# DISCLAIMER

This project was conducted with financial assistance from a grant from the Metropolitan Water District of Southern California (Metropolitan), the U.S. Bureau of Reclamation, the Environmental Protection Agency, the Central Arizona Project, the Southern Nevada Water Authority, the Southern California Gas Company, and the Western Resource Advocates through Metropolitan's Innovative Conservation Program (ICP). The ICP provides funding for research to help document water savings and reliability of innovative water savings devices, technologies, and strategies. The findings of this project, summarized in this report, are solely from the project proponent.

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# 2015 INNOVATIVE CONSERVATION PROGRAM

GRANTS FOR STUDIES THAT WILL DOCUMENT WATER SAVINGS AND RELIABILITY OF INNOVATIVE WATER SAVINGS DEVICES, TECHNOLOGIES, AND STRATEGIES.

# Final Report

## Agreement No. 167775

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## Executive Summary

This project “Investigation into UAS Utilization in Golf” or ICP 167775 was carried out by EYEON18 in partnership with three participating golf courses in Southern California and the Turfgrass Research Facility at the University of California, Riverside (UCR). This pioneering project seeks to validate the use of Unmanned Aerial Systems (UAS) technology for producing valuable information for water conservation on turfgrass and golf courses. Specifically, examining whether UAS derived data can inform irrigation management decisions, reduce excessive watering, and enhance playing conditions.

Thirty-four UAS missions were conducted over the study areas from May 2017 to September 2017. Data from these missions was provided to turfgrass managers where pre and post water use was recorded. The project was split into two formats.

The first format was a controlled study implemented at UCR where the turf type and watering schemes were tightly controlled with minimal turf stressors. Over the study period, water savings of 21% below ETo was achieved for the EYEON18 study plots. UAS missions at UCR helped to confirm target turf conditions for the warm season Bermuda grass similar to that used in golf course environments. Water savings was determined by comparing the total gallons applied to the plots under each watering regime from one week to the next. The conclusion of the study revealed total gallons used on the UAS monitored plots to be 79% of ETo. Put another way, researchers achieved a 21% irrigation savings below standard ETo irrigation.

The second format was a real-world application of UAS technology applied at the three golf courses. These real-world environments consisted of variable acreage, turf grasses, soil types, turf stressors and irrigation watering systems. For each golf course, Simulated Water Savings and Measured Water Savings were analyzed.

The simulated water savings was calculated for each study site over the study period to reveal the potential water savings which could have resulted if all adjustments recommended by the Project Team had been implemented. The total simulated water savings for three golf courses amounts to approximately 6.2 million gallons or about 19 acre feet saved (Table 11). This is the equivalent of 33 households in Southern California for one entire year (DWR 2011). If the recommended changes had been implemented, monetary savings for the three golf courses over the study period could have totaled $41,114 assuming 100% of the water was purchased at potable water rates for a representative water district in San Diego County.

The measured water savings data is attenuated since on many study dates irrigation changes were not properly captured by the irrigation systems. Therefore, the number of actual measured water saving changes recorded was less than the number of recommendations made by the Project Team Agronomists. Notably, of the data collected, actual measured water savings revealed water savings of 1-4% during the study period. A significant detail is the fact that the study golf courses who irrigate at 80% ETo, were able to find additional measured water savings in applying this technology.

The project results suggest that using (UAS) imagery can confirm target turf conditions and watering regimes which provide turfgrass managers the ability to increase water savings. Further, these results suggest that each site was able to refine irrigation practices towards optimal ETo watering regimes.  This technology provides a great wealth of information for the turfgrass manager's water conservation efforts.  Further research could help verify the water saving calculations of this technology with more robust data sampling.  The relationship between direct ground measurements and remotely sensed aerial imagery and vegetation indexes can also be clarified. Applying UAS imagery towards improved irrigation management in the golf industry requires additional coaching and education from experienced turfgrass managers and turfgrass researchers. Recommend continued research to support water savings calculations and educate the golf industry in the application of UAS imagery for irrigation system adjustment towards the most available water savings and optimal turfgrass performance.

## Introduction

EYEON18 is a technology service company that aims to help golf course management increase water efficiency and improve playing conditions. EYEON18 operates the Honeycomb AgDrone™ fixed wing agricultural Unmanned Aerial System (UAS) which utilizes multi-spectral capabilities to deliver two sets of imagery in unison: high-resolution visible light images and a plant health indicator (Normalized Difference Vegetation Index or NDVI). The dual imagery allows turf managers to quickly evaluate turf growth habits and patterns over large areas. The Team comprises 60+ years of turf management experience paired with a robust fixed-wing platform that can fly up to 800 acres per hour and the average golf course in 20 minutes (Figure 1).

EYEON18 uses the NDVI imagery to identify irrigation patterns and turfgrass growth habits. Figure 2 is an example of using NDVI to identify target areas where turf vigor is at a higher level than necessary for optimum playing conditions and efficient use of the water resource on the golf course. These areas are identified and noted in the imagery. The property managers can then make well informed, strategic and controlled irrigation adjustments to precise areas of the property. These target areas are metered for soil moisture levels and the NDVI values are identified in the UAS imagery. Adjustments are made to irrigation stations to match the target conditions based on the imagery plus metered ground observations (Figure 3). This method is tested as a novel and effective strategy for irrigation management across the entire golf course property.

Figure 1. The Honeycomb AgDrone™ fixed wing agricultural Unmanned Aerial System (UAS) used for aerial data capture for project ICP 167775. (Source: Honeycomb Corp.)

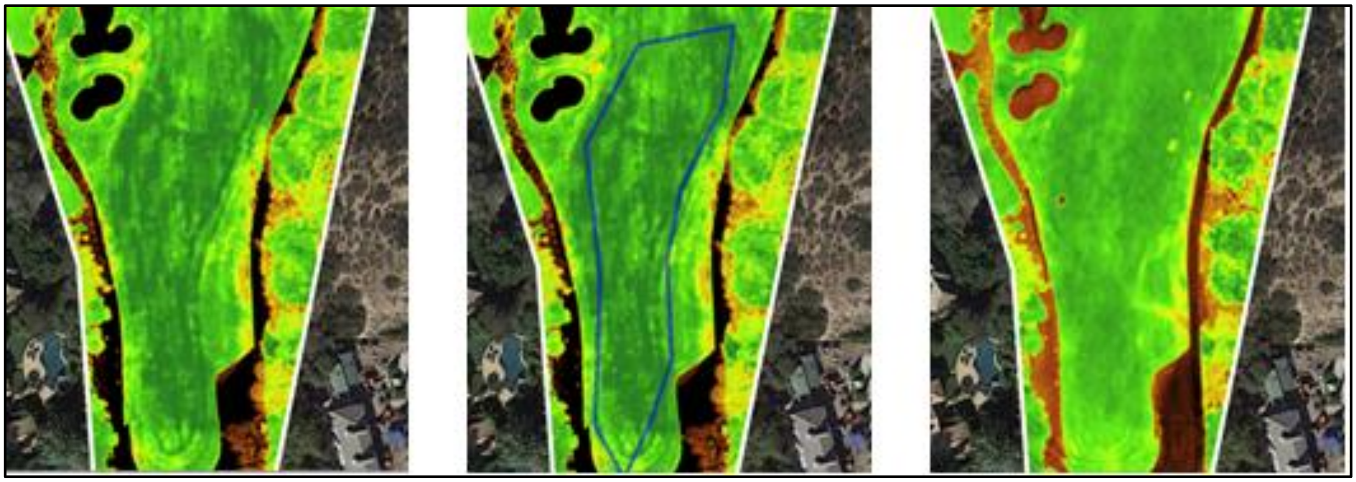


Figure 2. Normalized Difference Vegetation Index or NDVI imagery from unmanned aerial system (UAS) flights showing progression from high NDVI (left), highlight on area of interest (center) and lower NDVI with more consistent spatial distribution of NDVI values after irrigation adjustments (right). (Source: EYEON18)

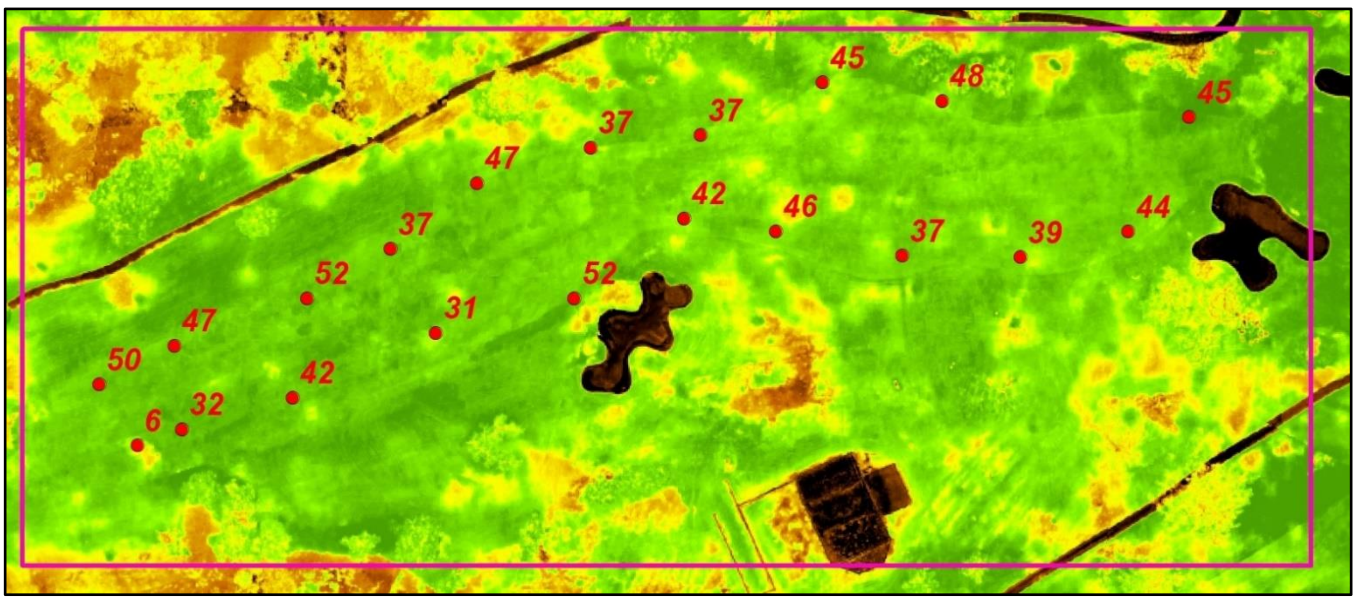



Figure 3. Sample overlay of soil moisture percent with Normalized Difference Vegetation Index or NDVI imagery. (Source: EYEON18).

## Project Description

### Goals and Objectives

The goal of this "Investigation into UAS Utilization in Golf" (Project) is to determine whether the Honeycomb AgDrone™ fixed wing agricultural UAS platform can deliver cost effective, timely and detailed information of ground conditions which enable golf course managers to make tangible real-time water savings decisions. The objective of this project is to bridge the gap between turfgrass researchers and turfgrass managers, first, by illustrating where interpretation of the UAS remotely sensed imagery has practical management applications in a controlled environment and, second, by identifying and testing the real-world applicability that remote sensing could solve. Specifically, can UAS derived data inform irrigation management decisions, reduce excessive watering, and enhance playing conditions.

