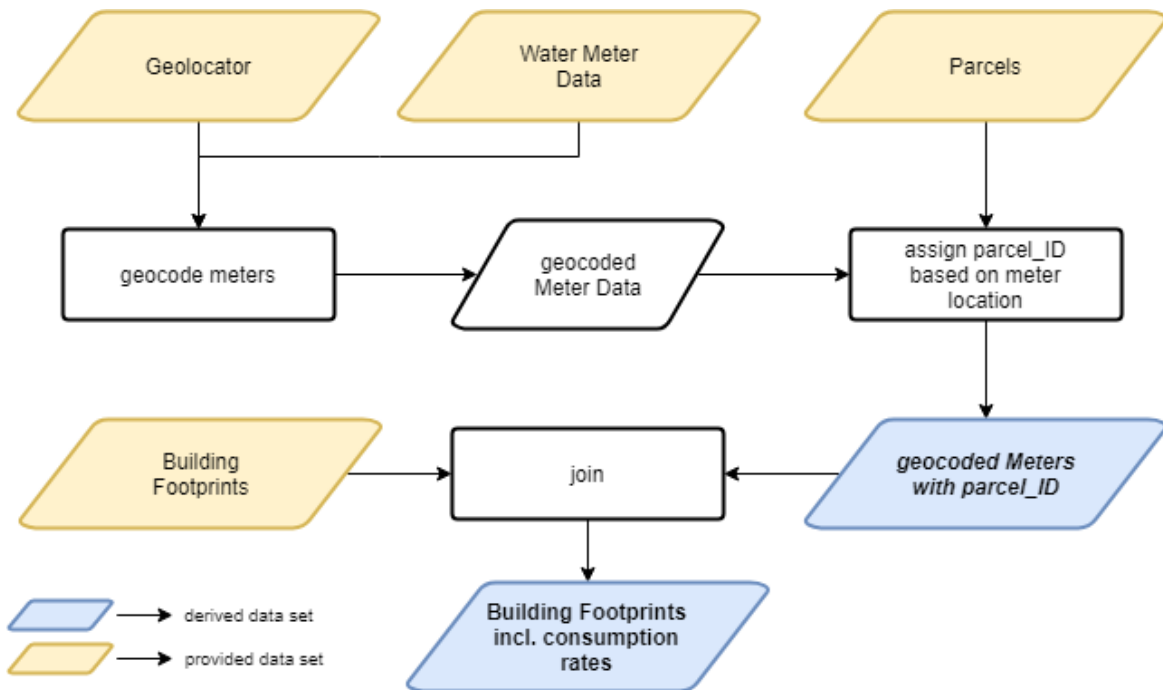


Figure 6: Geocoding meter data and assigning/joining parcel_ID and building footprints

3.3.2 Irrigated public areas

Because the Daybreak community is only about 35% developed at this time, the exact extent of the area within Daybreak used for the upcoming calculations needs to be determined based on the 2017 aerial image, as well as by taking the residential consumption rates into account, to make sure that only developed and inhabited areas are included. This is important for future calculations when the irrigation consumption for a fully developed Daybreak community will be estimated.

The next step requires the identification and manual digitization and classification of all non-residential open spaces, as well as all existing park strips in the area, which is accomplished with the help of the 2017 aerial image, the false color composite 2016 NAIP image, as well as the areas irrigated with secondary water obtained from the Daybreak Water Company (DWC). The DWC oversees Daybreak's secondary water system, which includes public and open area irrigation purposes. Figure 7 shows an extract of the initial DWC map with coarsely outlined extents irrigated with secondary water. The end result of the digitization process is depicted in Figure 8 and demonstrates a great level of details regarding classification as well as extent, where trails as well other non-irrigated areas are omitted from the irrigated areas.

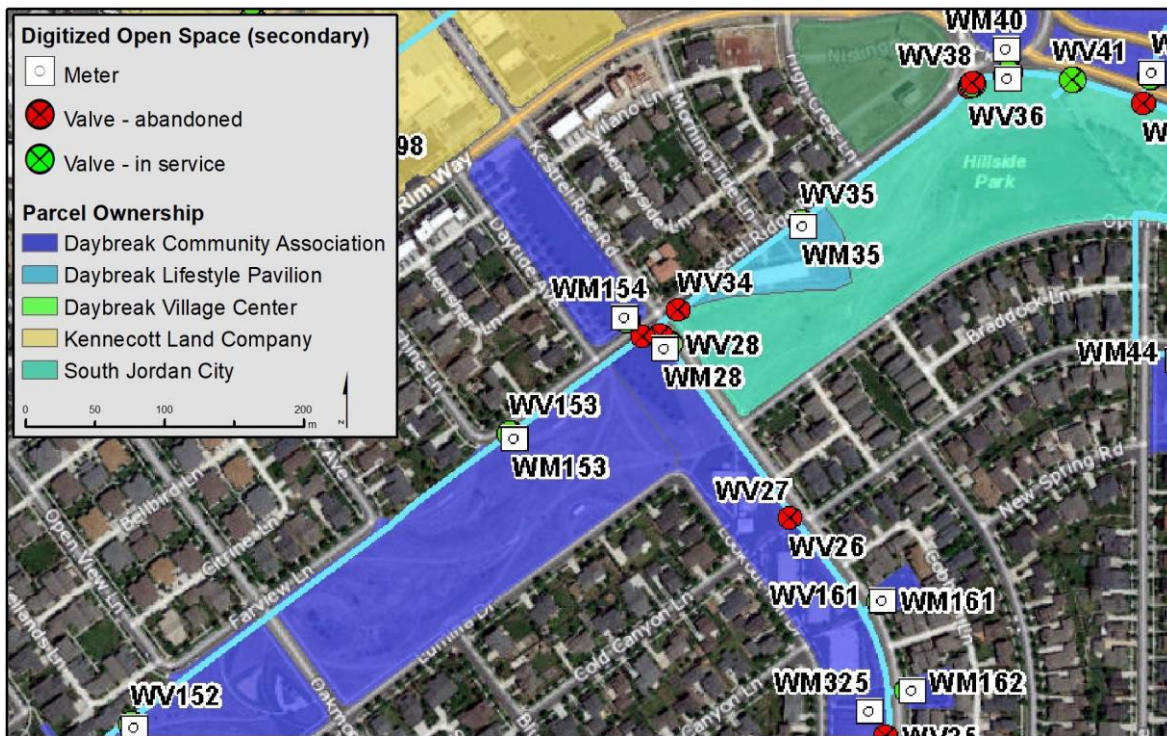


Figure 7: Extract of the map obtained from the DWC showing areas irrigated with secondary water



Figure 8: Manually digitized areas irrigated with secondary water based on the provided DWC map

The identified land covers for all public open spaces are classified as turf, mulch, and ungrouted grass, and can be clearly distinguished on the 2017 aerial image as well as on the false color composite 2016 NAIP image (Figure 9 and 10).



Figure 9: Classification of irrigated areas – 2017 RGB image

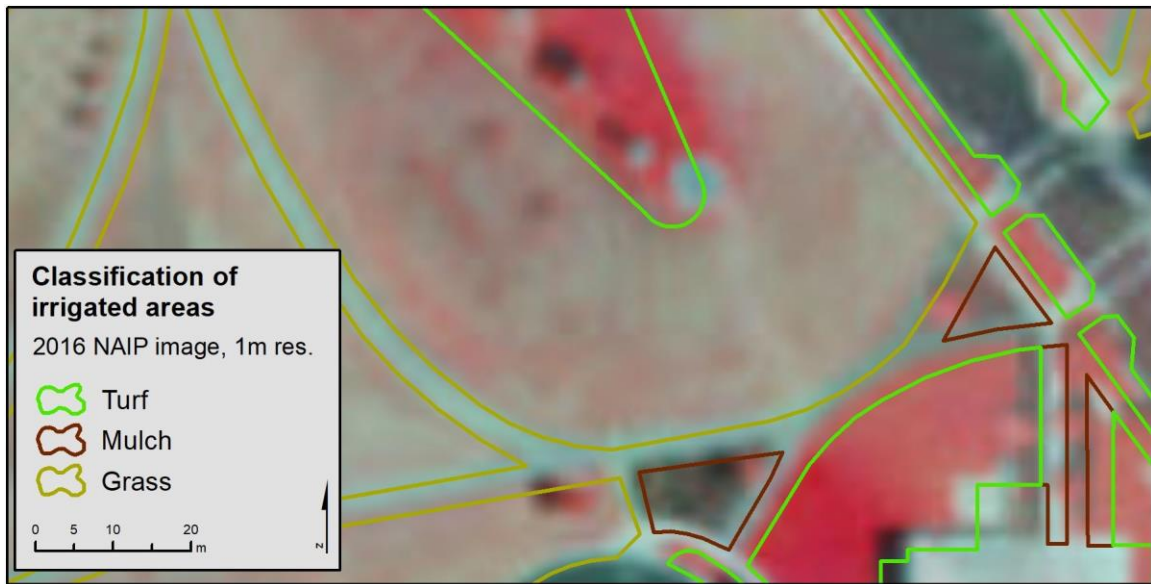


Figure 10: Classification of irrigated areas - 2016 NRG NAIP image

Even though other studies, such as Halper et al., (2015) use normalized difference vegetation index (NDVI) values to automatically identify and classify irrigated and non-irrigated areas and determine their extent, a manual digitization and classification based on visual inspections can be considered more appropriate in this study for several reasons. A manual digitization was determined to be feasible for the extent of the study area, which provides better accuracy in terms of area and classification. Park strips in Daybreak, for example, have a narrow width which ranges on average from 1.2m – 2m (4 - 6.5 ft), making them difficult to distinguish on the 1m NAIP image. Furthermore, since the false color composite image was taken in July, all trees located on the park strips have full leaf covered canopies that spread far beyond the boundary of the park strip, which would significantly distort the extent of the irrigated area. A manual digitization will eliminate this problem, since the outline and extent of the park strips is clearly visible on the high-resolution aerial image taken in March 2017. Figure 11 and 12 demonstrate the difference between the 3-inch per pixel resolution imagery obtained from South Jordan City and the 1-meter resolution NRG false color composite NAIP imagery. Both figures show the same park strips at an identical extent. Park strips are almost impossible to identify, and tree canopies extent noticeably past the park strip boundary into the street on the NRG image, while they are clearly identifiable on the 3-inch resolution aerial image (Figure 11).



Figure 11: Park strip land cover digitization and classification - 2017 aerial image, 3 inch per pixel resolution

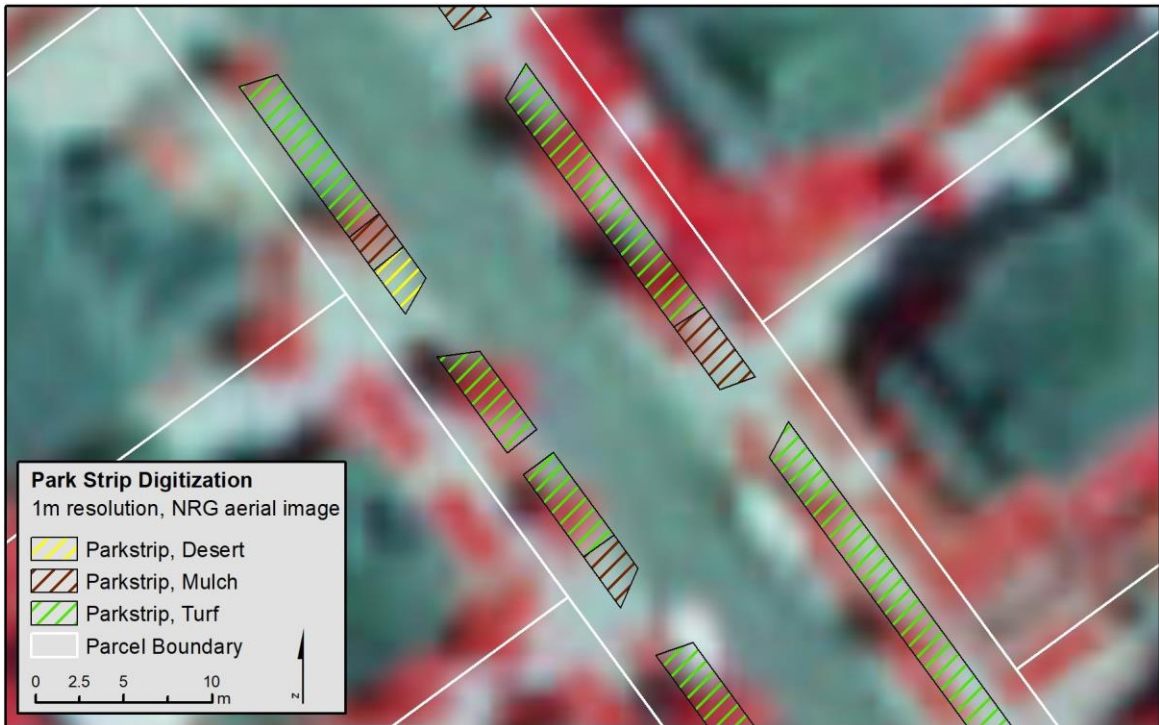


Figure 12: Park strip land cover digitization and classification - False color NRG image, 1m per pixel resolution

The monthly water consumption from the geocoded meters (subset landscape meters, type = 'Landscape') is then assigned to the digitized features based on their location, which allows us to determine whether an area is irrigated with culinary or secondary water, since all provided meter data from the city's utility billing department are for culinary water only. If an area cannot be assigned to a landscape meter listed in the meter data, it can be safely assumed that it is irrigated with secondary water. These areas will be compared to the information provided by DWC and assigned the corresponding consumption rates. For both types of areas, the usage rate for a specific area is calculated by normalizing its yearly consumption by its irrigated extent in square meter, which will result in average yearly consumption per square meter.

The resulting datasets, Irrigated Areas culinary (non-residential) with consumption rates as well as Irrigated Areas secondary (non-residential) with consumption rates, will provide an answer to research objective (1) *To map the different types of existing public irrigated areas and estimate their water consumption rates within the Daybreak community.*

Research objective (4) *To calculate the daily culinary water consumption within the community caused by temporary secondary water shut-offs* will be addressed by summing up the usage rates of all public areas irrigated with secondary water, dividing this value by the number of irrigation days, and applying a monthly factor to the resulting daily average. The monthly factor is necessary because it compensates for the significant irrigation volume changes during the season. Irrigation typically peaks during the driest and hottest months of the year, which are July and August. Since no monthly irrigation usage data for secondary water are available, the monthly factor will be calculated based on the consumption patterns for open space areas irrigated with culinary water. The result is an average secondary water consumption value within the area per day, which can be applied to calculate daily culinary water usage in case the water source is switched from secondary to culinary water.