### Project Team

EYEON18 staff for the Project (Project Team) included managing partners Tim Barrier CGCS; Javier Spyker, Esq.; and Aaron Crawford. Mr. Barrier and Mr. Crawford shared the role of Agricultural Scientist for the Project based on their decades of experience with agronomy and turf management. Mr. Spyker provided strategic, legal, and logistical support. Director of Flight Operations Gerald Ward served as Commercial Pilot / Safety Officer. Director of Technology Tyler Rowe, who holds an FAA Part 107 certification, served as Drone Operator for UAS missions. On many occasions, Mr. Barrier (also FAA Part 107 certified) served as primary or secondary Observer. At other times, Drone Operators / Observers Jescey Castaneda (also FAA Part 107 certified) or Jeffrey Riback joined Mr. Rowe at Study Sites. Director of Information Debbie Blackmore, MBA provided most of the Data Analyst functions, especially water use calculations.

### Project Study Sites

Four project sites were selected in Southern California. These sites allow for the study of water savings potential in a variety of distinct climate scenarios.

- The University of California, Riverside (UCR)
- Golf Course A
- Golf Course B
- Golf Course C

### Project Phases

Grant work was conducted in four phases between February and October 2017 as summarized in Table 1 and described in detail below.

| | |
|---|---|
| Phase I: Planning & Setup; Feb to Apr 2017 | |
| | Analyze potential study areas for safety and FAA compliance |
| | Gather sample data for analysis. Reevaluate Site Readiness and Site safety. |
| | Analyze sample data reevaluate method of data collection. |
| | Develop Project management plan |
| Phase II: Conduct 15 Data Collections; May to mid-Jul 2017 | |
| | Gather data and prepare for analysis |
| Phase III: Conduct 15 Data Collections; mid-Jul to Sep 2017 | |
| | Gather data and prepare for analysis |
| Phase IV: Analyze & Prepare Report; May to Oct 2017 | |
| | Analyze sample data |

Table 1. Project phases for "Investigation into UAS Utilization in Golf", ICP 167775.

**Phase I – Planning and Setup, February to April 2017**

Project Team and Study Sites executed Engagement Letters to obtain permissions and set project expectations. Stakeholders then performed project planning for the study, which included research design, discussion of site-specific requirements and scheduling of UAS missions for the duration of the study period. Each site was evaluated and cleared for safety and FAA compliance for UAS operations (for sample, see Appendix A). Site assessments and safety analysis were conducted by Director of Flight Operations Gerald Ward who serves as Commercial Pilot / Safety Officer alongside Project Team pilots who are FAA Part 107 Certified. Assessment include all facets of safe flight including but not limited to: Airspace, Topography, Weather, Home density, Power lines, structures, and trees.

Each UAS mission at each site was conducted by a FAA Part 107 Certified Pilot in Command and an observer. Site managers were in attendance for selected missions, especially at the beginning of the study period. UAS flights were fully insured and conducted in accordance with Title 14 Code of Federal Regulations including Part 107 (FAA 2016). In addition, activities were completed under the "EYEON18 Operations, Data Privacy and Security Policy" based in part on guidance from The National Telecommunications and Information Administration's (NTIA) "Voluntary Best Practices for UAS Privacy, Transparency, and Accountability" (NTIA 2016).

For each UAS mission, flight parameters were planned to be as constant as environmental conditions allowed. These include flight path, image overlap (which affects quality of image processing), flying altitude (which affects image resolution), etc. As planned, UAS flights were scheduled approximately every two weeks, beginning in late spring and extending into the hot summer months. Measurements were to be taken prior to each flight, including volume and timing of water, evapotranspiration, air temperature and sampling of soil moisture at representative locations. UAS images were analyzed and if watering adjustments are recommended, measurements were to be taken again after the adjustments have been made, with special focus on water volumes and timing.

**UAS Mission Design**

For each UAS mission, the Project Team performed the following steps:

- Design the flight plan for the UAS mission
- Conduct a thorough assessment of pre-flight safety and on-site conditions
- Characterize the soil conditions by taking an average of 3+ soil moisture samples in a small radius (~ 3"), record with GPS positioning
  - POGO Pro portable turf/soil moisture sensor
  - Sensor technology: Coaxial Impedance Dielectric Reflectometry
  - Turf variables: moisture, salinity, canopy temperature
  - Measurement depth: 2" - 2.5" below the surface
  - Garmin GPSMAP 64S (accurate to 3 meters) to pinpoint soil moisture reading location
- Assess the irrigation system water volumes for the area of interest before the mission
- Record the evapotranspiration (ET) based on local weather station input
- Collect aerial imagery using the Honeycomb AgDrone™ System (Figure 1 above)
  - Advanced fixed wing agricultural UAS
  - Dual camera payload with RGB HD and infrared, six-channel coverage in a single flight
  - Wingspan of the flight platform: 49"
  - Material: composite construction with Kevlar® exoskeleton
  - Powerplant: 575W electric motor
  - Battery: 8000mAh LiPo
  - Loaded weight at take-off: 4.95 lbs.
  - Camera resolution @ 400 ft.: 1.0 in (2.54 cm)
  - Average operating altitude during study: 300'-400'
  - Average speed during study: 36 mph
  - Average flight time for AOI: 20-25 min
  - Average flight time for 600-800 acres at 400': one hour
  - Software to direct automated portions of flight plan: Mission planner
  - Software to upload raw imagery to Honeycomb Farm cloud service: Connect
  - Software to document and manage UAS Flight Data: DroneLogBook
- Using the Honeycomb FarmTM cloud service:
  - Process raw imagery to produce high-resolution mosaics of flight area
    - Proprietary software algorithms to stitch raw imagery into mosaics
    - Six-channel image processing
  - Calculate the normalized difference vegetation index (NDVI) for the entire flight area
  - Analyze aerial imagery
    - visible red-green-blue (RGB)
    - NDVI, a representation of plant vigor and plant health
  - Make irrigation tuning recommendations using drawings and notes on the imagery
  - Share imagery and recommendations with Project Participants
    - Full zoom-and-pan navigation with user control over types of data displayed
    - Access via PC, laptop and mobile devices
- GIS and mapping software to analyze soil moisture data: ArcMap Version 10.4
- Assess the irrigation system water volumes for the area of interest after the mission
- Calculate the measured water savings using Microsoft Excel 2016

Further work was split into two formats, depending on the site. The first format was implemented at UCR where the plot size and layout, turf type and watering schemes were tightly controlled with minimal turf stressors. The second format was implemented at the three golf courses in real-world environments which consisted of variable acreage, turf grasses, soil types, turf stressors and irrigation watering systems. UAS missions were flown on maintenance days when courses were closed for play or when activity could be interrupted for the duration of the flight.

**Phase II – Conduct 15 Data Collections, May to July 2017**

During Phase II, the Project Team focused on collecting data, making irrigation recommendations, and evaluating the research design parameters. Efforts focused on flying 15 UAS missions and taking actions based on the analysis of the imagery. UAS parameters were held as constant as environmental conditions allowed, including flying altitude, image overlap (which affects quality of image processing), etc.

The three golf course study locations were flown consistently, about every other week. On-site work was carefully coordinated between the Project Team and each Superintendent. Soil moisture readings with GPS locations were used to overlay samples onto processed UAS imagery, allowing the Project Team to explore the accuracy and interpretative value of this data. Processed UAS imagery and related Project Team recommendations were shared with each Superintendent, usually within 24 hours, which informed their decision whether to adjust irrigation run times or patterns for subsequent days.

At the fourth location, the UC Riverside Turfgrass Research Facility (UCR TRF), new turf sod was installed in early May for the exclusive use of the Project. Given the study site and expected climate conditions, a warm season Bermuda grass was selected, in part because it is one of the dominant varieties used by golf courses in California. The first Phase II UAS mission at UCR was conducted in late May after allowing time for the turf to begin to establish or "grow in". Further UAS flights were temporarily suspended until all conditions were met for compliance to UCR special requirements.

Water usage data was collected before and after UAS missions at each of four Project sites. At golf courses, this involved taking downloads from sophisticated irrigation systems. At the UCR site, water volumes are tracked manually when water is applied by UCR researchers.

The Project Team worked closely Golf Course Project Participants to improve the method for identifying areas of interest or AOIs and aggregating water volumes for comparison. Also, discussions with Project Participants explored how best to incorporate evapotranspiration (ET) values, which irrigation systems use to automatically adjust run times.

**Phase III – Conduct 15 Data Collections, July to September 2017**

During Phase III, the Project Team continued to focus on collecting data, making irrigation recommendations, and evaluating the research design parameters. The Project Team planned to fly 15 UAS missions but actually flew 19 UAS missions, making irrigation recommendations after each based on analysis of the imagery. At the three golf course study locations, flights proceeded in the manner outlined in Phase II. At the fourth location, the UC Riverside Turfgrass Research Facility (UCR), flights resumed in mid-July on a weekly basis. The Project Team worked closely with UCR staff to implement weekly recommendations for irrigation treatments in accordance with the research plan.

Similar to Phase II, water usage data was collected before and after UAS missions at each of four Project sites. The complex irrigation systems in place at the Golf Course sites tracked a multitude of water parameters and therefore allowed/required careful evaluation. At the UCR site, water volumes were tracked manually by UCR staff. Analysis for the Variable % watering regime focused on the optimal irrigation volumes to simulate golf course target conditions.

## Phase IV – Analyze and Prepare Report, May to October 2017

Phase IV work began when UAS flights commenced in May and continued beyond the last flights in September. Imagery and water use reports were analyzed to identify the most succinct examples for reporting purposes and to evolve the methods for calculating water savings based on available data. A draft of the Phase IV report (this document) was submitted on 9/30.

## Weather and Precipitation near Study Sites

Weather data for three relevant climate zones over the course of the study period are shown in Table 2 (CIMIS 2017). The general study area is shown in Figure 4 relative to climate zones as defined by the California Irrigation Management Information System (CIMIS).

| CIMIS Weather Data<br>May 2017 - Sep 2017 | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CIMIS zone 3 | | | | | | CIMIS zone 6 | | | | | | CIMIS zone 9 | | | | | |
| Month | Total Eto (inches) | Total Precip (inches) | Avg Max Air Temp (F) | Avg Min Air Temp (F) | Avg Rel Hum (%) | Avg Wind Speed (mph) | Total Eto (inches) | Total Precip (inches) | Avg Max Air Temp (F) | Avg Min Air Temp (F) | Avg Rel Hum (%) | Avg Wind Speed (mph) | Total Eto (inches) | Total Precip (inches) | Avg Max Air Temp (F) | Avg Min Air Temp (F) | Avg Rel Hum (%) | Avg Wind Speed (mph) |
| May | 4.5 | 0.9 | 69.9 | 56.8 | 73.7 | 1.9 | 5.9 | 0.1 | 78.5 | 54.4 | 61.6 | 4.6 | 5.1 | 1.1 | 76.1 | 50.7 | 73.5 | 3.1 |
| Jun | 5.0 | 0.1 | 74.5 | 60.1 | 77.7 | 1.7 | 7.0 | 0.0 | 88.8 | 60.5 | 58.6 | 4.3 | 6.3 | 0.0 | 84.1 | 54.7 | 70.6 | 3.3 |
| Jul | 5.6 | 0.0 | 78.2 | 64.9 | 79.4 | 2.0 | 7.1 | 0.0 | 93.8 | 65.7 | 56.9 | 4.1 | 6.3 | 0.2 | 87.6 | 60.6 | 74.2 | 3.5 |
| Aug | 5.1 | 0.0 | 77.7 | 65.2 | 79.3 | 3.6 | 6.4 | 0.4 | 93.0 | 65.7 | 61.4 | 4.0 | 6.0 | 0.0 | 88.3 | 59.9 | 74.2 | 4.2 |
| Sep | 4.1 | 0.2 | 80.3 | 67.9 | 78.6 | 3.8 | 4.9 | 0.1 | 87.1 | 62.2 | 59.6 | 4.1 | 4.5 | 0.0 | 84.6 | 57.0 | 71.1 | 4.2 |
| Total/Avgs | **24.4** | **1.1** | **76.1** | **63.0** | **77.7** | **2.6** | **31.4** | **0.5** | **88.2** | **61.7** | **59.6** | **4.2** | **28.1** | **1.3** | **84.1** | **56.6** | **72.7** | **3.7** |

Table 2. Highlights of climate zone weather data for project study sites over the course of the study period. Source: California Irrigation Management Information System (CIMIS) at http://www.cimis.water.ca.gov/ in October 2017.

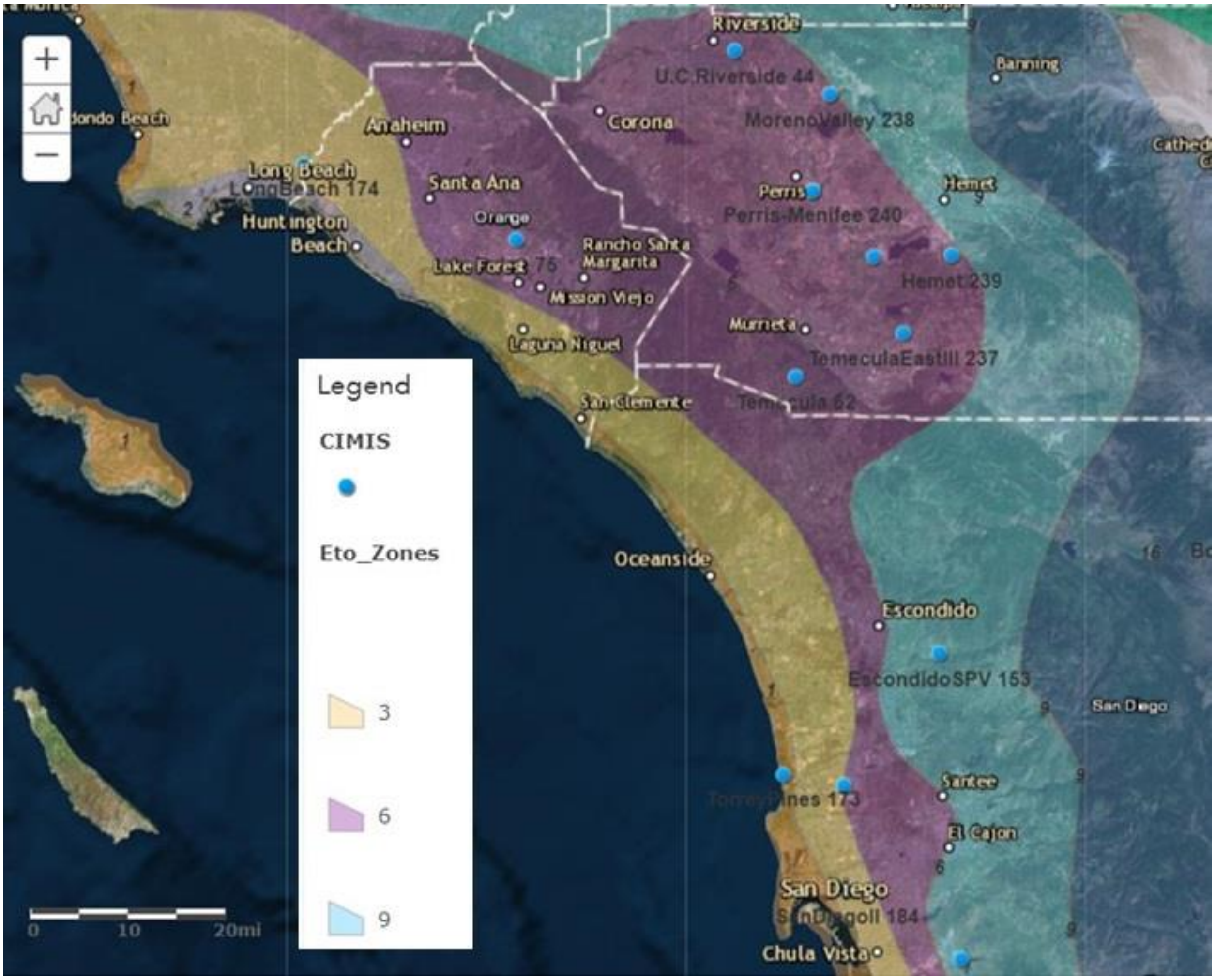


Figure 4. ICP 167775 General Study Area showing California Irrigation Management Information System (CIMIS) climate zones and weather stations (Source: Earthstar Geographics, www.arcgis.com).

In general across the study area, subtropical moisture provided humid and hot conditions, especially after the marine influence subsided from the end of June onward. Conditions got relatively warmer, drier and windier with distance inland, with zone 6 experiencing the hottest and driest averages. Precipitation events were infrequent during the study period. The weather for the Project Participant sites in zone 3 was predictable with morning low clouds, mild winds and warm temperatures at flight time, usually mid to late morning.

## Data Collection

Controlled experiments were conducted at UCR from May through September 2017. Over the same period, EYEON18 gathered and analyzed UAS imagery to identify irrigation patterns and turfgrass growth habits at the Golf Courses. These areas were identified and noted in the imagery provided to turfgrass managers, who made adjustments to irrigation stations to match target conditions based on the imagery plus metered ground observations. Irrigation data was captured from the irrigation central control system.

The Project Team planned to fly 30 UAS missions but actually flew a total of 34 UAS missions for the study with 8, 9, 9, and 8 flights at Golf Course A, B, C and UCR, respectively (Table 3). On occasion, flights had to be rescheduled due to weather (UAS missions cannot be flown when it is raining, also precipitation events reset the ground conditions and therefore can render UAS flight information less informative), golf course scheduling conflicts, equipment repairs, or other special requirements. A small number of flights had to be re-flown due to sensor malfunction on the UAS or processing errors on the Honeycomb Farm cloud service.

All UAS missions are accounted for in the EYEON18 DroneLogBook though some missions have more than one entry. A second entry would be recorded if a short test flight or a second partial or full flight was required to complete the UAS mission. A sample entry is shown in Appendix B.

Soil moisture readings were taken at the time of each UAS mission, typically around one golf feature such as a fairway. The number of samples varied based on the AOI, the launch/land location of the UAS mission team and the preferences of the golf course superintendent. Using GIS software, soil moisture data was displayed over UAS visual and NDVI imagery to assist the Project Team in interpreting ground conditions, to evaluate spatial patterns in the soil moisture, and to provide context for the irrigation tuning recommendations (Figure 3 above). Study site managers did not receive soil moisture analysis deliverables as part of the Project.

| ICP 167775 - Phase IV Flight Data Summary | | | | | |
|---|---|---|---|---|---|
| **Date** | **Location** | **A** | **B** | **C** | **UCR** |
| 5/23/2017 | Golf Course A | 1 | | | |
| 6/7/2017 | Golf Course A | 1 | | | |
| 6/20/2017 | Golf Course A | 1 | | | |
| 7/3/2017 | Golf Course A | 1 | | | |
| 7/21/2017 | Golf Course A | 1 | | | |
| 7/31/2017 | Golf Course A | 1 | | | |
| 8/14/2017 | Golf Course A | 1 | | | |
| 8/28/2017 | Golf Course A | 1 | | | |
| 5/15/2017 | Golf Course B | | 1 | | |
| 5/22/2017 | Golf Course B | | 1 | | |
| 6/5/2017 | Golf Course B | | 1 | | |
| 6/19/2017 | Golf Course B | | 1 | | |
| 7/3/2017 | Golf Course B | | 1 | | |
| 7/17/2017 | Golf Course B | | 1 | | |
| 7/31/2017 | Golf Course B | | 1 | | |
| 8/14/2017 | Golf Course B | | 1 | | |
| 9/11/2017 | Golf Course B | | 1 | | |
| 5/17/2017 | Golf Course C | | | 1 | |
| 5/24/2017 | Golf Course C | | | 1 | |
| 6/6/2017 | Golf Course C | | | 1 | |
| 6/21/2017 | Golf Course C | | | 1 | |
| 7/5/2017 | Golf Course C | | | 1 | |
| 7/26/2017 | Golf Course C | | | 1 | |
| 8/9/2017 | Golf Course C | | | 1 | |
| 8/23/2017 | Golf Course C | | | 1 | |
| 9/13/2017 | Golf Course C | | | 1 | |
| 5/25/2017 | University of California, Riverside | | | | 1 |
| 7/18/2017 | University of California, Riverside | | | | 1 |
| 7/27/2017 | University of California, Riverside | | | | 1 |
| 8/3/2017 | University of California, Riverside | | | | 1 |
| 8/17/2017 | University of California, Riverside | | | | 1 |
| 8/24/2017 | University of California, Riverside | | | | 1 |
| 8/30/2017 | University of California, Riverside | | | | 1 |
| 9/6/2017 | University of California, Riverside | | | | 1 |
| | **TOTAL flights, by location** | **8** | **9** | **9** | **8** |
| | **TOTAL flights, all locations** | | | | **34** |

Table 3. Flight Summary. Unmanned aerial system (UAS) data capture flights conducted for ICP 167775 by EYEON18 from May to September 2017.

Ground Sampling Distance or GSD is the linear dimension of a sample pixel's footprint on the ground (www.asprs.org). The smaller the GSD, the higher resolution of the imagery and the more detail that is captured by the camera sensor. In this study, the GSD or resolution of the UAS imagery is approximately 2-3 *centimeters* while the GPS accuracy used with soil moisture sampling was up to 3 *meters.* This difference in GSD made the alignment between soil moisture values and UAS imagery very difficult. At UCR, flags were placed at each sample site and therefore the sampling locations were fixed over time, making it easier to align to UAS imagery. At the golf courses, the sampling locations varied from UAS mission to UAS mission and it was not feasible to flag the sampling sites. Therefore, for the golf courses, the *average* soil moisture around each sampling site was calculated to better understand trends on the ground when producing recommendations. Further work must be done to tie the UAS imagery and soil measurements together to take advantage of the data. This might include experimenting with more accurate GPS for the soil moisture sensor.

## Irrigation Tuning Recommendations

Study sites were provided with imagery data and recommendations for adjustments to irrigation systems via the Honeycomb Farm™ cloud service (see example in Figure 5). The imagery was analyzed and outlined by EYEON18 Agronomists. The outlined areas within each shared UAS image are suggested areas for an adjustment in irrigation run times or volumes. EYEON18 agronomists communicated with each Project Participant to review their analysis of UAS imagery.