Figure 13 outlines the processes explained in this section.

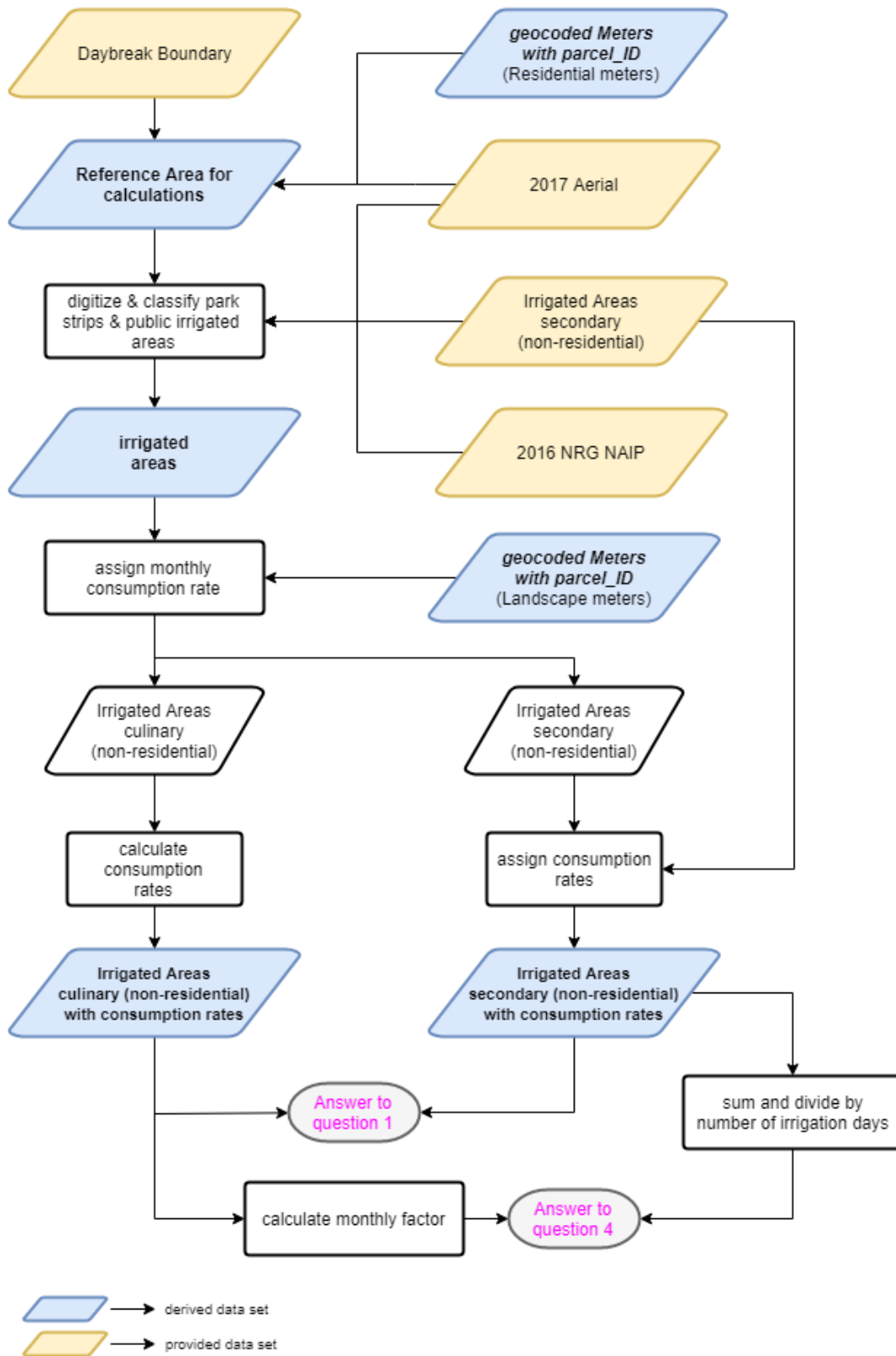


Figure 13: Identifying extent, type, and consumption rates for existing, non-residential open space areas and determining daily culinary water consumption caused by temporary secondary water shut-offs.

3.3.3 Park strip consumption and conservation potential

The procedures and methods used to address research objective (2) *To assess if the park strip area for an existing residential unit has a statistically significant impact on the unit's average water consumption, and to evaluate the water conservation potential for park strips within the community* are described in this section.

First, a random sample of 100 units within Daybreak, and 100 units outside of Daybreak, will be created from the ***Building Footprints in zones w. consumption rates*** dataset. The irrigated areas of each individual sample will then be manually digitized, visually classified assisted by ground truth data and linked to the building footprints, which results in 200 sample SFR units with detailed irrigated area types and extents, as well as irrigation usage and consumption rates. As it is the case with park strips, manual digitization is indispensable given the available data, because it delivers highly accurate results regarding irrigated area extents compared to an automatic classification based on the NRG false color composite aerial image. Figure 14 shows the results of manually digitizing and classifying irrigated areas for one of the selected samples based on the 2017 3-inch resolution aerial image. In comparison, Figure 15 displays the digitized areas projected on the 1-meter resolution NRG aerial image and demonstrates the necessity of manual digitization for this project.



Figure 14: manual digitization and ground cover classification of irrigated areas for a selected sample lot based on 3in resolution aerial image

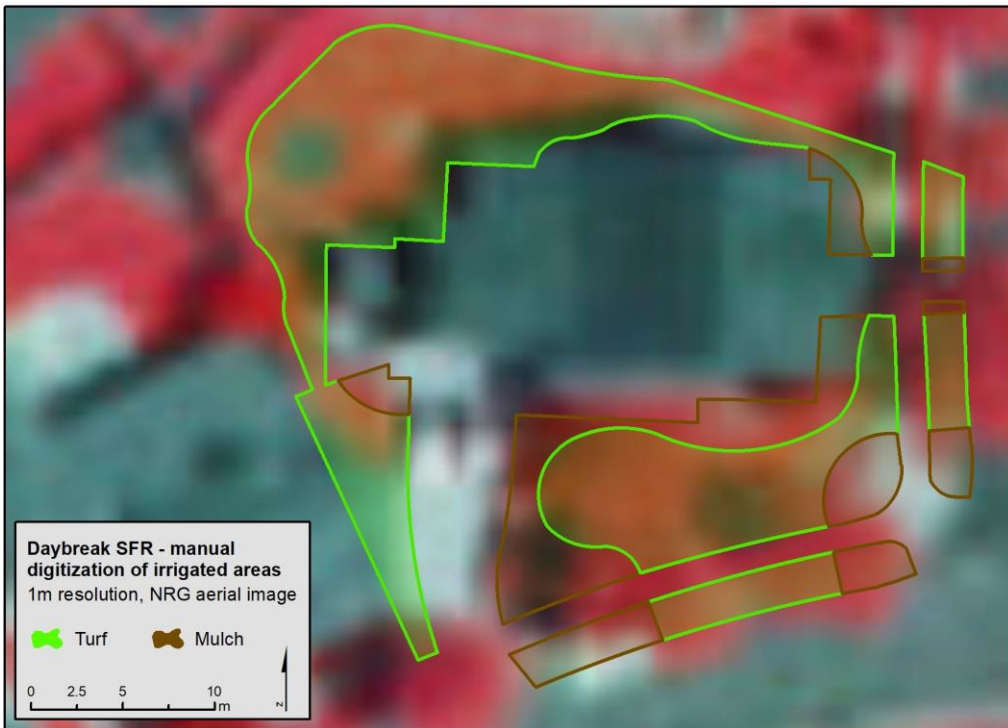


Figure 15: Sample lot with 1m resolution NRG aerial image

The park strip percentage is then calculated for all 200 samples and is used for the following statistical analysis in combination with the total annual irrigation consumption of the individual sample. A simple linear regression analysis, with park strip percentage being the independent variable and annual irrigation consumption per square meter the dependent variable, will be used to determine if larger areas of park strips will lead to an increase in overall irrigation usage. The regression analysis is chosen over a correlation analysis, because an assumption of causality between the two variables can be made. This process is shown in Figure 16.

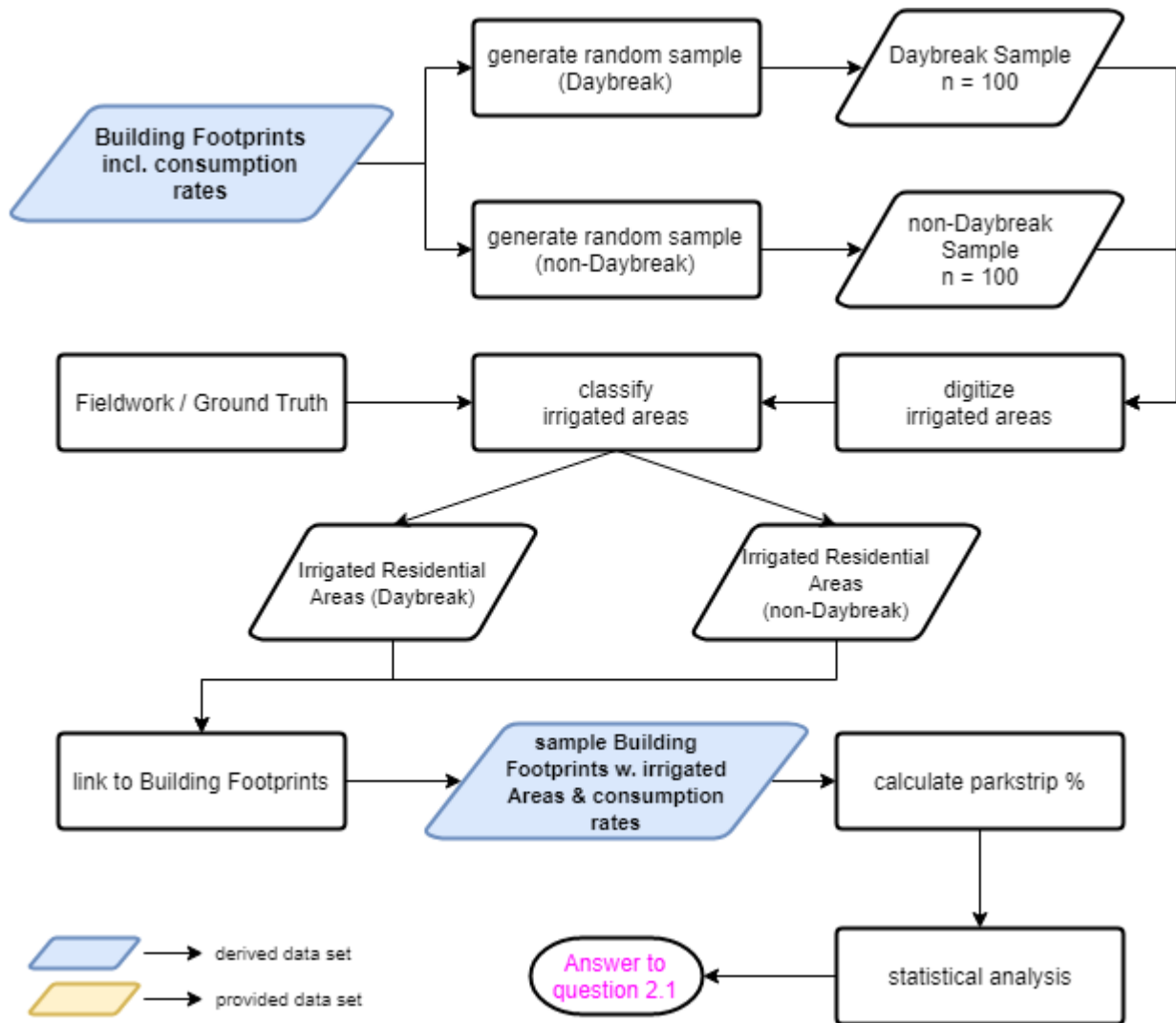


Figure 16: Evaluating park strip impacts

As far as the conservation potential for park strips concerns, the rules regarding landscape design established by the Daybreak Home Owner Association (HOA) are very restrictive and prohibit artificial turf or a complete replacement of turf with impermeable material. The admissible water

saving conservation measures that can be applied directly to park strips are limited to redesigning turfed areas into xeriscaping. Xeriscaping is typically defined as water-efficient landscaping that minimizes the need for supplemental irrigation by planting native and drought-resistant plants, replacing turf with mulch or gravel, and changing the irrigation for the affected areas to a drip line irrigation system.

The process to estimate the park strip water conservation potential requires extracting all residential and public park strips irrigated with culinary water (Figure 17) from the previously digitized irrigated areas and assigning the corresponding irrigation water usage rates obtained from preceding calculations.