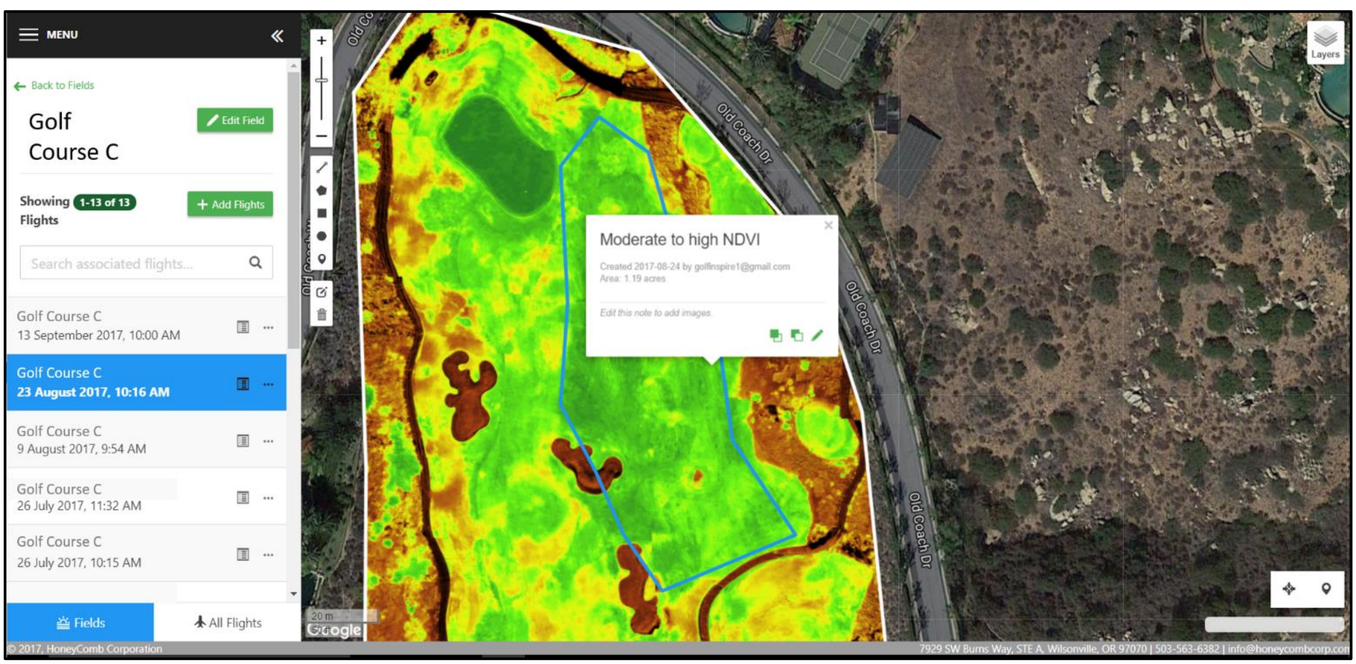
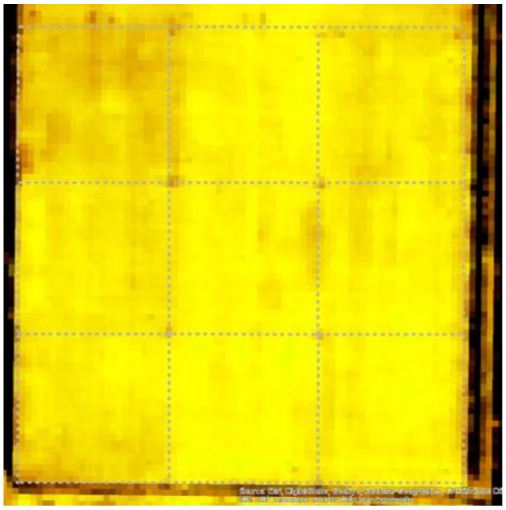


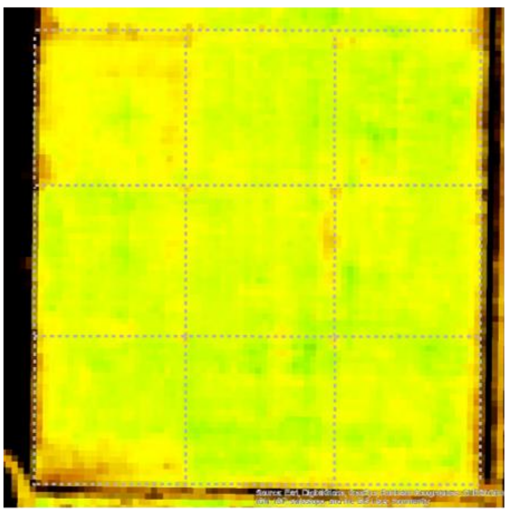

Figure 5. Irrigation Tuning Recommendations: Sample of note shared with Project Participant Golf Course C, 23 Aug 2017. Note includes observed NDVI levels which correspond to amount of irrigation adjustment. Area of polygon also recorded. (Source: EYEON18)

At the Turfgrass Research Facility at the University of California, Riverside (UCR), the recommended irrigation adjustments were designed to manage the EYEON18 turf plots to a level expected at the golf course environments (Figure 6). For the golf courses, these adjustments were guidelines only and it was left to the sole discretion of the golf course Superintendent to react based on the management preferences of the property.

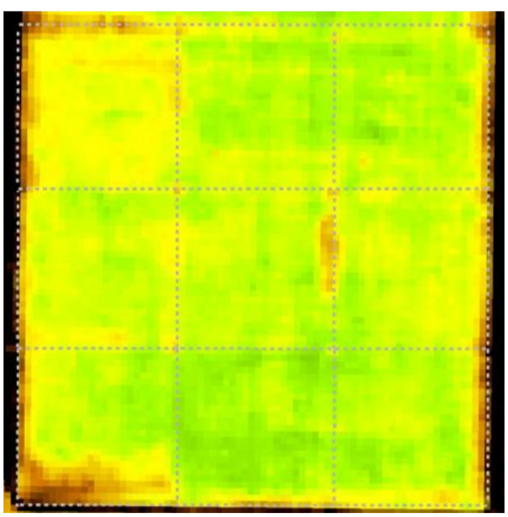
Figure 6. NDVI imagery at the University of California, Riverside. Progression from unmanned aerial system (UAS) flights showing change in Normalized Difference Vegetation Index or NDVI imagery. (Source: EYEON18).



a) NDVI image from UAS flight on 8/17. Somewhat equal distribution of low NDVI with areas of greater stress indicated in darker shades / brown.



b) NDVI image from UAS flight on 8/24. Variation in watering beginning to show. Upper left and lower left plots indicate the most stress while the upper right and lower middle reflect the most vigor.



c) NDVI image from UAS flight on 8/30. Upper left and lower left plots continue to appear most stressed while lower middle section shows highest NDVI.

## Analysis

Three separate analyses were performed at the study locations, which allowed for comparison and aggregation of study data and results: Crop evapotranspiration, Measured Water Savings and Simulated Water Savings. Each analysis is described below. Each analysis is then discussed as performed at each study location along with the results.

### Crop evapotranspiration

The first analysis involves evapotranspiration (ET). Changes in climate cause significant variations in ET, which must be accounted for when calculating water savings. For the study, the Project Team determined how much water would be required to replenish the turf on the day measurements were analyzed, based on ET values provided by weather stations. This value is Crop ET under standard conditions or ETc and is defined as the "amount of water that is lost through evapotranspiration" (Allen et al. 1998). Evaluating water volumes which are above or below the ETc for a given day helps separate the effect of irrigation actions directed by the Superintendent from the variations in total gallons demanded by the changing weather conditions. Superintendents will use their judgment to direct the volume and spatial distribution of irrigation water without negatively or unpredictably affecting the long-term health of the turf. Note that ETc calculations use acreage as input. Total acreage at each golf course was carefully matched to the 18-hole areas of interest to provide for consistent calculations throughout the study period.

For each study site, Crop Evapotranspiration was calculated as follows: *Equation (1)*

$$ET_c = ET\ \frac{inches}{day} * \#\text{ of Irrigated Acres} * \text{conversion factor } K\ \frac{gallons}{day}$$

Where:

ET = Evapotranspiration for previous 24-hour period, inches/day
1 acre = 6,273,000 inches$^2$
1 day = 1,440 minutes
1 gallon = 231 inches$^3$
K = 27,155.84, conversion factor from acre inch to gallons per day calculated as follows:

$$
\begin{aligned}
ET_c &= ET\ \frac{inches}{day} * \#\text{ of irrigated acres } \frac{6{,}273{,}000\ inches2}{acre} * \frac{gallon}{231\ inches3} * \frac{day}{1{,}440\ minutes} \\
&= ET\ \frac{\cancel{inches}}{\cancel{day}} * \#\text{ acres } \frac{6{,}273{,}000\ \cancel{inches2}}{\cancel{acre}} * \frac{gallon}{231\ \cancel{inches3}} * \frac{\cancel{day}}{1{,}440\ minutes} \\
&= ET * \# * \frac{6{,}273{,}000}{231*1{,}440}\ \frac{gallons}{\cancel{minute}} * \frac{1{,}440\ \cancel{minutes}}{day} \\
&= ET * \# * (18.86 * 1{,}440)\ \frac{gallons}{day} \\
&= ET * \# * 27{,}155.84\ \frac{gallons}{day}
\end{aligned}
$$

$$272\ \frac{gallons}{day} = .01\ ET * 1\text{ acre}$$

For one acre of irrigated land, every .01 inch/day change in ET equates to approximately 272 gallons of water per day. This is similar to the result if using the University of California, Davis Flow Rate calculator (http://aqua.ucdavis.edu/Calculations/Flow_Rate.htm) where 1 acre inch = 27,204 gallons / day or .01 acre inch = 272 gallons / day.

**Irrigation Management at Golf Study Sites**

Before presenting the second and third analysis methods, a description of irrigation central control systems used at Golf Courses sites is warranted. These systems are sophisticated irrigation scheduling programs which control the amount of precipitation or watering at each sprinkler head throughout the property. A 100-acre golf course may have several thousand individual sprinkler heads. As installed, each sprinkler head is identified and connect by stations, with an associated default runtime(s) for each cycle. The Precipitation data is entered for each Station based on several factors: head type, number of heads per station, spacing, nozzle type and line pressure are used to calculate the gallons per minute (gpm) of the station and the inches per hour per station. Stations are assigned to a similar feature such as fairway or greens for purposes of irrigation management. Each individual feature has a percentage adjustment which affects all assigned stations default runtimes. Features are grouped into programs such as "front 9 Greens" or "back 9 Greens", and a percentage adjustment is available to affect all areas assigned to that Program. Each level of irrigation can be adjusted individually or using a percentage value for the entire database. All Programs are then subject to the Global Adjustment Percentage. Global Adjustment effects all Programs and areas, stations assigned to them. Evapotranspiration (ET) adjustments affect the global adjustment percentage, i.e., all levels. ET numbers are polled from the weather station or entered manually before each irrigation cycle. As a result, watering is modified to account for weather conditions without the need to modify individual levels.