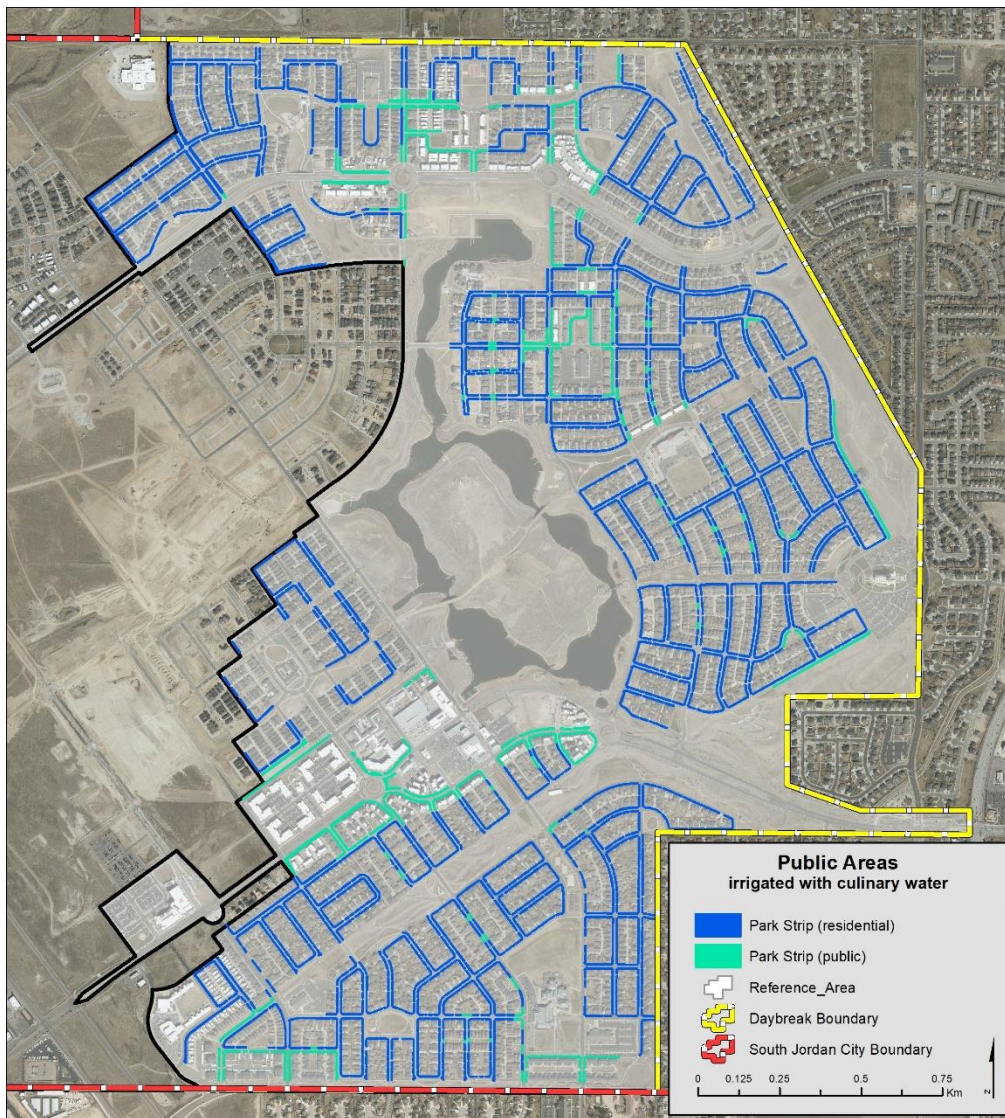


Figure 17: Public and residential park strips within the reference area

Possible water usage savings can be estimated by applying results from recognized studies. Existing studies regarding xeriscaping and the resulting water saving potential were conducted by Sovocool and Morgan, (2005), or Gleick et al., (2003), and their findings will be applied to all digitized residential and public park strip areas located within Daybreak, in order to evaluate how much culinary water can theoretically be conserved based on the used method (Figure 18).

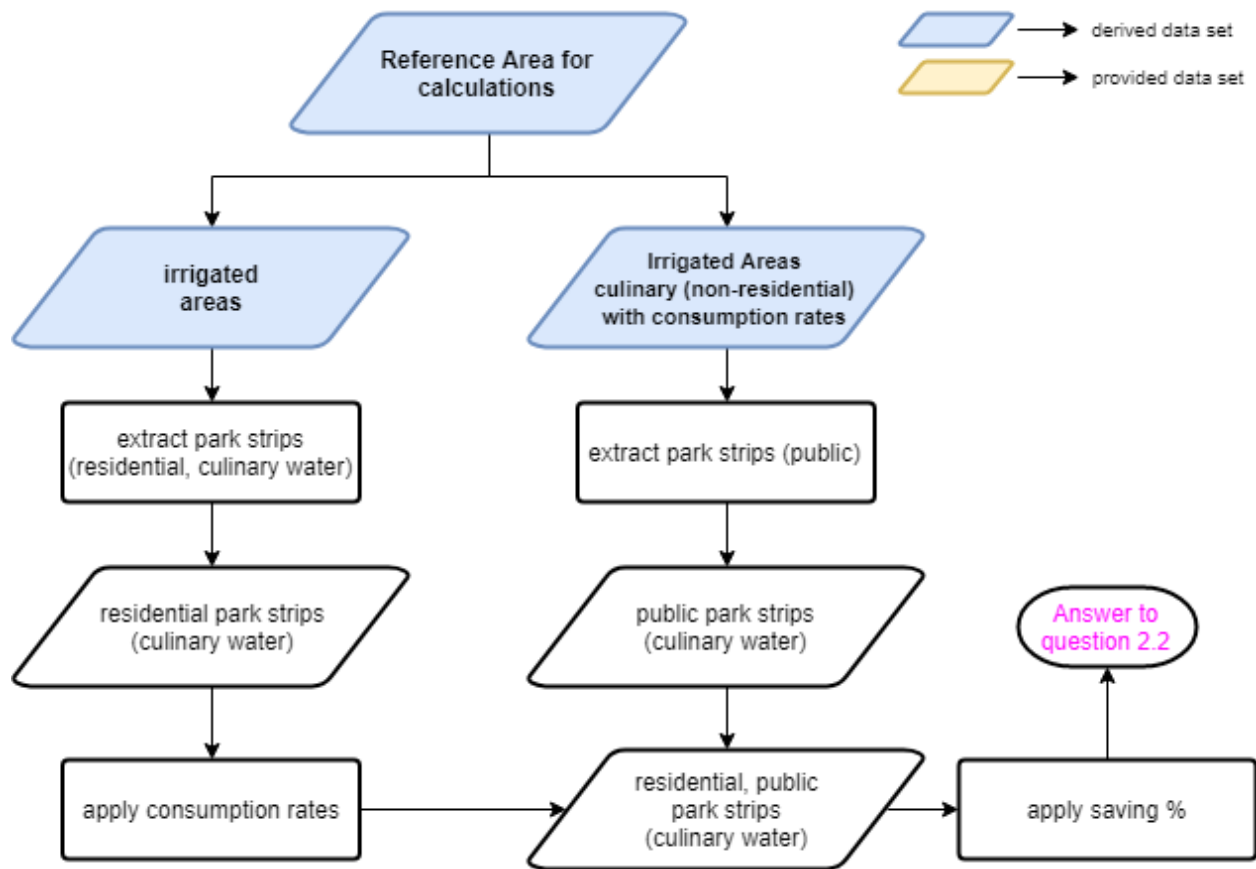


Figure 18: Calculating culinary water conservation potential for park strip irrigation

3.3.4 Single-Family Residence irrigation water usage

Research question (3) *To assess if residential units in Daybreak have a significantly higher average irrigation water usage compared to residential units in South Jordan located outside of Daybreak* requires comparing the average irrigation consumption rates per square foot for single-family residences (SFR) located within Daybreak to those located outside of Daybreak.

First, a sub selection of all citywide SFRs (type='Residential' AND subtype='Dwelling') will be created out of the *Building Footprints incl. consumption rates*, that only contain units with a monthly water consumption greater than 0, which ensures that buildings that were uninhabited during a given month (water usage = 0) are excluded from the sample population. In addition to that, the units have to be located within Daybreak or within the residential zones R-3 – R-5 (3-5 lots per acre), R-M (multi dwelling), RM-4 – RM-8 (multi dwellings, 4-8 lots per acre), BH-MU (Bangerter Highway, Mixed Use), and M-U Historic (Mixed Use - Historic) outside of Daybreak. This selection ensures that units with similar lot sizes and outdoor areas are being compared to each other, since these factors have been identified to significantly affect irrigation water consumption (Chang et al., 2010). Furthermore, units outside of Daybreak cannot be located within a weir zone, which indicates that these SFRs have access to secondary water for irrigation purposes, which would distort the average consumption of culinary water used for irrigation (Figure 19).

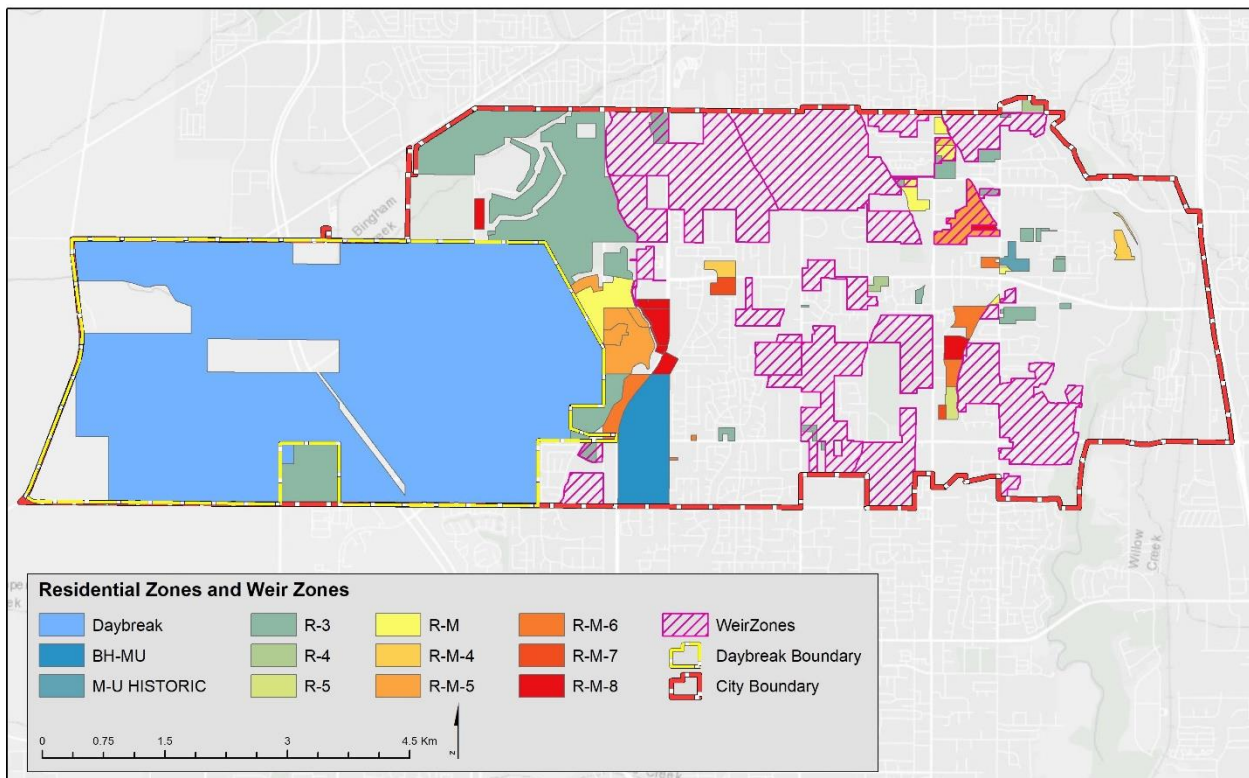


Figure 19: Admissible residential SFR zones and weir zones

The largest residential lot within Daybreak has a size of 0.46 acres (1,861.55 m²), and because

several SFR lots outside of Daybreak still occupy areas larger than one acre (4,046.86 m²) despite being located in a zone that describes much smaller lots, they have to be labeled as outliers and removed from the selection in order to not skew the analysis results. The reason for the exclusion of these outlier lots is because the size of an irrigated area can directly influence the amount of water used per unit of irrigated area. A study conducted by Maheshwari, (2016), for example, found that the amount of water used per area unit was up to four times lower on larger areas (150-200 m²) compared to small areas (<50 m²).

Based on the minimum use month and average minimum month method developed by Gleick et al., (2003), the indoor and outdoor consumption for the selected units is calculated. The minimum use method selects the month with the lowest water use as the baseline, or indoor use, whereas the average minimum month method calculates the indoor use by averaging the three lowest months, usually December, January, and February. The outdoor use is obtained by calculating the difference between each of the summer months and the indoor use. The underlying assumption for these methods is that the indoor use stays relatively constant during the year, which was confirmed by DeOreo et al., (2011). Even though other studies came to the conclusion that the minimum and average minimum methods tend to underestimate outdoor use and overestimates indoor use in warm, arid climates, mainly due to the fact that some irrigation occurs during the winter months, they are the most appropriate methods for this study. The reason for this is because northern Utah experiences very cold winters, and irrigation is extremely unlikely to occur from December through March. Therefore, the lowest use month or the average of the lowest three months, respectively, can be confidently considered as the residential indoor use in South Jordan.

As a final step, statistical analyses will find an answer to question 2 and determine if the total annual irrigation for SFR units within Daybreak is significantly different compared to units outside of Daybreak with similar lot sizes. The statistical tests conducted on the data will include a One-Sample *t* Test on the consumption values of all Daybreak SFRs with respect to the mean of the data selection, as well as a Two-Sample *t* Test that evaluates whether the Daybreak and non-Daybreak irrigation values both have means that come from the same distribution of mean values.

The processes described in this section are outlined in Figure 20.

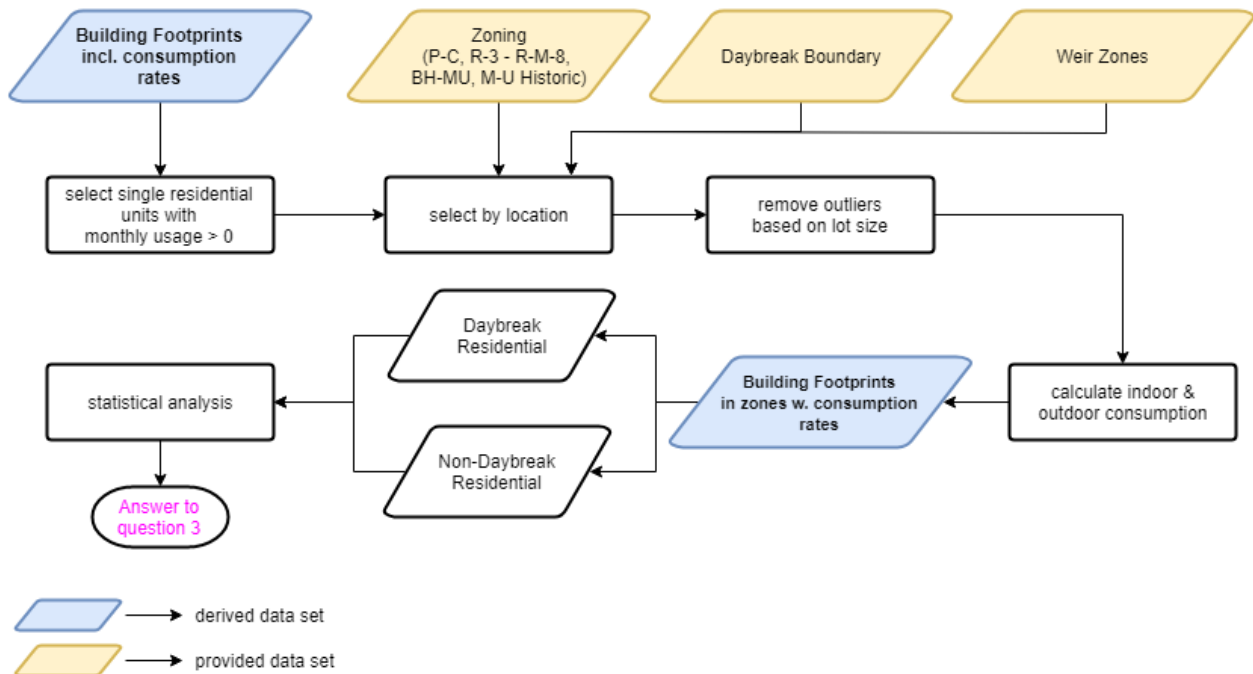


Figure 20: Calculating and comparing irrigation usage for residential homes

3.3.5 Future residential and open space irrigation volume

In order to estimate how much water Daybreak will consume for single-family residential and open space irrigation purposes once completed around the year 2025, and in doing so addressing objective (5) *To estimate future residential and open space irrigation volume once Daybreak is completed in 2025*, the total irrigation volumes obtained from previous calculations need to be summed and extrapolated to the entire Daybreak area.