EYEON18 uses the Normalized Difference Vegetative Index (NDVI) to identify irrigation pattern indicators of the turfgrass growth habits. Turf managers identified "target areas" on the property that would best represent their management goals for conditioning. These target areas were metered for soil moisture levels and the NDVI values were identified in the UAS imagery. Adjustments were made to individual station runtime percentages to the target conditions from the imagery, plus metered ground observations.

Individual Station runtime adjustments are necessary to account for the effects that unique microclimates have on localized turf health and quality. In some cases, percentage adjustments can be applied to Areas or at the Program level, but most commonly are made to individual stations. "Tuning" the Station accounts for local needs of the turfgrass and produces uniform playing conditions for entire areas and programs. The goal is to provide the best possible field of play by utilizing this technology's ability to precisely recommend irrigation adjustments throughout the golf course grounds. The perspective of up-to-date aerial imagery allows turf managers to view the property as a whole and to identify large growth and irrigation patterns that are not as easily recognized at ground level.

## Measured Water Savings

The second analysis is measured water savings, the reduction in water use observed after irrigation adjustments were made at study sites. As planned, measured water savings would be calculated from the irrigation logs at each golf course as total flow in gallons per cycle. The difference between total gallons used *before* and *after* the implementation of irrigation tuning adjustments would represent measured water savings for one cycle.

The TORO Lynx® systems at Golf Courses A and B can provide runtime and gallons per minute for every sprinkler head for the entire golf course. This export produces thousands of records per overnight run cycle, which were provided to the Project Team in a PDF report and converted to Excel. Note that an irrigation head may have 0 to many rows of runtime data per cycle to accommodate specific watering targets and turfgrass conditions. For every runtime record or row, runtimes in minutes were converted to decimal values and multiplied by the gallons per minute, resulting in gallons per runtime row per cycle (Figure 7). In Excel, pivot tables were used to summarize total gallons for each runtime row per cycle, e.g., 1FW17 indicating hole # 1, fairway #17 in the central control system (Figure 8). Water data for irrigated areas outside the study area were removed, e.g., for a 27-hole golf course, the extra 9 holes were excluded or the practice green and clubhouse areas were removed, leaving only water data for the study area covering 18 holes at each golf course. Total flow per cycle in gallons was totaled. For each UAS mission at Golf Courses A and B, measured water savings represents the comparison of the total flow for the run cycle *before* adjustments to the total flow of the run cycle *after* adjustments within the AOI corresponding to the 18-hole area of interest. At Golf Course C, the TORO SitePro® system provided only total gallons for a run cycle for each UAS mission date. Therefore, total flow *before* and *after* adjustments was used without the need to aggregate by irrigation head or station.

| Start | End | Area | Hole | Tag | GCnum | Desc | Program | Flow gpm | RTmmss | Rtdec | Rt_gal |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/24/2017 8:30:00 PM | 5/24/2017 8:34:24 PM | Tees | 1 | 1 | 1-11-01 | 1TE1 | 2 | 19 | 04:24 | 4.4000 | 83.60 |
| 5/24/2017 8:30:00 PM | 5/24/2017 8:34:24 PM | Tees | 1 | 2 | 1-11-02 | 1TE2 | 2 | 19 | 04:24 | 4.4000 | 83.60 |
| 5/24/2017 8:30:00 PM | 5/24/2017 8:34:24 PM | Tees | 1 | 4 | 1-11-04 | 1TE4 | 2 | 19 | 04:24 | 4.4000 | 83.60 |
| 5/24/2017 8:30:00 PM | 5/24/2017 8:34:27 PM | Fairways | 1 | 35 | 1-14-05 | 1FW35 | 3 | 19 | 04:27 | 4.4500 | 84.55 |
| 5/24/2017 8:30:00 PM | 5/24/2017 8:33:33 PM | Fairways | 1 | 36 | 1-14-12 | 1FW36 | 3 | 19 | 03:33 | 3.5500 | 67.45 |

Figure 7. Example of export from TORO Lynx® system showing runtime rows controlling irrigation for specific sprinkler locations, with additional columns added for water use analysis: RTmmss (runtime in minutes and seconds), Rtdec (runtime in decimal minutes), and Rt_gal, which is the total flow for this runtime record in gallons (equal to Rtdec * Flow gpm). (Source: Superintendent at Golf Course B and EYEON18)

| | A | B | C | D |
|---|---|---|---|---|
| 1 | Row Labels | Count of Flow gpm | Sum of Rtdec | Sum of Rt_gal |
| 1018 | 1TE2 | 1 | 4.400000002 | 83.60000003 |
| 1019 | 1TE3 | 1 | 7.466666673 | 164.2666668 |
| 1020 | 1TE4 | 1 | 4.400000002 | 83.60000003 |
| 1021 | 1TE5 | 1 | 7.466666673 | 164.2666668 |
| 1022 | 1TE6 | 1 | 7.466666673 | 164.2666668 |

Figure 8. Example of pivot table summarizing runtime rows for locations 1TE2 through 1TE6 for the entire overnight irrigation cycle where: Sum of Rtdec is the total runtime for this sprinkler location, in decimal minutes; Sum of Rt_gal, is the total flow for this sprinkler location, in gallons. (Source: EYEON18)

A sample calculation of measured water savings is shown in Figure 9. On 7/17, Total Flow is 325,000 gallons, summarized from all runtime rows for an irrigation cycle. ETc of 407,376 gallons was calculated using ET in/day then subtracted from Total Flow. This remainder is the amount of water over which the Superintendent has relative control beyond the effects of weather and precipitation. The amount above (below) ETc indicates how much current irrigation settings are running compared ETc, in this example 82,376 gallons or 20% below ETc on 7/17. After irrigation adjustments are made, savings are not simply the difference in Total Flow; rather, savings are normalized for weather by subtracting ETc. In the example, on 7/18 the net change below ETc from 7/17 is -2%.

| MEASURED WATER SAVINGS | | |
|---|---|---|
| **Sample Golf Course** | | |
| | | |
| Irrigated Acres | **100** | |
| % ET / water budget factor | **80%** | |
| Date | **7/17** | **7/18** |
| ET, in/day | **0.15** | **0.18** |
| Total Flow, gal | **325,000** | **380,000** |
| ETc, gal | **407,376** | **488,851** |
| Above (below) ETc, gal | **(82,376)** | **(108,851)** |
| Above (below) ETc, % | **-20%** | **-22%** |
| Net change above (below) ETc, % | | **-2%** |

Figure 9. Measured Water Savings for a sample, hypothetical golf course with 100 irrigated acres.

**Simulated Water Savings**

At the golf courses, irrigation adjustments were made under the discretion of each Superintendent and as a result, on many dates, Project Team irrigation recommendations were not implemented. Therefore, the number of actual adjustments was less than the number of recommendations made by the Project Team Agronomists.

The Project Team was interested in the potential water savings which could have resulted if all adjustments recommended by the Project Team had been implemented. Therefore, simulated water savings were calculated for each study site over the study period.

After each UAS mission, the EYEON18 Agronomist highlighted areas of interest on the UAS imagery. Notes were provided with each highlight or polygon, e.g., "High NDVI, possible reduction of 5%-10%", meaning that the water applied by irrigation heads within this zone could be decreased based on analysis of the imagery (example in Figure 5 above). Acreage for each polygon is calculated automatically when the note is added.

For each golf course, simulated water savings were calculated as follows: *Equation (2)*

$$\text{Water Savings}_{simulated} = \Sigma \text{ Water Savings}_{simulated} \text{ per day} * \text{number of days to end of study}$$

Where:

$$\text{Water Savings}_{simulated} \text{ per day} = \text{acreage} * \frac{heads}{acre} * \frac{flow\ rate}{head} * \text{runtime minutes} * \text{\% change}$$

Acreage = polygon statistic from website

$\frac{heads}{acre}$ = 16 (constant)

$\frac{flow\ rate}{head}$ = 22 $\frac{gallons}{minute}$ (constant)

Runtime = 10 minutes (constant)

% change:

| Note | % decrease in irrigation |
|---|---|
| Very High NDVI | 15 |
| High NDVI | 10 |
| Moderate NDVI | 5 |

Number of days to end of study = days from date of UAS imagery to 9/30.

Simulated water savings assume that all irrigation heads within each polygon would be adjusted by the recommended percent and held at that level until the end of the study, i.e., the savings would accrue daily. To demonstrate, assume that on a particular day, say the Project Team identified four areas of interest (Figure 10). Total simulated savings for each AOI would be (acreage * 16 heads / acre * 22 gpm per head * 10 minutes runtime * % reduction), e.g., for the first row, (2 acres * 16 * 22 * 10 * 10% reduction) = 704 gallons simulated water savings for that AOI for that day. Repeat for the remaining three AOIs to get 1,725 gallons simulated water savings for all AOIs for that day. Assume the adjustments were held for the 73 days remaining in the study period for a simulated savings total of 96,360 gallons. To estimate the simulated water use for the entire golf course, use the same assumptions for flow, i.e., the same heads/acre, gpm/head, and runtime minutes, but apply the calculations for the entire 100 acres. In this case, simulated water use per day for the entire golf course would be (100 * 16 * 22 * 10) or 352,000 gallons. With 73 days remaining in the study period, simulated water use to end would be 25,696,000. The percent water saved would be the gallons saved divided by the gallons used, i.e., 125,910 / 25,696,000 or 0.5%.

If the reduction was too drastic, the NDVI imagery for future dates would show stress and the Project Team Agronomist would recommend an upward adjustment for the same area of interest (polygon) during the study period. Note: Upward adjustments were recommended at UCR but not at any of the golf course sites during the study period.

| SIMULATED WATER SAVINGS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Sample Golf Course** | | | | | | | | | | |
| heads/acre | 16 | | 100 | irrigated acres | | | | | | |
| gpm/head | 22 | | 352,000 | water use, total acres, gal | | | | | | |
| runtime minutes | 10 | | | (simulated) | | | | | | |
| date begin | 5/1/2017 | | | | | | | | | |
| date end | 9/30/2017 | | | | | | | | | |
| date of UAS flight | cum. water savings to end, gal | # days to end | water USE to end, gal | water USE per day, gal | water savings per day, gal | water savings per day per AOI, gal | # heads per AOI | acres per AOI | # adj's | note |
| 7/19/2017 | | | | | | 704 | 32 | 2.0 | 10.0% | High NDVI |
| 7/19/2017 | | | | | | 616 | 56 | 3.5 | 5.0% | Moderate NDVI |
| 7/19/2017 | | | | | | 229 | 21 | 1.3 | 5.0% | Moderate NDVI |
| 7/19/2017 | | | | | | 176 | 8 | 0.5 | 10.0% | High NDVI |
| 7/19/2017 | 125,910 | 73 | 25,696,000 | 352,000 | 1,725 | | | | | |
| **Total** | 125,910 | | 25,696,000 | | | | 117 | 7 | 4 | |
| **%** | 0.5% | | | | | | | | | |

Figure 10. Simulated Water Savings for a sample, hypothetical golf course with 100 irrigated acres, with calculations for four areas of interest (polygons with notes for changing irrigation settings).

## Results – The University of California, Riverside (UCR)

### Study Site

The Project Team coordinated research with Dr. James Baird, Ph.D., Turfgrass Specialist at the UCR Turfgrass Research Facility (UCR). Dr. Baird's research interests include turfgrasses; improvement with emphasis on fescues, ryegrasses, bermudagrass, and kikuyugrass; water conservation; salinity management; pest management with emphasis on weeds and diseases. Additional work was spearheaded by Dr. Marco Schiavon, Ph.D., Assistant Researcher and from Pawel Petelewicz, Ph.D., a postdoctoral Scholar, both working with the UCR TRF. Dr. Schiavon's research interests focus on water conservation to irrigate turfgrass in California while Dr. Petelewicz's emphasis is on turfgrass and pest management. The UCR Turfgrass Research Facility consists of several acres of turfgrass research plots, greenhouses and offices located at the UCR Agricultural Experiment Station. According to the California Irrigation Management System (CIMIS), UCR is located in Reference EvapoTranspiration (ET) zone 6, "Los Angeles Basin" (CIMIS 2017).

Programs at UCR focus on current problems and issues such as:

- Resource efficiency in the areas of water, nutrition, pest management, and energy and labor input in sites such as lawns, parks and golf courses;
- Environmental enhancement and protection; and
- Turfgrass persistence and performance with increased traffic on heavily used sports fields

As described in "Turfgrass and Landscape Research Field Day" (Baird et al. 2017), turfgrass for the experiment was 'Tifway II' bermudagrass established from sod on 27 April 2017. Soil was a Hanford fine sandy loam. Turf received 0.5 lb. N/1000 ft2 every 6 weeks for a target of 5 lbs. N/1000 ft2/yr. Mowing height was 0.5 inches (3 days/wk).

### Experiment

UAS missions at UCR were conducted in late May after allowing time for the turf to begin to establish or "grow in". Flights were temporarily suspended until all conditions were met for compliance to UCR special requirements: 1) increased levels of insurance for the UAS, 2) employ a University of California Part 107 certified pilot (Sophia Koutzoukis and Holly Andrews) to participate in each mission in order to operate under UCR's Waiver for controlled airspace.

The UCR TRF based their research on scheduling irrigation to replace a percentage of reference evapotranspiration (ETo) using a CIMIS weather station located on UCR grounds. Nine plots of 20' x 20' were randomly assigned to one of three watering regimes (Figure 11). Regime No. 1 was Variable % ETo as directed by the Project Team. Regime No. 2 was 75% ETo selected by UCR as the appropriate crop coefficient for this turfgrass. Regime No. 3 was 1.5 inches/week, analogous to "frequent" irrigation. Irrigation was the same for all regimes, i.e., targeted at 75% ETo, from late April to 17 July when separate irrigation treatments were initiated. From mid-July to the end of September, weekly irrigation budgets were divided into 3 events (days) per week by hand watering with a hose/nozzle with a known output (gpm).

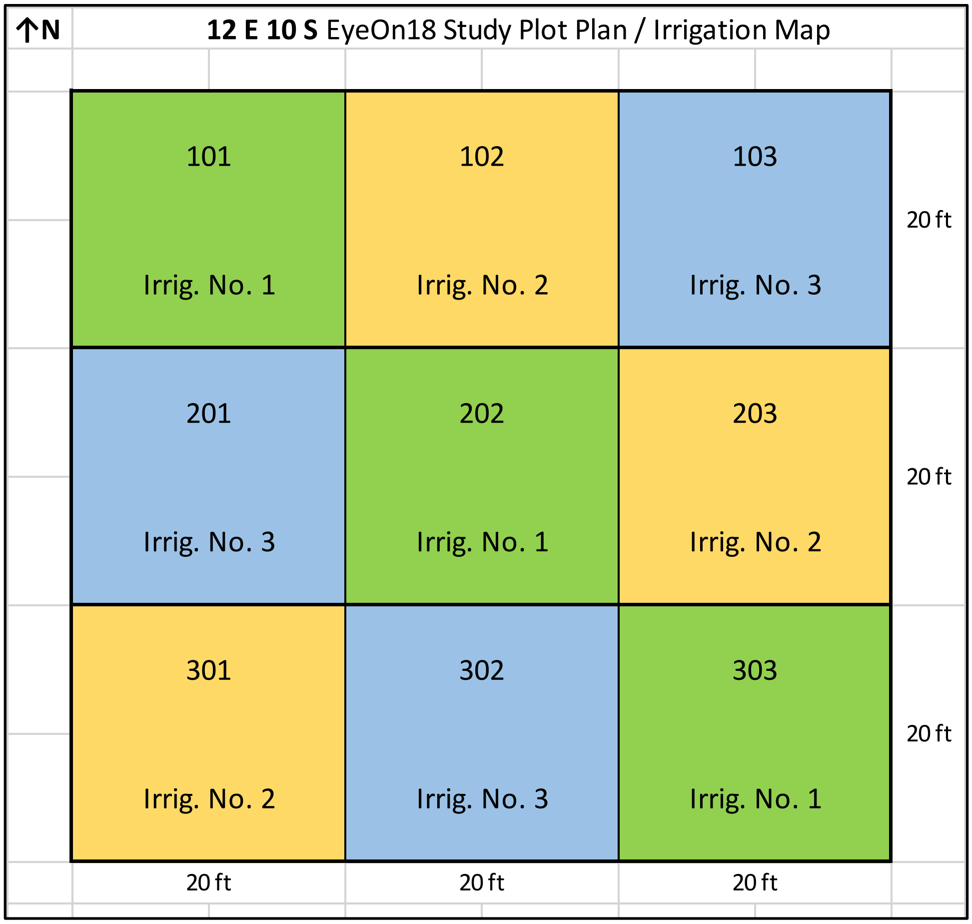


Figure 11. Plot Plan / Irrigation Map for ICP 167775 turfgrass experiments conducted at The University of California, Riverside (UCR) from May through September 2017. Each plot square is 20’ x 20’. Color of plots indicate watering regime: green = No 1. Variable ETo Replacement (EYEON18), yellow = No 2. 75% ETo and blue = No 3. 1.5 inches/week. (Source: University of California, Riverside research staff)

A set number of soil moisture readings were taken by the Project Team at the time of each UAS mission. Within each 20’ x 20’ sod plot, five evenly-spaced samples were taken for a total of 45 samples per UAS mission (Figure 12). UCR TRF staff also evaluated ground level turf quality each week, including NDVI (using a Green Seeker handheld crop sensor).

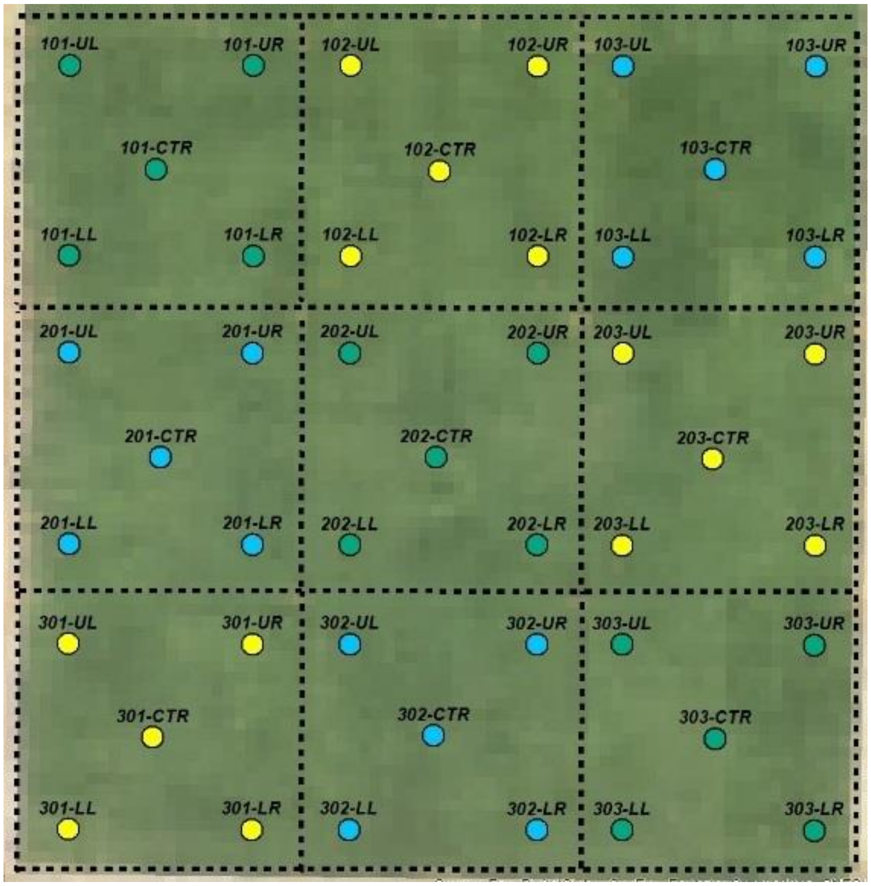


Figure 12. Soil moisture sample locations over visible UAS imagery for ICP 167775 turfgrass experiments at the University of California, Riverside from May through September 2017. Each plot square is 20' x 20'. Color of dots indicate watering regime: green = No 1. Variable ETo Replacement (EYEON18), yellow = No 2. 75% ETo and blue = No 3. 1.5 inches/week. (Source: EYEON18).

## Water Savings

The controlled study at the University of California, Riverside (UCR) shows that using UAS imagery can provide turfgrass managers with irrigation savings. Over the study period, water savings of 21% below ETo were achieved for the EYEON18 study plots. Water savings were determined by comparing the total gallons applied to the plots under each watering regime from one week to the next. Volumetric water content was recorded within each plot during each flight.

Table 4 shows the actual water volumes applied during the controlled study, along with corresponding ET values. All plots began the study with irrigation applications of 75% of ETo, applied manually 3 times per week. The progression of NDVI imagery at UCR is shown in Figure 6 above. Plot No.1 was the Variable % ETo plot controlled by EYEON18 using the UAS imagery. During weeks 5, 6 and 7 upward adjustments were made to the Variable % ETo plots to adjust for stress indicators in the NDVI imagery. The conclusion of the study revealed total gallons used on the UAS monitored plots to be 79% of ETo. a 21% irrigation savings below standard ETo irrigation. Table 5 details how the 79% of ETo was calculated for the EYEON18 plots at UCR. Plot No. 2 was maintained at 75% of ETo for the entire study. The total gallons used on plot No. 2 to be 78% of ETo or a 22% savings of full ETo irrigation. Plot No. 3 had a total of 1.5 inches of water applied during the 3 irrigation applications each week to represent "frequent irrigation". Irrigating to a consistent precipitation rate per week resulted in 104% of ETo.