First, the annual irrigation consumption for all single-family residential buildings within the reference area that exhibit a monthly water consumption value greater than zero for all 12 months is calculated to obtain an irrigation volume average that can then be applied to all residential units in the reference area. This step is necessary since units unoccupied for more than one month (monthly water consumption = 0) would significantly distort the actual irrigation usage. The annual consumption for all residential units can then be summed up, and, along with the previously calculated usage for non-residential open spaces using culinary or secondary water for irrigation, added to the total irrigation volume within the reference area. Since the reference area only covers a fraction of the entire Daybreak neighborhood (Figure 21), the

obtained values need to be multiplied by a determined factor, so they can be imposed on the entire Daybreak area

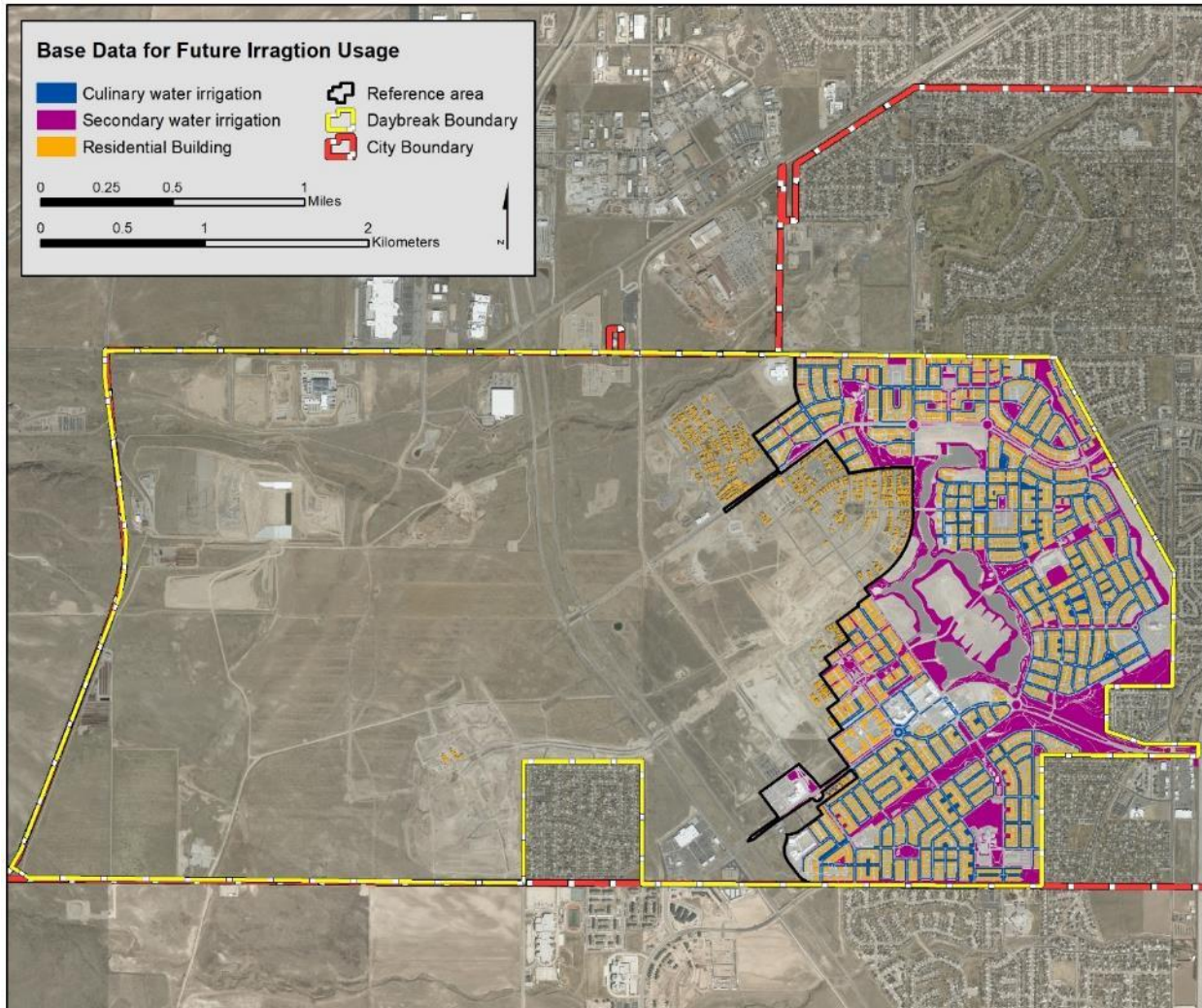


Figure 21: Base data for future irrigation usage once Daybreak is completed

Based on the multiplication results, the annual SFR residential and open space irrigation consumption can be estimated once the community is fully developed (Figure 22).

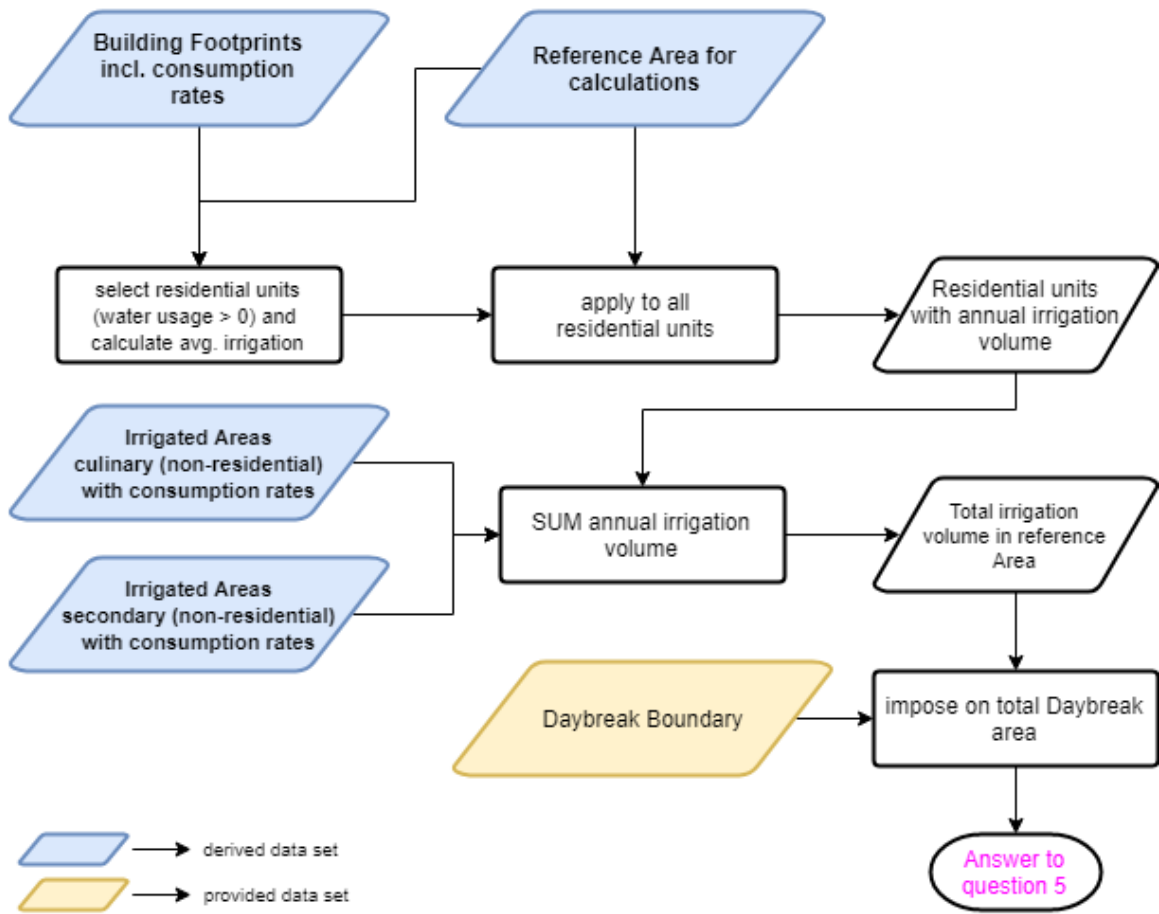


Figure 22: Estimating future Daybreak irrigation usage

4. Results

4.1 Irrigated public areas

4.1.1 Location and extent

To determine the location, extent, and consumption rates of public areas irrigated with culinary or secondary water, a total of 2,537 features within the reference area were identified and digitized based on the 2016 aerial image used along with the data provided by the Daybreak Water Company (DWC). Only areas accessible to the public, such as non-residential park strips, common areas, and open spaces, were included in the dataset, while park strips along store fronts or churches, as well as green spaces surrounding apartment complexes were excluded, since they are considered to be private areas.

Based on these criteria, the total extent of irrigated public areas was 1,028,204.45 m² (11,067,500.61 ft²), with areas irrigated by secondary water covering 949,810.88 m² (10,223,679.26 ft²), and areas irrigated by culinary water covering 78,393.57 m² (843,821.35 ft²). The location of the features is depicted in Figure 23 (culinary water) and Figure 24 (secondary water).