| Week | Week starting date | Previous weekly CIMIS $ET_0$ | Variable ETo Replacement | 75% ETo Replacement | 1.5 inches of water / week | Variable ETo Replacement | 75% ETo Replacement | 1.5 inches of water / week |
|---|---|---|---|---|---|---|---|---|
| | | | ---------- inches ---------- | | | ------------ gallons ------------ | | |
| 1st | 7/19/2017 | 1.7 | 1.3 | 1.3 | 1.5 | 322 | 322 | 374 |
| 2nd | 7/27/2017 | 1.6 | 1.2 | 1.2 | 1.5 | 290 | 290 | 374 |
| 3rd | 8/03/2017 | 1.1 | 0.8 | 0.8 | 1.5 | 201 | 201 | 374 |
| 4th | 8/10/2017 | 1.4 | 1.0 | 1.0 | 1.5 | 252 | 252 | 374 |
| 5th | 8/17/2017 | 1.6 | 1.3 | 1.2 | 1.5 | 323 | 307 | 374 |
| 6th | 8/24/2017 | 1.4 | 1.2 | 1.0 | 1.5 | 304 | 258 | 374 |
| 7th | 8/31/2017 | 1.2 | 1.1 | 0.9 | 1.5 | 270 | 224 | 374 |
| 8th | 9/06/2017 | 1.5 | 1.2 | 1.2 | 1.5 | 286 | 286 | 374 |
| **Total** | | **11.5** | **9.1** | **8.6** | **12** | **2248** | **2140** | **2992** |

Table 4. Weekly reference evapotranspiration (ETo) and watering consumption (inches and gallons) for the three irrigation treatments on bermudagrass turf. (Source: University of California, Riverside, 2017, "Turfgrass & Landscape Research Field Day", p 50)

| MEASURED WATER SAVINGS<br>University of California, Riverside | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Acreage** | | | | | | | | | |
| Plot size, ft | 400 | | | | | | | | |
| Plots per regime | 3 | | | | | | | | |
| Total size per regime, ft | 1,200 | | | | | | | | |
| Total size per regime, acres | 0.02754821 | | | | | | | | |
| **Water Calculations** | | | | | | | | | |
| Irrigated Acres | 0.02754821 | | | | | | | | |
| %ET / water budget factor | 100% | | | | | | | | |
| Watering Regime | No 1 (E18) | No 1 (E18) | No 1 (E18) | No 1 (E18) | No 1 (E18) | No 1 (E18) | No 1 (E18) | No 1 (E18) | No 1 (E18) |
| Date | all | 7/19 | 7/27 | 8/3 | 8/10 | 8/17 | 8/24 | 8/31 | 9/6 |
| ET (in/period) | 11.50 | 1.70 | 1.60 | 1.10 | 1.40 | 1.60 | 1.40 | 1.20 | 1.50 |
| Variable % ET (in/period) | 11.50 | 1.30 | 1.20 | 0.80 | 1.00 | 1.30 | 1.20 | 1.10 | 1.20 |
| Variable % ET (%) | 79.28% | 76% | 75% | 73% | 71% | 81% | 86% | 92% | 80% |
| Total Flow (gal) | 6,744 | 966 | 870 | 603 | 756 | 969 | 912 | 810 | 858 |
| ETcrop (gal) | 8,604 | 1,272 | 1,197 | 823 | 1,047 | 1,197 | 1,047 | 898 | 1,122 |
| Above (below) ETcrop (gal) | (1,860) | (306) | (327) | (220) | (291) | (228) | (135) | (88) | (264) |
| Above (below) ETcrop (%) | -21.62% | -24% | -27% | -27% | -28% | -19% | -13% | -10% | -24% |

Table 5. Measured Water Savings for Project ICP 167775 showing average of 79% ETo over course of study for Variable % ETo (EYEON18 plots) in controlled experiments at the University of Riverside, California. Variable % ETo is derived by dividing Variable ETo Replacement inches by Previous weekly CIMIS ETo. (Source: University of California, Riverside research staff and EYEON18)

## Results - Golf Course A

### Study Site

Golf Course A is a non-equity, privately owned facility located in San Diego County approximately 4.5 miles inland in CIMIS Reference ET zone 3, "Coastal Valleys" (CIMIS 2017). The golf course was constructed using 419 hybrid Bermuda grass for all surfaces excluding the greens. The Bermuda growing season begins around the middle of March and extends through the middle of November when the turf goes into dormancy. The 419 Bermuda grass is one of the more drought tolerant warm season grasses available. The greens are Poa annua with some bentgrasses in the population. The golf course had more than 100 acres of irrigated turf but following the MWD turf reduction program in 2014/15 the acreage was reduced to 58 acres. Available water sources are: reclaimed and potable sources. Management uses the latest Toro central control system (Toro Lynx®) and Flex 800 and 690 gear drive rotors to irrigate.

### Analysis

The progression of NDVI imagery at Golf Course A is shown in Figure 13. The high NDVI fairway (reflected as darker green within the polygon) was identified for the Superintendent to make irrigation runtime adjustments. The last image in the sequence shows the effects of those irrigation changes. The fairway is now displaying a lower NDVI value and increased uniformity. This leads to not only adding the benefits of water savings, but also increasing the predictable playability of the Golf Course.

Irrigation data was recorded during the study period for *before* and *after* irrigation runtime adjustments.

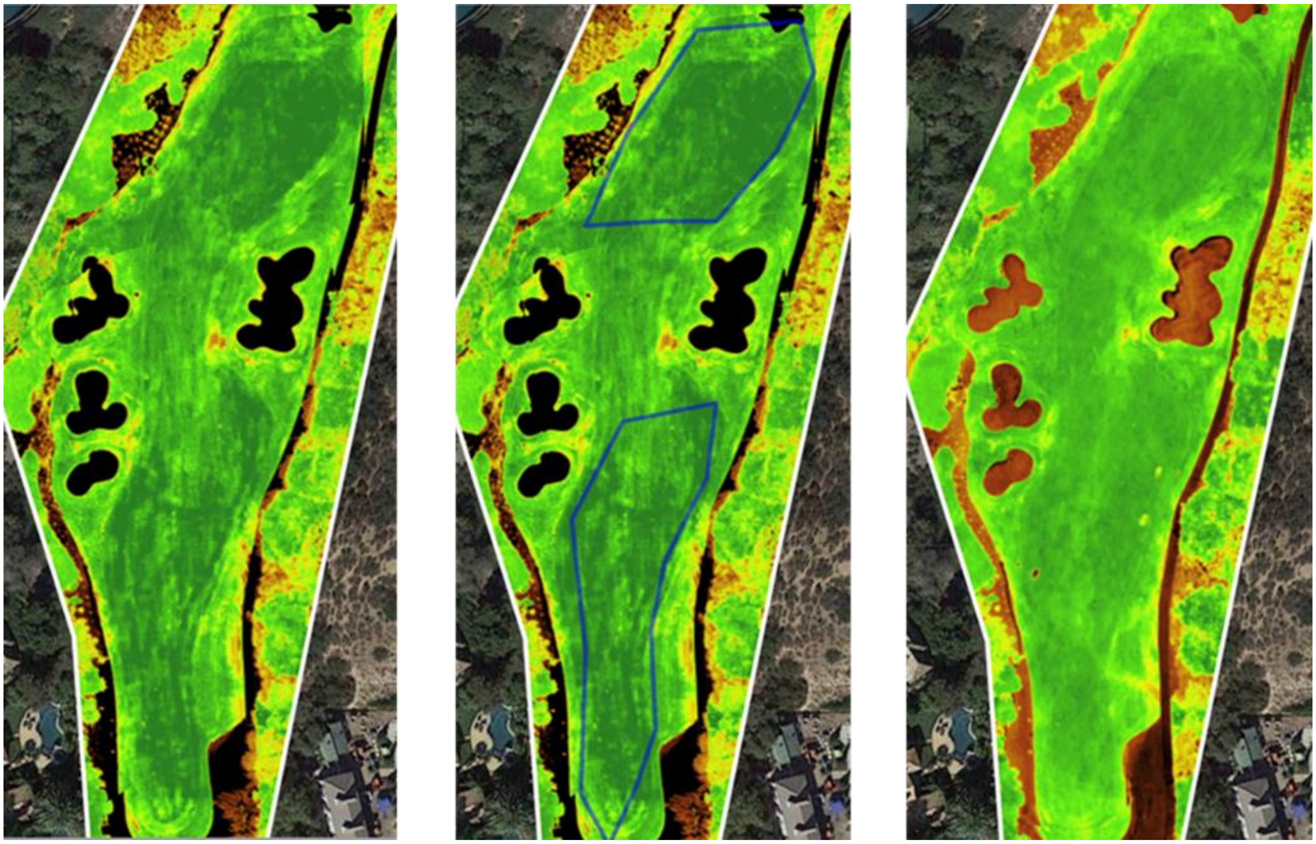


Figure 13. NDVI imagery at Golf Course A. Dark green areas of high NDVI (left) are marked by Project Team with polygons recommending irrigation tuning (center). The final image in the sequence shows lower NDVI and more consistent spatial distribution of NDVI values after irrigation adjustments (right). (Source: EYEON18)

### Measured Water Savings

Measured water savings at Golf Course A were indeterminate with two significant factors contributing to the outcome. First, the fairways were not being irrigated in the earlier part of the study. Fairways represent a large percentage of the golf course, especially at this property given the extensive turf removal projects completed in 2014/2015. Therefore, analysis of water use data for the earliest UAS missions was deemed unrepresentative due to the small turf acreage represented in the calculations. Second, irrigation logs for later UAS missions were unrecoverable due to a malfunction with the central control system. The Project Team continued to make irrigation recommendations for the remainder of the study which the Superintendent implemented at their discretion.

**Simulated Water Savings**

Simulated water savings for Golf Course A are shown in Table 6. For each UAS mission, the potential savings represented within an area of interest (polygon on the UAS imagery) was determined using the calculations outlined in the Analysis section: (acreage * heads/acre * gpm/head * runtime minutes * % reduction). Estimates for all polygons/recommendations for one flight were summarized, e.g., for 5/23, the simulated water savings was 4,662 gallons. Assuming the adjustments were made on 5/23 and held until the end of the study, the cumulative water savings would be: (savings per day) * (number of days remaining in the study), e.g., for 5/23, water savings of 4,662 gallons * 130 days remaining would be a potential water savings of 606,091 gallons by the end of the study period. Cumulative savings for each flight were calculated, the sum of which is 1,316,941 gallons for Golf Course A.

Simulated water use for the entire golf course on a particular was estimated using the same formula for 58 acres, e.g., 204,160 gallons per day. Cumulative water use using simulation assumptions would be: (use per day) * (number of days remaining in the study from the first day recommendations were implemented). If the first irrigation adjustment was made on 5/23 with 130 days remaining, the simulated water use for the entire golf course would be 25,540,800 gallons. As a result, the simulated water savings as a percent of total simulated water use for Golf Course A would be 5.0%.

| | | | | | |
|---|---|---|---|---|---|
| **SIMULATED WATER SAVINGS** | | | | | |
| **Golf Course A** | | | | | |
| heads/acre | 16 | | 58 | irrigated acres | |
| gpm/head | 22 | | 204,160 | water use, total acres, gal | |
| runtime minutes | 10 | | | (simulated) | |
| date begin | 5/1/2017 | | | | |
| date end | 9/30/2017 | | | | |
| date of UAS flight | cum. water savings to end, gal | # days to end | water USE to end, gal | water USE per day, gal | water savings per day, gal |
| 5/23/2017 | 606,091 | 130 | 26,540,800 | 204,160 | 4,662 |
| 6/7/2017 | 365,433 | 115 | | | 3,178 |
| 6/20/2017 | 189,753 | 102 | | | 1,860 |
| 7/3/2017 | 53,571 | 89 | | | 602 |
| 7/21/2017 | 75,476 | 71 | | | 1,063 |
| 7/31/2017 | 7,515 | 61 | | | 123 |
| 8/14/2017 | 16,709 | 47 | | | 356 |
| 8/28/2017 | 2,393 | 33 | | | 73 |
| **Total** | 1,316,941 | | 26,540,800 | | |
| **%** | 5.0% | | | | |

Table 6. Simulated Water Savings for Golf Course A. (Source: EYEON18)

## Results - Golf Course B

### Study Site

Golf Course B is a private, non-equity facility located in San Diego County approximately 4 miles inland in CIMIS Reference ET zone 3, "Coastal Valleys" (CIMIS 2017). The golf course was constructed using salt tolerant Paspalum 'Excalibur' warm season grass for all play surfaces excluding the greens due to the sodic nature of the native soils. The greens are composed of Poa annua and Bentgrasses. The Paspalum growing season begins around the first week of April and extend through the first frost in November. The golf course has 184 acres of irrigated turf using 3 water sources: well water, reclaimed, and potable. Management uses the latest Toro central control system (Toro Lynx®) and Flex 800 and 690 gear drive rotors to irrigate.