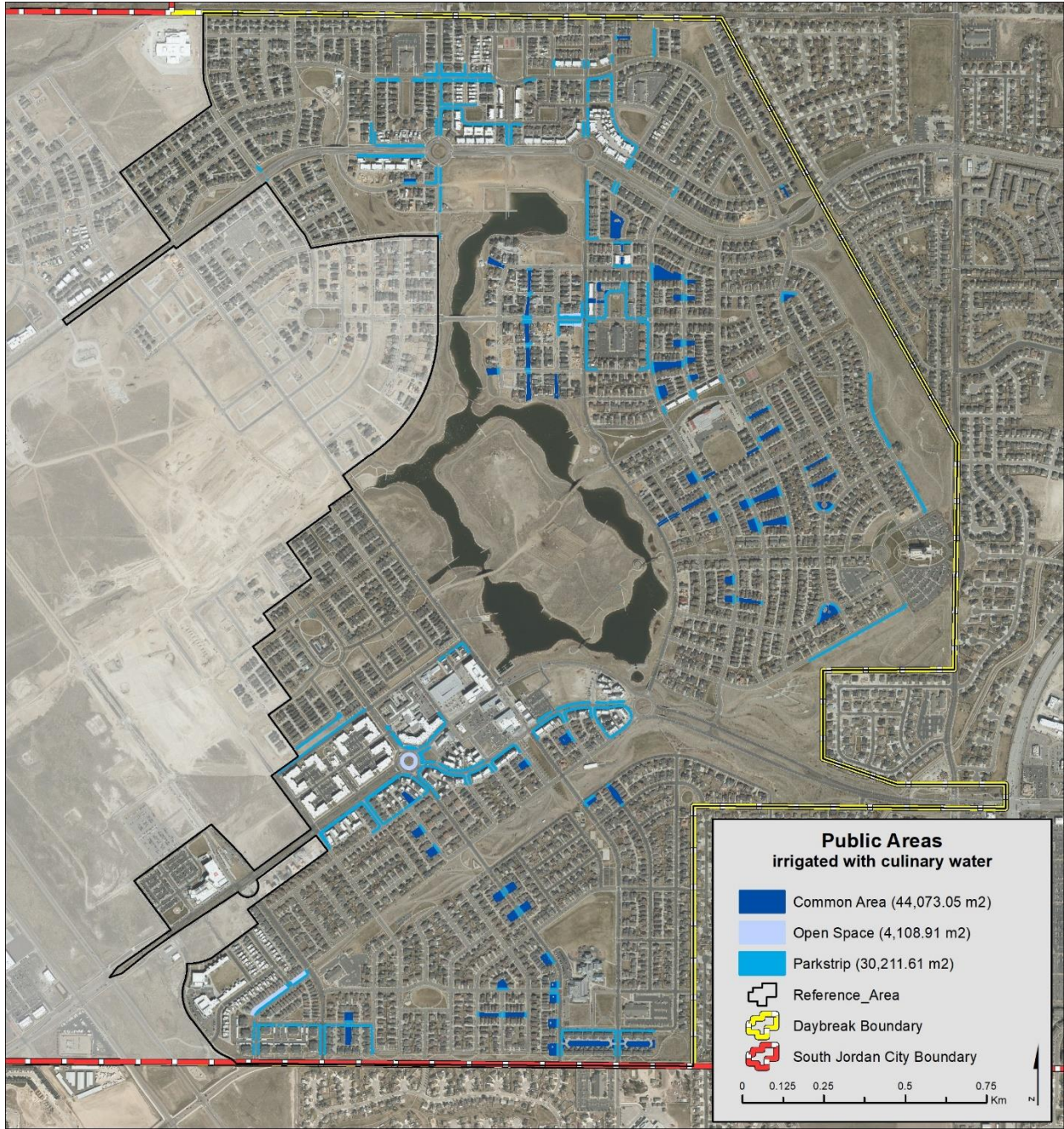


Figure 23: Daybreak - public areas irrigated with culinary water

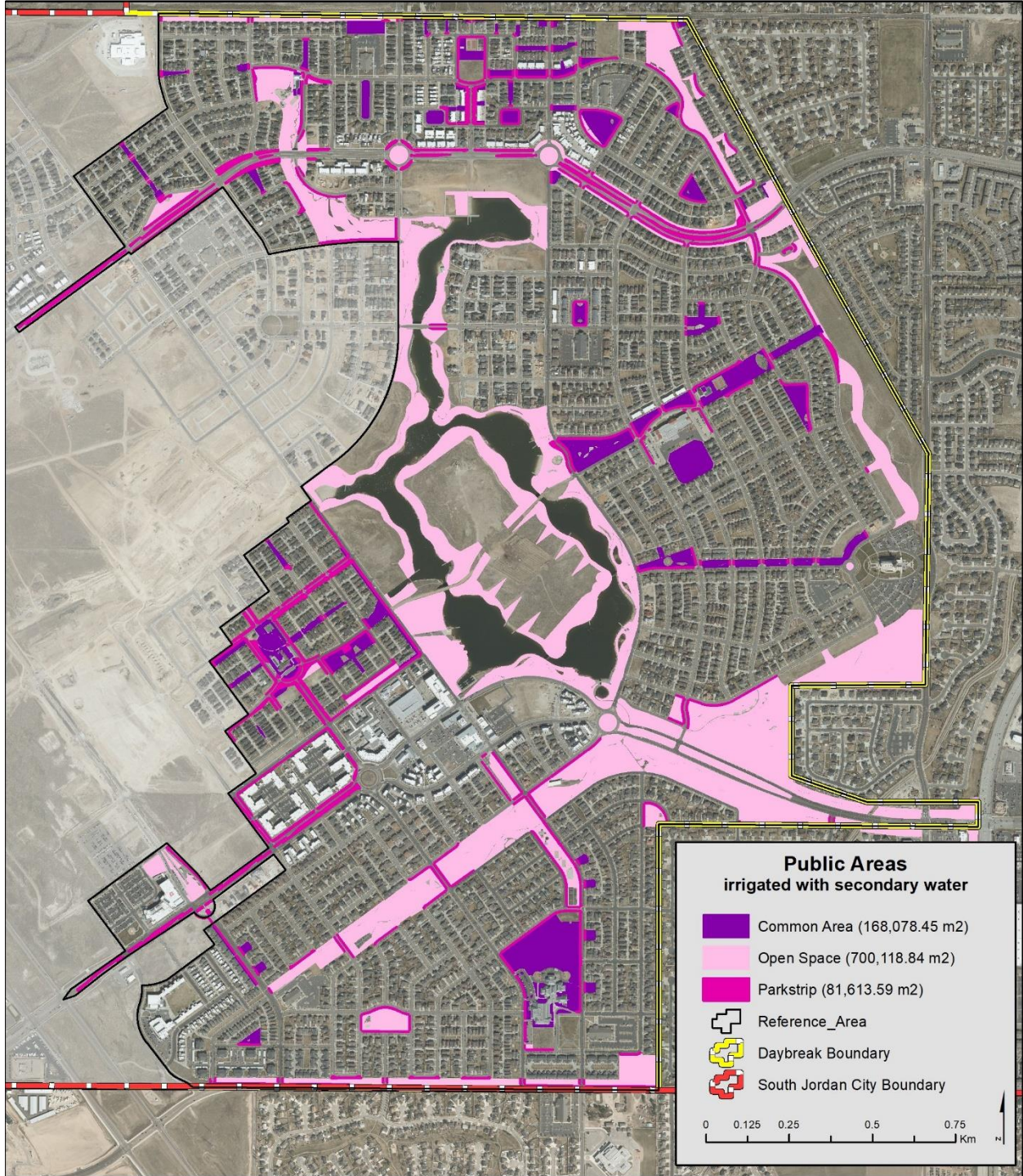


Figure 24: Daybreak - public areas irrigated with secondary water

4.1.2 Consumption rates

4.1.2.1 Culinary Water

In order to calculate the culinary water consumption rates per area unit for the individual features, areas that were identified to be exclusively supplied by a single meter, first needed to be grouped and then assigned the meter's total water consumption as listed in the data obtained from South Jordan's utility billing department. This process resulted in 57 grouped areas extending over 41,253.98 m² (444,054.14 ft²). After calculating the annual water consumption in l/m² and gal/ft² by dividing a grouped area's total usage by its extent, the percentages occupied by the different land covers with respect to a group's total extent were calculated for each grouped area, which provided the independent variable for the following regression analysis. The regression, with l/m² as the dependent variable, was used to determine if land covers other than turf have a significantly lower water usage per area unit, which would mandate a distinction regarding the consumption rates. No outliers or zero values were excluded from the data set, because all observations resemble valid, measured values that cannot be labeled as data errors. In the case of culinary water, mulch was the only identified cover besides turf. The analysis resulted in an F-value of 3.8779 (Table 2) that is lower than the critical value $F_{0.05,1,55}$ of 4.0162, which suggests that no significant relationship exists between the percentage of mulched covered areas and the average water consumption per unit area (Figure 25, Table 2). Consequently, mulched areas were assumed to have the same irrigation usage rates as turfed areas, and no distinction was made between the two land covers.

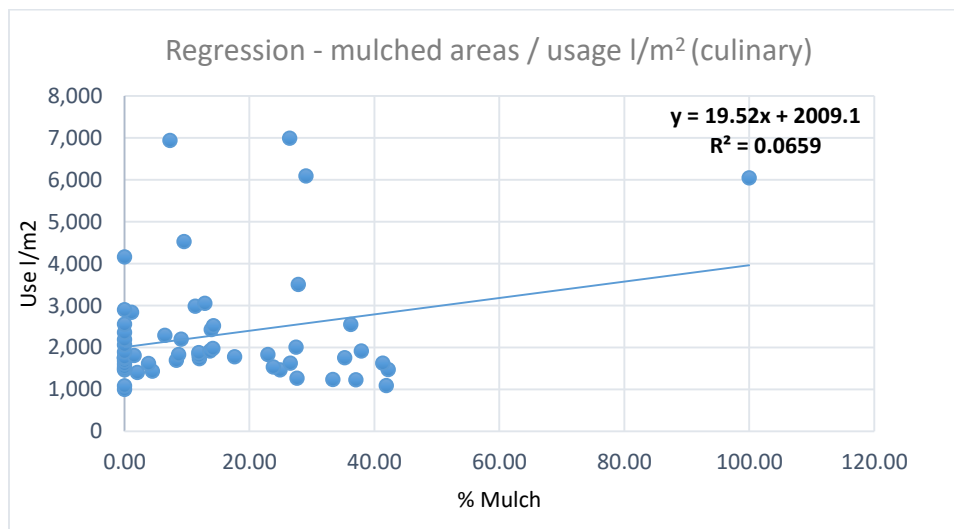


Figure 25: Regression analysis graph - mulched areas / water consumption

Table 2: Regression analysis statistics - mulched areas / water consumption (culinary water)

Regression Statistics		ANOVA					
Multiple R	0.2566388		<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
R Square	0.0658635	Regression	1	6831616.5	6831616.5	3.8779024	0.0539715
Adjusted R Square	0.0488792	Residual	55	96892308	1761678.3		
Standard Error	1327.2823	Total	56	103723924			
Observations	57						

Based on the extent and water consumption data for the 57 grouped areas, the average annual culinary water usage was calculated to be 2.296 m³ (2,295.91 l/m², 56.35 gal/ft²). This usage was then applied to all public areas irrigated with culinary water within the reference area, which resulted in an estimated total annual usage of 179,984 m³ (179,984,282 liters, 47,546,817 gal) (Table 3).

Table 3: Total culinary irrigation water usage for all public areas

Public Irrigated Areas - Culinary Water						
Type	Area m ²	Area ft ²	usage l/m ²	usage gal/ft ²	total usage (m ³)	total usage (gal)
Park Strips	30,211.61	325,195.02	2,295.91	56.35	69,363	18,323,769
Common Area	44,073.05	474,398.39	2,295.91	56.35	101,188	26,730,934
Open Space	4,108.91	44,227.95	2,295.91	56.35	9,434	2,492,113
Culinary total	78,393.57	843,821.36			179,984	47,546,817

4.1.2.2 Secondary Water

A similar approach was used to calculate the consumption rates for areas irrigated with secondary water. Based on the data provided by the Daybreak Water Company (DWC), digitized areas that are exclusively supplied with secondary water by a single meter were identified, grouped, and assigned the total water usage of the corresponding meter, which resulted in 98 areas. The irrigated extent around the lake was tied to 9 separate meters and had to be grouped into a single area with summed up consumption values, because the extent for the individual meters could not be identified. The average consumption rate per area unit was calculated by dividing the total water usage for a grouped area by its extent, and the percentage each land cover occupied within a group was calculated. No outliers were removed from the dataset, and a regression analysis was then conducted to evaluate if a significant correlation exists between different land covers and average water consumption per area unit. For areas irrigated with

secondary water, three different land covers were identified: turf, mulch, and ungrouted grass. While no correlation was found to exist between the percentages of mulched area with respect to the grouped area's total extent (Figure 26, Table 4), a significant correlation was identified between ungrouted grass and average consumption rates (Figure 27, Table 5). The F value of 24.5957 exceeds the critical value $F_{0.05,1,96}$ of 3.94, and with an R^2 value of 0.2040, over 20% of the values fit the model.

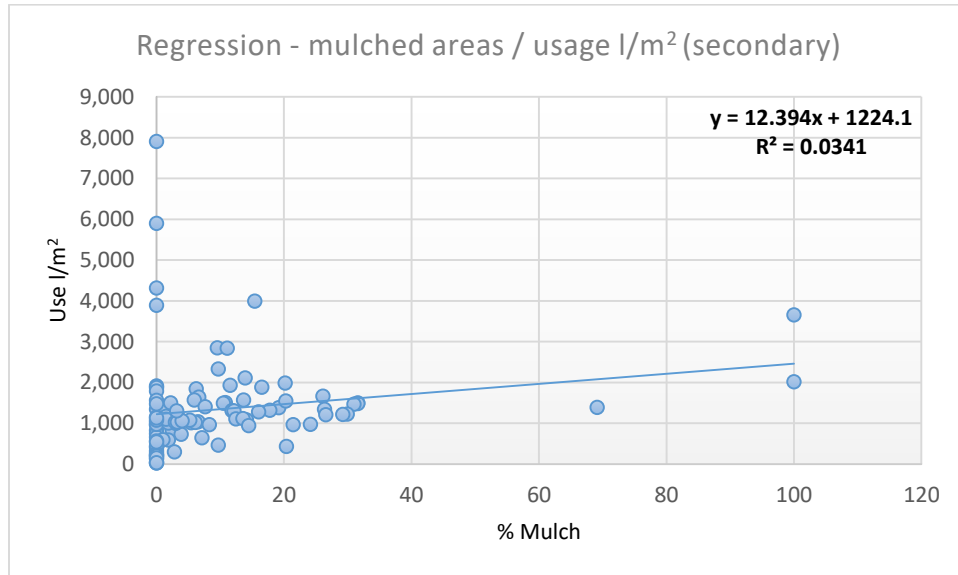


Figure 26: Regression analysis graph - mulched areas / water consumption (secondary)

Table 4: Regression analysis statistics - mulched areas / water consumption (secondary water)

Regression Statistics		ANOVA					
Multiple R	0.1846		<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
R Square	0.0341	Regression	1	4330110.11	4330110.11	3.3853	0.0689
Adjusted R Square	0.0240	Residual	96	122791063	1279073.57		
Standard Error	1130.9613	Total	97	127121173			
Observations	98						

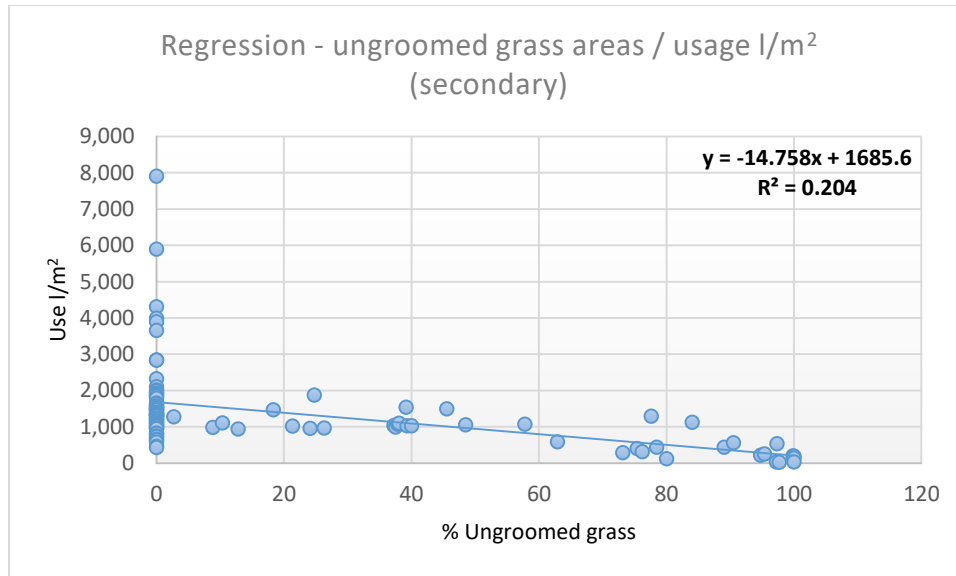


Figure 27: Regression analysis graph - ungroomed grass areas / water consumption (secondary)

Table 5: Regression analysis statistics - ungroomed grass areas / water consumption (secondary)

Regression Statistics		ANOVA					
Multiple R	0.4516		df	SS	MS	F	Significance F
R Square	0.2040	Regression	1	25926592.11	25926592.11	24.5957	0.000003
Adjusted R Square	0.1957	Residual	96	101194581.2	1054110.22		
Standard Error	1026.6987	Total	97	127121173.3			
Observations	98						

According to the results of the statistical analyses, the average water consumption for areas covered with ungroomed grass is found to be significantly different than the usage for turf and mulch covered regions. Therefore, the annual water consumption of four grouped areas with 100% ungroomed grass cover, extending over a total 55,835.16 m² (601,004.61 ft²), were used to calculate the usage per m² for this type of land cover, which resulted in an average consumption value of 0.143 m³ (142.75 l/m², 3.50 gal/ft²) per year. Accordingly, areas covered exclusively with turf or mulch were used to obtain the usage per area unit for non-grass features. For these areas, the average, annual irrigation water consumption was calculated to be 1.714 m³ (1,714.49 l/m², 42.08 gal/ft²). The consumption rates were then applied to all areas irrigated with secondary water, which resulted in a total annual water usage of 804,471 m³ (804,470,545 l, 212,518,639 gal). The total extent and water usage for these areas is listed in Table 6.

Table 6: Total secondary irrigation water usage for all public areas

Public Irrigated Areas - Secondary Water							
Type	Cover	Area m ²	Area ft ²	usage l/m ²	usage gal/ft ²	total usage (m ³)	total usage (gal)
Park Strips	Turf/Mulch	81,613.59	878,481.40	1,714.49	42.08	139,925	36,964,353
Common Area	Grass	5,213.18	56,114.25	142.75	3.50	744	196,587
Common Area	Turf/Mulch	162,865.26	1,753,067.10	1,714.49	42.08	279,230	73,764,786
Open Space	Grass	519,025.54	5,586,744.40	142.75	3.50	74,089	19,572,297
Open Space	Turf/Mulch	181,093.30	1,949,272.10	1,714.49	42.08	310,482	82,020,614
	Total	949,810.87	10,223,679.25			804,471	212,518,639

4.2 Park strip impact

The data obtained from the 200 digitized samples were used to evaluate if the percentage of park strip area with respect to a residential unit's total irrigated area has a statistically significant impact on the its average water consumption.

4.2.1 Average park strip usage

Since park strip area percentage is the independent variable for the following regression analyses, only units with a percentage greater than zero were included in the sample data, resulting in a total of 156 units, of which 99 are located within Daybreak, and 57 outside of Daybreak. The average park strip area for all selected samples was 11.11% of a unit's total irrigated area, with park strips for SFR units within Daybreak occupying almost 2.5 times more area proportionally (14.2%) when compared to non-Daybreak SFRs (5.74%). The average irrigation usage in cubic meters per m² for all 156 selected samples was 1.438 m³ (1,437.88 l/m², 35.29 gal/ft²) (min1) and 1.396 m³ (1,395.61 l/m², 34.25 gal/ft²) (min3). The mean irrigated area extent, park strip percentage, as well as average annual usage rates for minimum use month (min1) and minimum 3-month average (min3) are listed in Table 7.

Table 7: Average irrigation area and usage rates for digitized samples

Daybreak (count 99)		Non-Daybreak (count 57)		All Samples (count 156)	
avg. irrigated area m ²	351.02	avg. irrigated area m ²	430.28	avg. irrigated area m ²	379.98
avg. irrigated area ft ²	3,778.35	avg. irrigated area ft ²	4,631.45	avg. irrigated area ft ²	4,090.06
avg. park strip %	14.20	avg. park strip %	5.74	avg. park strip %	11.11
avg. usage m ³ /m ² (min1)	1.593	avg. usage m ³ /m ² (min1)	1.169	avg. usage m ³ /m ² (min1)	1.438
avg. usage m ³ /m ² (min3)	1.547	avg. usage m ³ /m ² (min3)	1.134	avg. usage m ³ /m ² (min3)	1.396
avg. usage gal/ft ² (min1)	39.09	avg. usage gal/ft ² (min1)	28.69	avg. usage gal/ft ² (min1)	35.29
avg. usage gal/ft ² (min3)	37.96	avg. usage gal/ft ² (min3)	27.82	avg. usage gal/ft ² (min3)	34.25

The regression analyses conducted on the selected samples, with average irrigation usages in liter/m² for the min1 and min3 scenarios being the dependent variables, resulted in an R² value of 0.1971 for the minimum use month (min1) consumption values, and 0.19 for the minimum 3-month average (min3), which indicates that almost 20% of the values fit the model (Figure 28 and 29). In both cases, the resulting F-values of 37.8102 (min1) and 36.1237 (min3) exceed the critical value $F_{0.05,1,154}$ of 3.902 (Table 8 and 9). According to the results, the null hypothesis H₀, stating that the percentage of park strip area with respect to a unit's total irrigated area has no significant impact on the average water consumption, needs to be rejected in favor of H_A, indicating that park strip area does have a significant impact on the average irrigation usage.

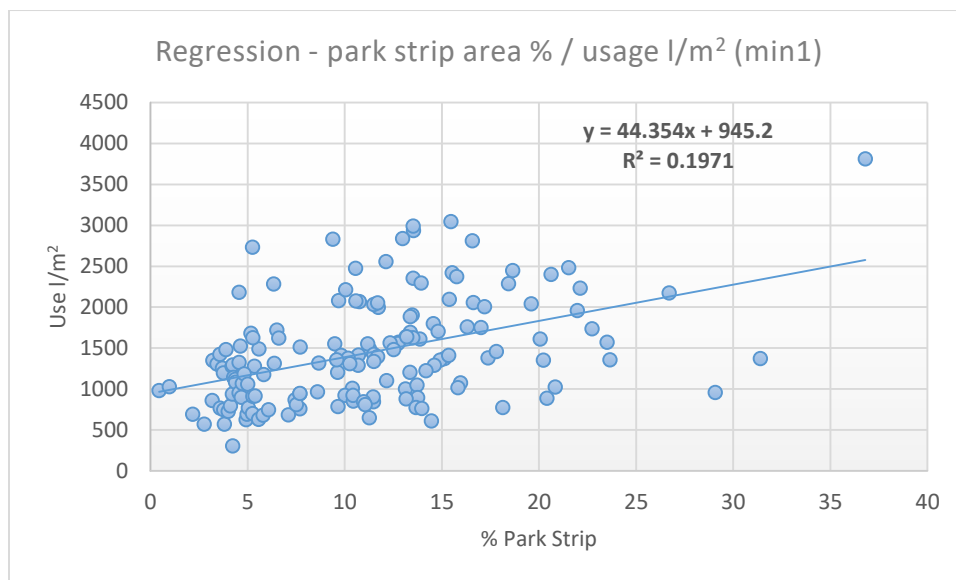


Figure 28: Regression analysis graph - park strip area percentage / water consumption (min1)

Table 8: Regression analysis results - park strip area percentage / water consumption (min1)

Regression Statistics		ANOVA					
			<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Multiple R	0.4440	Regression	1	11974680.57	11974680.57	37.8102	0.0000
R Square	0.1971	Residual	154	48772599.49	316705.1915		
Adjusted R Square	0.1919	Total	155	60747280.06			
Standard Error	562.7657						
Observations	156						

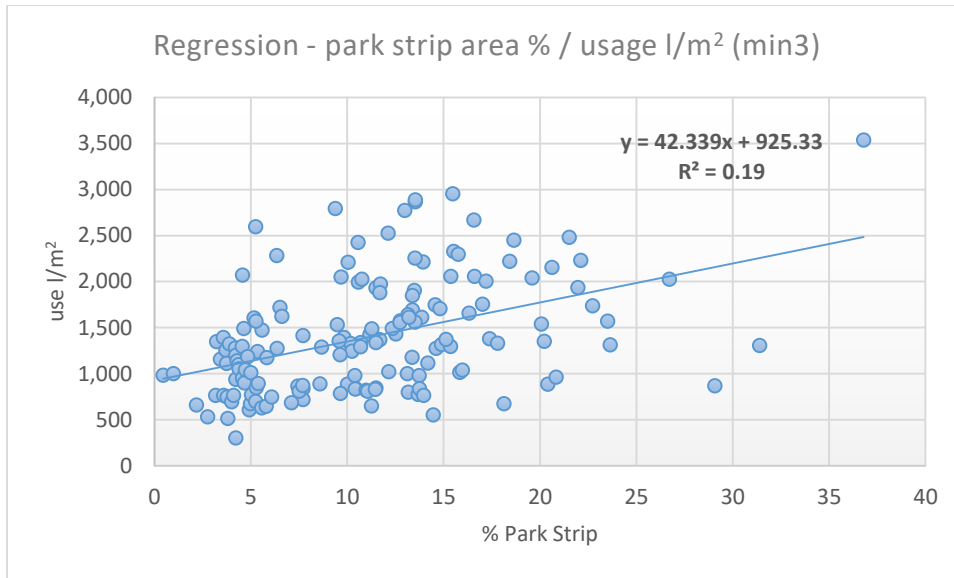


Figure 29: Regression analysis graph - park strip area percentage / water consumption (min3)

Table 9: Regression analysis results - park strip area percentage / water consumption (min3)

Regression Statistics		ANOVA					
Multiple R	0.4359		<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
R Square	0.1900	Regression	1	10911111.65	10911111.65	36.1237	0.0000
Adjusted R Square	0.1847	Residual	154	46515524.32	302048.8592		
Standard Error	549.5897	Total	155	57426635.97			
Observations	156						

4.3 Single-Family Residence (SFR) irrigation water usage

In order to evaluate whether or not South Jordan single-family residences (SFR) located within Daybreak have a statistically different irrigation usage compared to units outside of Daybreak, the water meter consumption data for all SFRs that were located in the previously outlined zoning requirements had to be analyzed. A total of 5,082 buildings within South Jordan’s city boundary matched the criteria, of which 2,018 SFRs were located within Daybreak, and 3,064 units outside of Daybreak. 16 non-Daybreak units were removed from the data, because their lot sized exceeded the largest Daybreak lot size of 0.46 acres (1,861.55 m²), leaving a total of 3,048 SFRs outside of Daybreak.

4.3.1 SFR - Average irrigation consumption

The minimum use month (min1) as well as the average minimum 3-month (min3) consumption was calculated for each building based on an irrigation season length spanning from April to November (Figure 30 and 31), which resulted in an average annual irrigation water consumption of 480.752 m³ (480,752 l, 127,001 gal) as determined by the minimum month method, and 464.025 m³ (464,025 l, 122,582 gal) as determined by the average minimum 3-month method for SFR units located in Daybreak. South Jordan residences outside of Daybreak consumed just over 13% more water for irrigation and used an average of 553.52 m³ (553,521 l, 146,225 gal) (min1) or 534.27 m³ (534,268 l, 141,139 gal) (min3). Table 10 lists the results of these calculations. However, when comparing the average usage per area unit based on the 200 digitized samples from the previous section, SFR units in Daybreak used over 17% more water per m² compared to non-Daybreak units.

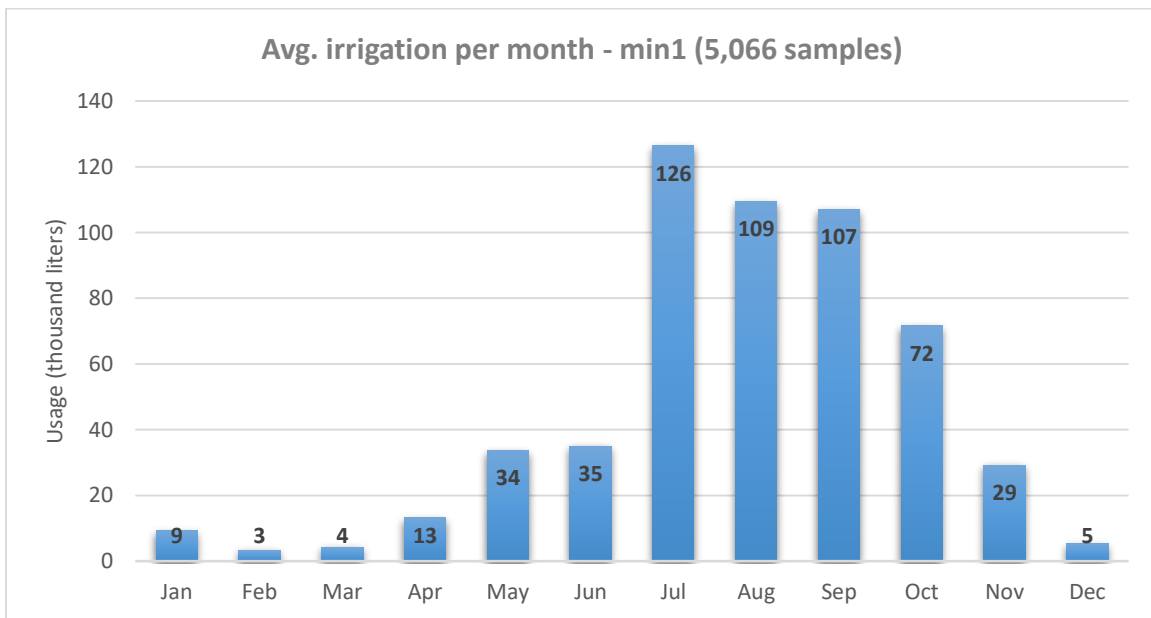


Figure 30: Average irrigation per month - minimum use month (min1)

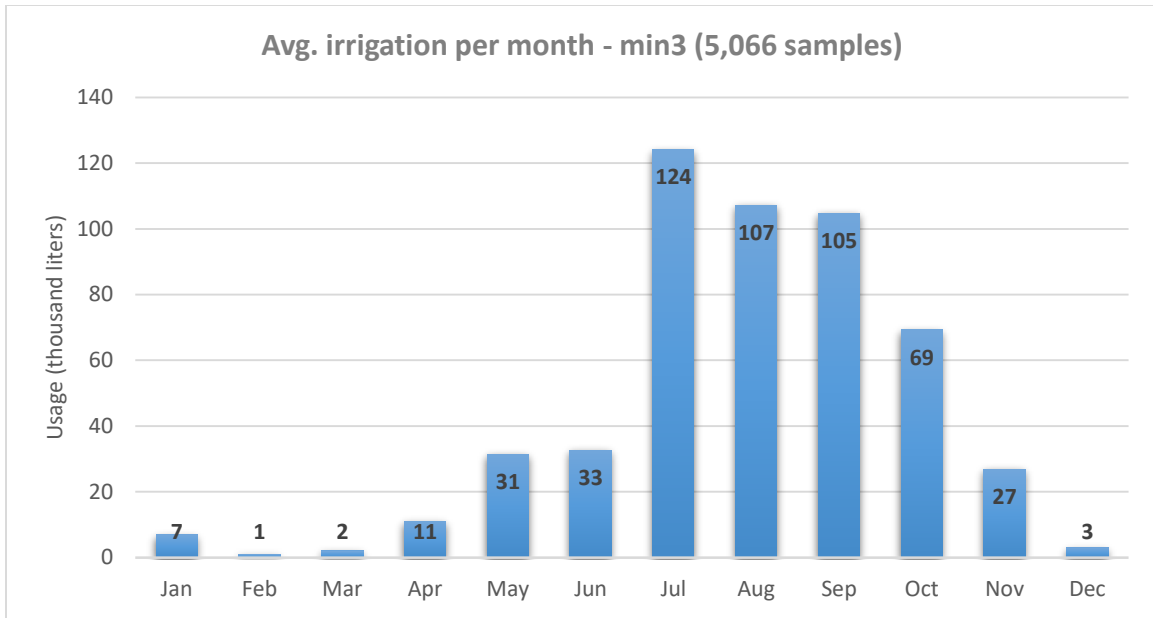


Figure 31: Average irrigation per month – minimum 3-month average (min3)

Table 10: Average annual irrigation volume for single family residences (SFR)

Daybreak	count: 2018	non-Daybreak	count: 3048	Total	count: 5066
avg min1 (m ³)	480.753	avg min1 (m ³)	553.521	avg min1 (m ³)	524.534
avg min1 (gal)	127,001	avg min1 (gal)	146,225	avg min1 (gal)	138,567
avg min3 (m ³)	464.025	avg min3 (m ³)	534.269	avg min3 (m ³)	506.288
avg min3 (gal)	122,582	avg min3 (gal)	141,139	avg min3 (gal)	133,747

4.3.2 SFR – statistical analyses

A One-Sample t-Test was conducted to determine if the null hypothesis (H_0), stating that average annual irrigation consumption for Daybreak SFRs is not significantly different compared to the mean of the entire dataset, held true. The analysis was performed on the minimum use month (min1) as well as the average minimum 3-month (min3) consumption values, and in both cases, the resulting t-value was lower than the critical two-tailed value $t_{0.05,2017}$ of (+/-) 1.9611 at a significance level of $\alpha = 0.05$ (Table 11).

$t = -6.0319$ (minimum use month (min1))

$t = -5.8898$ (minimum 3-month average (min3))

Based on the results, H_0 was rejected, and it was concluded that the average annual irrigation water consumption for SFR units within Daybreak is significantly different than the mean of the dataset for both the minimum month and average minimum 3-month, scenarios.

Table 11: statistical analysis results – One-sample T-test for min1 and min3 usage

t-Test: One-Sample Minimum Use Month (min1)		t-Test: One-Sample Average Minimum 3-Month (min3)	
	<i>min1 (L)</i>		<i>min3 (L)</i>
Mean	480,752.70	Mean	464,025.36
Variance	106,315,386,311.33	Variance	103,905,018,158.23
Observations	2,018	Observations	2,018
Hypothesized Mean	524,534.09	Hypothesized Mean	506,288.00
df	2017	df	2017
t Stat	-6.0319	t Stat	-5.8898
P(T<=t) one-tail	0.0000	P(T<=t) one-tail	0.0000
t Critical one-tail	1.6456	t Critical one-tail	1.6456
P(T<=t) two-tail	0.0000	P(T<=t) two-tail	0.0000
t Critical two-tail	1.9611	t Critical two-tail	1.9611

The second analysis conducted on the data was a Two-Sample t-Test to evaluate if the average irrigation usage Daybreak SFRs differs significantly from non-Daybreak SFRs, and whether their irrigation values have means that come from the same distribution of mean values. As was the case with the One-Sample t-Test, the null hypothesis, stating that there is no difference between the sample populations, had to be rejected, because the obtained t-values are much lower than the critical two-tailed value $t_{0.05,5064}$ of (+/-) 1.9604 at a significance level of $\alpha = 0.05$ (Table 12 and 13).

$t = -8.1386$ (minimum use month (min1))

$t = -7.9590$ (minimum 3-month average (min3))

Both analyses led to the conclusion that the average annual irrigation usage is significantly lower for single family residences within Daybreak compared to units outside of Daybreak.

Table 12: statistical analysis results - Two- sample T-test for min1 usage

t-Test: Two-Sample assuming equal variances - minimum use month (min1)		
	Daybreak SFR min1 (L)	non-Daybreak SFR min1 (L)
Mean	480,752.6975	553,520.5837
Variance	106,315,386,311.3330	90,937,547,087.4335
Observations	2,018	3,048
Pooled Variance	97,062,567,173.2561	
Hypothesized Mean Difference	0.0000	
df	5,064	
t Stat	-8.1386	
P(T<=t) one-tail	0.0000	
t Critical one-tail	1.6452	
P(T<=t) two-tail	0.0000	
t Critical two-tail	1.9604	

Table 13: statistical analysis results - Two- sample T-test for min3 usage

t-Test: Two-Sample assuming equal variances - minimum 3-month average (min3)		
	Daybreak SFR min3 (L)	non-Daybreak SFR min3 (L)
Mean	464,025.3621	534,268.9754
Variance	103,905,018,158.2290	88,395,554,299.6253
Observations	2,018	3,048
Pooled Variance	94,573,000,706.1821	
Hypothesized Mean Difference	0.0000	
df	5,064	
t Stat	-7.9590	
P(T<=t) one-tail	0.0000	
t Critical one-tail	1.6452	
P(T<=t) two-tail	0.0000	
t Critical two-tail	1.9604	

4.4 Impact of secondary water shut-offs

To estimate the daily culinary water usage for public greenspace irrigation within Daybreak in the case when the secondary water supply has been temporarily shut off, it was first necessary to determine length of the irrigation season as well as the water consumption per day for a given month. The latter was necessary, because the irrigation volume experiences significant monthly

fluctuations, and usually peaks between July and September, which are the hottest and driest months of the year.

Since monthly usage data for secondary water were not available, the consumption values for the 57 identified open spaces irrigated with culinary water were used to estimate the length of the irrigation season, as well as to calculate the factor that needs to be applied to the monthly average to determine the water consumption per day for a given month. It was assumed that the irrigation patterns for areas watered with secondary water are similar to those irrigated with culinary water. As depicted in Figure 32, irrigation for public green spaces spans over seven months from May to November, which amounts to a total irrigation season length of 214 days. The calculations also show that the irrigation volume peaked in August and September with a factor of 1.77 and 1.89, meaning that the water consumption for these two months was 1.77 and 1.89 times higher than the monthly irrigation season average of 12,789 m³ (12,788,743 l, 3,378,429 gal) for the identified areas.

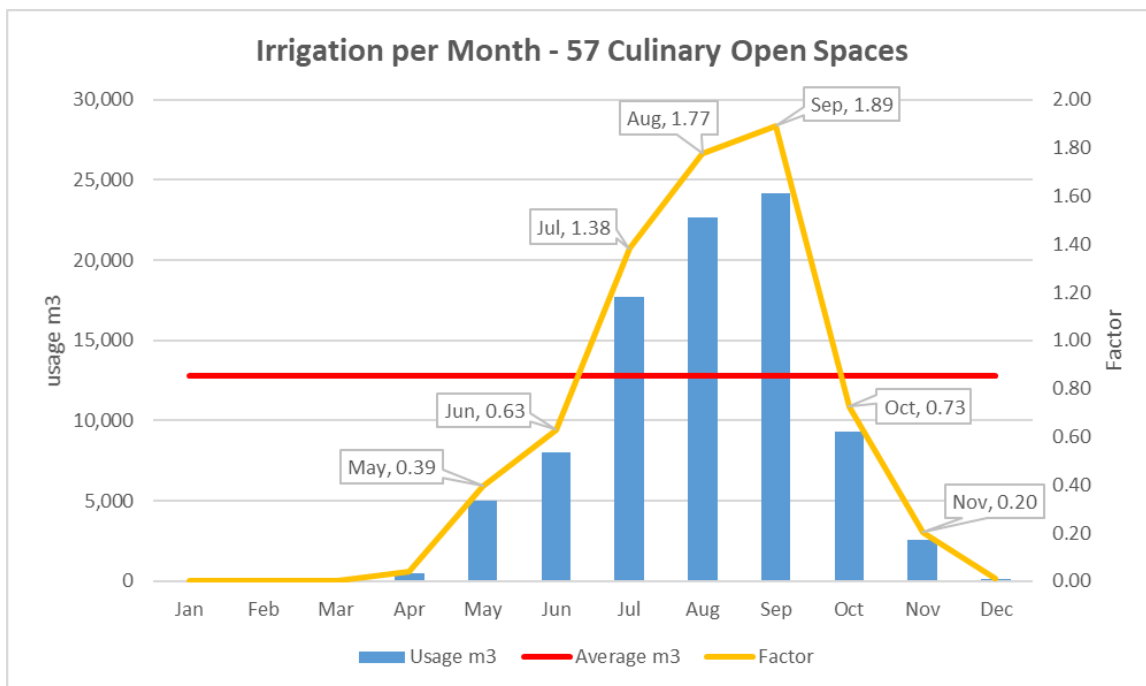


Figure 32: irrigation pattern for open spaces irrigated with culinary water: monthly usage, average usage, and multiplication factor

The values listed in Figure 32 were then applied to the areas irrigated with secondary water, which resulted in an average irrigation volume of 114,924 m³ (114,924,364 l, 30,359,805 gal) per month or 3,759 m³ (3,759,208 l, 993,078 gal) per day. Table 14 lists the daily average after taking the monthly factor into consideration.

Table 14: Average daily water consumption for open spaces irrigated with secondary water

	May	Jun	Jul	Aug	Sep	Oct	Nov
Factor	0.39	0.63	1.38	1.77	1.89	0.73	0.2
Avg. daily Irrigation (m ³)	1,466	2,368	5,188	6,654	7,105	2,744	752

4.5 Future SFR and open space irrigation volume

In order to evaluate how much water Daybreak will be using for single-family residential (SFR) and open space irrigation once the community is fully developed, the average annual SFR irrigation consumption had to be calculated first.

3,073 SFR units were located within the reference area, of which 2,005 exhibited continuous meter data with no zero values for a given month, indicating that these buildings were occupied for 12 months of the year. The average annual irrigation usage for this selection, based on the minimum use month (min1) and minimum 3-month average (min3) methods, was 500.371 m³ (500,371 l, 132,184 gal) per year, and 475.291 m³ (475,291 l, 125,558 gal) per year respectively. The average values were then applied to all SFR buildings within the reference area, which resulted in a total residential irrigation volume of 1,537,640 m³ (1,537,640,158 l, 406,201,556 gal) per year for the minimum use month, and 1,460,569 m³ (1,460,569,300 l, 385,841,588 gal) for the minimum 3-month average. Since open spaces irrigated with culinary and secondary water are metered separately, the previously calculated water consumptions of 179,984 m³/year (culinary open space) and 804,471 m³/year (secondary open space) were added to the irrigation volume for the reference area, which resulted in a total annual irrigation usage of 2,522,095 m³ (2,522,094,985 l, 666,267,008 gal) (min1) and 2,445,024 m³ (2,445,024,128 l, 645,907,042 gal) (min3) (Table 15).

Table 15: Irrigation volume for the reference area

Reference Area Irrigation Volume	water source	min1 (m ³ /year)	min3 (m ³ /year)	min1 gal/year	min3 gal/year
SFR Units (count 3,073)	culinary	1,537,640	1,460,569	406,201,554	385,841,588
Public Open Space	culinary	179,984	179,984	47,546,817	47,546,817
sub total	culinary	1,717,624	1,640,554	453,748,371	433,388,405
Public Open Space	secondary	804,471	804,471	161,873,423	161,873,423
Total		2,522,095	2,445,024	615,621,795	595,261,829

Due to the fact that the total Daybreak area is 3.58 times larger than the reference area, the values listed in Table 15 had to be multiplied by this factor in order to obtain the potential irrigation usage for the entire community.

$$\text{Daybreak Area (ft}^2\text{)} / \text{Reference Area (ft}^2\text{)} = \text{Multiplication Factor}$$

$$210,446,568.20 / 58,780,815.05 = 3.58$$

Based on these calculations, the estimated total irrigation consumption for single family residences and public open spaces irrigated with culinary and secondary water, once Daybreak is fully developed, will be 9,029,100 m³/year (9,029,100,049 l, 2,203,926,028 gal) for the minimum use month (min1), and 8,753,186 m³/year (8,753,186,380 l, 2,131,037,348 gal) for the minimum 3-month average (min3) method (Table 16). While secondary irrigation usage accounts for over 30% of the total irrigation volume, most of the water is being used for SFR irrigation, which consumes about 60% (60.97% min1, 59.74% min3) of the total volume (

Table 17).

Table 16: Estimated irrigation volume for fully developed Daybreak community

Estimated Daybreak Irrigation Volume	water source	min1 (m ³ /year)	min3 (m ³ /year)	min1 gal/year	min3 gal/year
SFR Units (count 3,073)	culinary	5,504,752	5,228,838	1,454,201,566	1,381,312,886
Public Open Space	culinary	644,344	644,344	170,217,605	170,217,605
sub total	culinary	6,149,096	5,873,182	1,624,419,170	1,551,530,491
Public Open Space	secondary	2,880,005	2,880,005	579,506,857	579,506,857
Total		9,029,100	8,753,186	2,203,926,028	2,131,037,348

Table 17: Irrigation usage percentages

Reference Area Irrigation Volume	water source	min1 % of total	min3 % of total
SFR Units (count 3,073)	culinary	60.97	59.74
Public Open Space	culinary	7.14	7.36
sub total	culinary	68.10	67.10
Public Open Space	secondary	31.90	32.90

4.6 Park strip water conservation potential

Based on the manually digitized features, residential and public park strips irrigated with culinary water cover a total area of 243,508 m² (2,621,103 ft²) within the reference area, of which 94.45%, or 229,999 m² (2,475,686 ft²), are covered with water demanding turf. Out of the turf-covered park strips, 125,812 m² (1,354,229 ft²) fall in the residential category, whereas 104,187 m² (1,121,457 ft²) are mostly located along public open space areas, schools, as well as multi-family units, and are considered to be public (Table 18).

Table 18: Residential and public park strips within the reference area

	Area m ²	Area ft ²	Turf-Covered m ²	Turf-Covered ft ²
Residential	131,683.20	1,417,426.21	125,811.96	1,354,228.64
Public	111,825.20	1,203,676.42	104,186.78	1,121,457.20
Total	243,508.40	2,621,102.63	229,998.74	2,475,685.84

Since previous calculations resulted in different water consumption values per area unit for public and residential features (Table 3 and 11), possible irrigation water savings for these areas were calculated separately.

Based on the Daybreak usage rates of 2.296 m³ (2,295.91 l/m², 56.35 gal /ft²) for non-residential and 1.593 m³ (1,592.59 l/m², 39.09 gal/ft²) for residential areas under the minimum use month scenario (min1), the total annual culinary water consumption for turf-covered park strips within the reference areas was calculated to be 439,570 m³ (439,570,341 l, 116,122,199 gal), comprised of 239,204 m³ (239,203,477 l, 63,190,873 gal) for public, and 200,367 m³ (200,366,865 l, 52,931,326 gal) for residential park strips (Table 19).

Table 19: Park strip irrigation volume for turf-covered features within the study area

	Area m ²	Usage rate l/m ²	Total usage (m ³)
Residential	125,811.96	1,592.59	200,367
Public	104,186.78	2,295.91	239,204
Total			439,570

The conservation potential of 76.4% by converting turf to xeriscapes, as concluded by Sovocool and Morgan, (2005), was then applied to the individual usage rates, which resulted in a total irrigation volume decrease within the reference area of 335,832 m³ (335,831,741 l, 88,717,360 gal) per year to a combined overall usage of 103,739 m³ (103,738,601 l, 27,404,839 gal) (Table 20).

Table 20: Potential water savings for residential and public park strip irrigation

	Area m ²	Usage rate l/m ²	Usage rate - 76.4%	Total usage (m ³)
Residential	125,811.96	1,592.59	375.85	47,287
Public	104,186.78	2,295.91	541.83	56,452
Total				103,739

Imposed on the entire community with the previously determined multiplication factor of 3.58 (section 4.5), the theoretical culinary water saving that can be achieved in a fully developed Daybreak neighborhood by converting turf-covered park strips to xeriscapes was calculated to be 1,202,277 m³ (1,202,277,633 l, 317,608,150 gal) per year.

5. Discussion and limitations

Based on the results from this study, the average SFR unit in Daybreak uses between 65.09% (min3) and 68.04% (min1) of its annual household water budget for outdoor irrigation purposes, while units in South Jordan outside of Daybreak use about 3% more culinary water for irrigation, ranging from 68.01% (min3) to 70.70% (min1). As concluded by DeOreo et al., (2011), lot size is a factor that affects water consumption, which can explain the difference in irrigation consumption between Daybreak and non-Daybreak SFRs. According to the previously used selection of 5,066 units (section 4.3), lot sizes for non-Daybreak SFRS are on average 36.3% larger, which should have resulted in a more substantial volume difference than 3%. However, the average indoor consumption that served as the baseline to estimate outdoor usage was found to be higher for SFRs outside of Daybreak (Table 21). Furthermore, the calculated irrigation usage per area unit was over 17% higher for SFRs within Daybreak, which used 1.604 m³ (1,604.47 l/m², 39.38 gal/ft²) on average compared to 1.327 m³ (1,327.32 l/m², 32.58 gal/ft²) for non-Daybreak SFRs. The higher indoor consumption as well as the lower usage per area unit contributed to the relatively low volume difference of only 3%, despite the significantly larger lot sizes.

Table 21: average SFR indoor use

	m ³ /month (min1)	gal/month (min1)	m ³ /month (min3)	gal/month (min3)
avg. indoor use - Daybreak	13.530	3,574.33	15.621	4,126.69
avg. indoor use - non-Daybreak	15.362	4,058.07	17.768	4,693.79

These numbers are very similar to the 70% concluded by Gleick et al., (2003), as well as the 70-80% estimate used by the City of South Jordan (Maloy, 2017). Nonetheless, results from other studies such as Vickers, (1991), U.S. Environmental Protection Agency (EPA), (2017), or Kjelgren et al., (2000), highly underestimate the outdoor irrigation percentage, and should not be used to assess current or future water usage consumptions for the study area defined in this paper. Vickers for example concluded on 30-50%, while the EPA's estimates range from 30-60%. Even the results presented by Kjelgren based on a study only 32 kilometers away in Salt Lake City, do not compare to the irrigation usage for the study area in this paper. Kjelgren's study determined an average outdoor consumption of only 48% of the total annual household water usage. These variations regarding irrigation usage estimates demonstrate that many factors,

including regional, economic, and climatic differences, as well as the used methodology can significantly affect the results.

Similar differences can be observed for existing conservation potentials. Results from this study display possible annual water savings for park strips in Daybreak between 57.001 m³ (57,001 l, 15,058 gal) for the minimum 3-month average method (min3) and 58.529 m³ (58,628 l, 15,488 gal) for the minimum use month method (min1). These values are up to two times higher compared to the proclaimed savings according to the Jordan Valley Water Conservancy District of 7,000 to 10,000 gallons per year (Jordan Valley Water Conservancy District, 2017). Based on the 200 digitized samples, the average park strip area within Daybreak accounts for 14.2% of the total irrigated area for a single family residence (SFR), while park strips for SFRs outside of Daybreak only cover 5.74% on average of the total irrigated area. Unsurprisingly, larger turf-covered park strip areas will result in higher water savings when converted to xeriscape areas. On the other hand, the savings of 76.4% as concluded by Sovocool and Morgan, (2005) are only theoretical and best case scenario. Even though other studies, such as Wilson and Feucht, (2007), concluded on similar values regarding the water saving potential, different xeriscape designs might not achieve the same conservation rate as used in this study. Furthermore, the total Daybreak-wide conservation potential for park strips, once the community is completed, of over 1 billion liters per year can only be achieved if 100% of turf-covered park strips are converted to xeriscapes, which is highly unrealistic. Even though there are several other water conservation methods available that do not include a physical transformation of turf areas to less water demanding spaces, their conservation potential was not addressed in this paper, since they typically affect the entire irrigated area of a residential unit and cannot be exclusively applied to park strips. Some of these measures include redesigned water rate structures to encourage water conservation, or smart radio sprinkler controllers that access local weather data to adjust irrigation times and frequencies.

As far as irrigation usage for public and open space areas concerns, great caution was exercised while digitizing the areas irrigated with secondary water based on the map provided by the Daybreak Water Company (DWC). However, it was not always possible to identify the exact extent of the individual zones fed by a specific meter. For example, the area around the Lake was comprised of 9 regions, each supplied by its own meter. However, the extent of the individual

areas was not clear, and as a result, the entire region around the lake had to be grouped into a single region and was assigned the total water usage of the summed-up lake meters (Figure 33). This posed a potential problem, because the grouped area accounted for 18.3% of the total area irrigated with secondary water within the reference area and contained all three land covers (turf, mulch, and grass). A lake meter that feeds an area covered exclusively by one vegetation type would have provided valuable information regarding the consumption rate per area unit for this specific land cover. The average usage rates for turf, mulch, and grass were calculated by only taking areas into consideration that were solely covered by a single vegetation type.

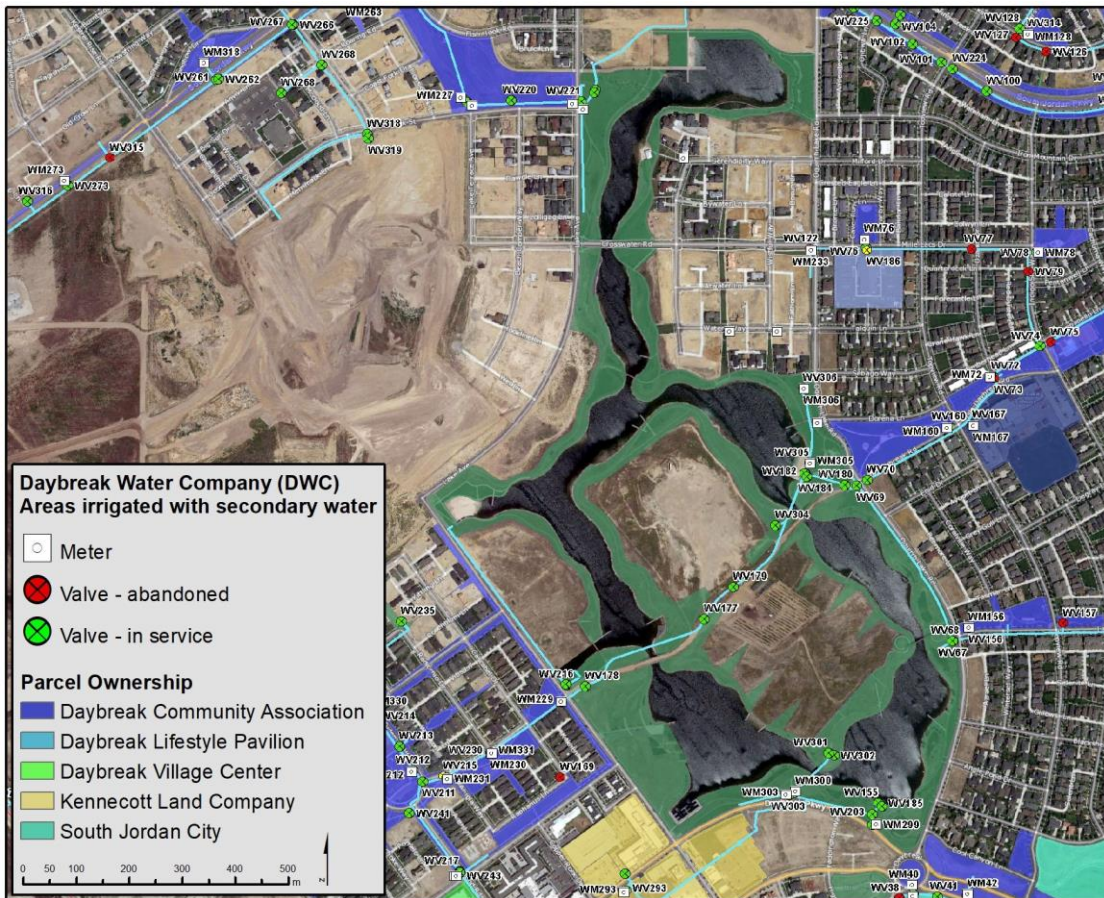


Figure 33: Oquirrh Lake – extract of the secondary water meter map obtained from the DWC

A similar problem occurred for public areas irrigated with culinary water. A total of 191 landscape meters were found in the reference area, of which 178 were successfully linked to the meter usage data obtained from the city’s billing department. However, the exact extent supplied by an individual landscape meter was only identified for 57, or 32% of the linked meters. A

higher number of identified areas fed by a specific landscape meter would have not only affected the calculated usage rate per area unit and its accuracy, but would have also improved the numbers for total current usage as well as projected future usage. Additionally, more data could have also addressed the unexpected result of no correlation between the extent of mulched areas and potentially reduced water consumption. Since mulched areas are mostly watered through drip line irrigation systems, they can use up to 50% less water compared to areas irrigated with traditional sprinkler systems (Gleick et al., 2003).

Another aspect that potentially affected the results of this study was the single family residence occupancy rate. The monthly consumption rates in the obtained meter readings are listed in 1,000 gallon increments, and even though units with zero-values in the monthly utility data were excluded from all calculations, residences occupied for only a few days in a given month could still show a water consumption of at least 1,000 gallons, and consequently a continuous water usage over a 12-month period. While a scenario like this can influence a unit's indoor consumption in the winter months, and with it the baseline used to calculate outdoor usage in the summer months, it also has the potential to significantly lower the calculated irrigation usage for a given month during the summer. However, since the average SFR irrigation values were calculated from a sample consisting of 2,018 (Daybreak) and 3,048 (non-Daybreak) units, the impact of several residences that were not occupied for a full 365 days per year is questionable.

Along the same line, it is also necessary to mention that the calculated values for current and future SFR irrigation are based on a 100% occupancy rate throughout the year. Even though it is not realistic to assume that all residences in Daybreak are, or will be, inhabited for a continuous 12 months, it was beyond the scope of this paper to take the average tenancy for SFRs into consideration when calculating consumption rates.

An additional factor regarding the estimations for future irrigation consumptions that needs to be taken into consideration is land use. The calculations for this paper assumed that the undeveloped areas, once completed, will experience the same ratio of single family residences, parks, and other open areas as the reference area. However, a shift to larger lots or a higher percentage of SFRs for future developed areas will consequently lead to increased water demands due to higher irrigation usage, and will result in much higher values regarding outdoor irrigation consumption.

6. Conclusion

As of today, Daybreak's undeveloped area of approximately 12.5 km² (3,088 acres) leaves room for thousands of new residential units, as well as large recreational and open space areas, that will be irrigated with either secondary or culinary water.

Based on the findings of this study, public irrigated areas including open spaced, parks, and park strips occupy 21.5% of the reference area used in this paper, with water usage rates ranging from 0.143 m³ (142.75 l/m², 3.50 gal/ft²) (secondary, ungrouted grass) to 2.296 m³ (2,295.91 l/m², 56.35 gal/ft²) (culinary, turf/mulch).

The majority of the total reference area irrigation volume is being consumed by irrigation practices with culinary water for single family residences (SFR). While the total irrigation consumption for SFRs within Daybreak is significantly lower compared to units outside of Daybreak, their average usage rate per area unit, based on the data obtained from 200 digitized samples, is over 17% higher compared to non-Daybreak units.

About 4.5% of the reference area is comprised of residential and public park strips. The results from this study show that the higher the percentage of turf-covered park strip area is for an individual SFR unit with respect to its total irrigated area, the more likely the irrigation water rate per area unit will increase. On the other hand, park strips also offer a great conservation potential. A conversion of turf-covered park strips to xeriscapes can theoretically save up to 58,600 l/year per SFR unit, which translates to an average of almost 11% of a unit's entire outdoor water consumption.

Elevated levels of cyanobacteria caused by algae blooms occurring in Utah Lake were detected in three out of the last four years. In extreme cases, the secondary water supply for areas that receive their secondary water from Utah Lake, including Daybreak, needs to be shut off and switched to culinary water due to potential health risks. Based on the secondary water consumption within the study area, the daily culinary water usage in such a scenario is estimated to be over 7 million liters per day (7,105 m³) at its peak.

The amount of culinary and secondary water that will be used to per year to accommodate a finished Daybreak community will be in the billions. The estimations from this study range from

8.75 - 9.03 billion liters per year (8,753,186 m³ - 9,029,100 m³), with SFR units irrigated with culinary water being responsible for about 60% of the entire volume.

The availability of water is crucial for economic growth (Frontier Economics, 2012), which also holds true for the City of South Jordan, where it essentially dictates how and if new developments can be successfully implemented. In addition to a multitude of other related challenges, a shortage of water will not only make newly constructed residences uninhabitable, but will also bring new constructions to a halt in general.

Mandatory water conservation measures, as already imposed in several neighboring states, could become reality in the near future, and the estimated savings from this study could justify future city guidelines and ordinances regarding the landscaping of residential and public park strips or entire residential units.

Assessing how much water is currently being used, how much water will be used in the future, and how much water can be conserved within the Daybreak community, as this study tried to accomplish, provides important information that will aid South Jordan's decision makers when faced with current or future challenges related to the city's water consumption or water budget.

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