The characteristics and growth habits of the Paspalum and Bermudagrass register differently in NDVI and must be recognized while making irrigation recommendations and adjustments. This is where the EYEON18 method has advantages over UAS solutions which require multiple flights to capture both visible and near-infrared imagery. Multi-Spectral data is collected during the same flight as visible imagery. This allows the Project Team consultants and the turfgrass Managers to reference features and turf types in high resolution visual and NDVI side by side (Figure 14). The progression of NDVI imagery at Golf Course B is shown in Figure 15.

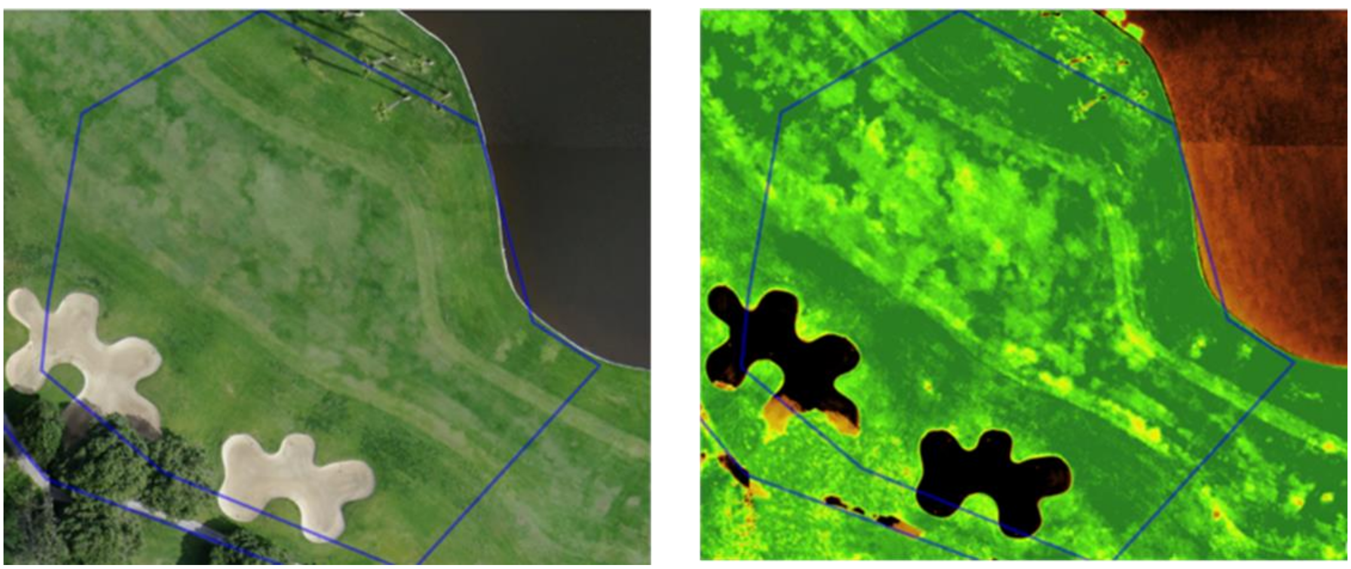


Figure 14. UAS imagery showing visible bands (left) and NDVI (right) of the same area at Golf Course B. The area of interest in the blue polygon consists of mixed turfgrass species, which register differently in the imagery. (Source: EYEON18)

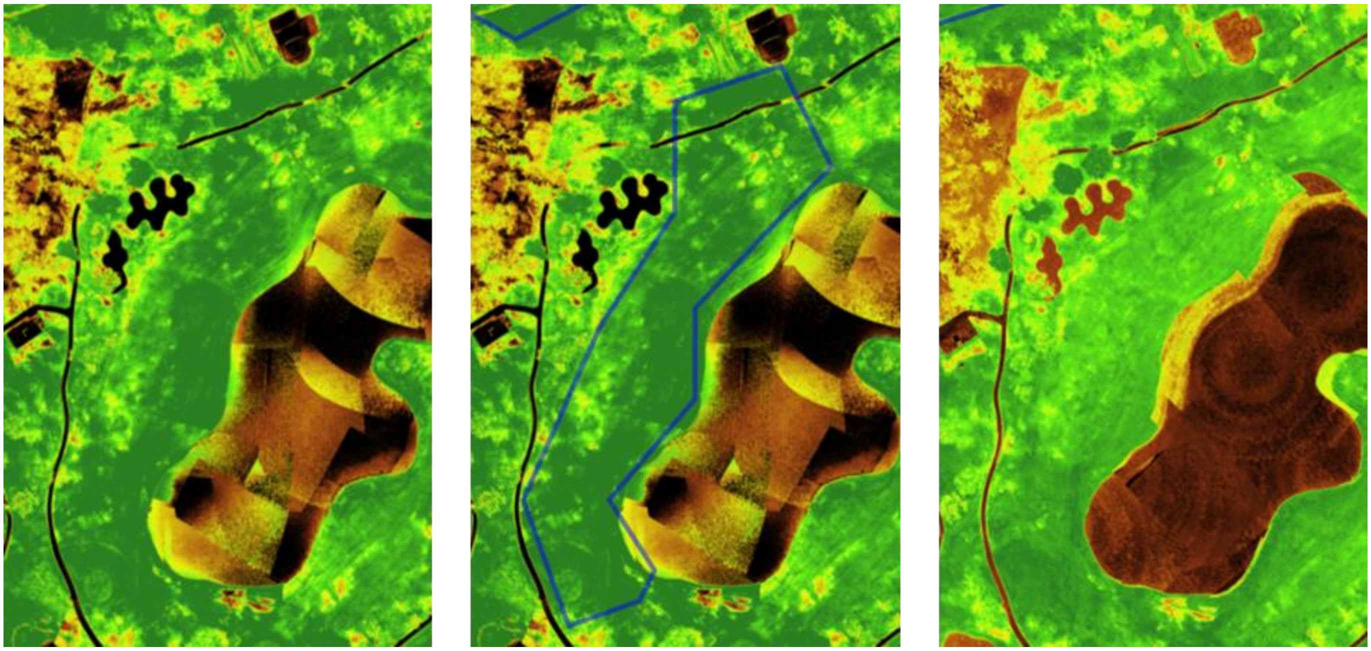


Figure 15. NDVI imagery at Golf Course B from UAS flights showing change in Normalized Difference Vegetation Index or NDVI imagery. (Source: EYEON18). Progression of NDVI imagery from UAS flight on 5/22 (left), from UAS flight on 5/22 with polygon highlighting area of interest with high NDVI (center), and from UAS flight on 6/5 showing lower NDVI values and more even distribution of plant health indicators.

**Measured Water Savings**

Similar to Course A, Course B is also running at 80% of ET. The comparison showed an additional water savings of 1% above the water conservation measures that were already in place. A representative sample of measured water savings is shown in Table 7.

Total Flow was extracted from the irrigation report provided by the Superintendent. ETc was calculated using the 24-hour average ET acquired from a local weather station. On 5/25pre, before irrigation adjustments were made, ETc was 863,122 gallons, which is much higher than the Total Flow, indicating that the irrigation system was watering well below the levels required for 100% replenishment of water loss due to evapotranspiration. After adjustments, the Total Flow planned for the next irrigation cycle was a bit further below ETc. The difference in water volumes on 5/25 *before* and *after* irrigation adjustments was -1%.

| MEASURED WATER SAVINGS | | |
|---|---|---|
| **Golf Course B** | | |
| | | |
| Irrigated Acres | **184** | |
| %ET / water budget factor | **80%** | |
| Date | **5/25pre** | **5/25post** |
| ET, in/day | **0.17** | **0.17** |
| Total Flow, gal | **424,644** | **412,429** |
| Etc, gal | **863,122** | **863,122** |
| Above (below) Etc, gal | **(438,478)** | **(450,693)** |
| Above (below) Etc, % | **-51%** | **-52%** |
| Net change above (below) Etc, % | | **-1%** |

Table 7. Representative sample of measured water savings at Golf Course B. Change in irrigation based on Project Team recommendations as a percent of ET is approximately 1%. (Source: Golf Course B Superintendent and EYEON18)

**Simulated Water Savings**

Simulated water savings for Golf Course B are shown in Table 8. For each UAS mission, the potential savings represented within an area of interest (polygon on the UAS imagery) was determined using the calculations outlined in the Analysis section: (acreage * heads/acre * gpm/head * runtime minutes * % reduction). Estimates for all polygons/recommendations for one flight were summarized, e.g., for 5/22, the simulated water savings was 10,338 gallons. Assuming the adjustments were made on 5/22 and held until the end of the study, the cumulative water savings would be: (savings per day) * (number of days remaining in the study), e.g., for 5/22, water savings of 10,338 gallons * 131 days remaining would be a potential water savings of 1,354,309 gallons by the end of the study period. Cumulative savings for each flight were calculated, the sum of which is 4,812,474 gallons for Golf Course B.

Simulated water use for the entire golf course on a particular was estimated using the same formula for 184 acres, e.g., 647,680 gallons per day. Cumulative water use using simulation assumptions would be: (use per day) * (number of days remaining in the study from the first day recommendations were implemented). If the first irrigation adjustment was made on 5/22 with 131 days remaining, the simulated water use for the entire golf course would be 84,846,080 gallons. As a result, the simulated water savings as a percent of total simulated water use for Golf Course B would be 5.7%.

| SIMULATED WATER SAVINGS | | | | | |
|---|---|---|---|---|---|
| **Golf Course B** | | | | | |
| heads/acre | 16 | | 184 | irrigated acres | |
| gpm/head | 22 | | 647,680 | water use, total acres, gal | |
| runtime minutes | 10 | | | (simulated) | |
| date begin | 5/1/2017 | | | | |
| date end | 9/30/2017 | | | | |
| date of UAS flight | cum. water savings to end, gal | # days to end | water USE to end, gal | water USE per day, gal | water savings per day, gal |
| 5/22/2017 | 1,354,309 | 131 | 84,846,080 | 647,680 | 10,338 |
| 6/5/2017 | 852,921 | 117 | | | 7,290 |
| 6/19/2017 | 774,791 | 103 | | | 7,522 |
| 7/3/2017 | 1,218,268 | 89 | | | 13,688 |
| 7/17/2017 | 260,436 | 75 | | | 3,472 |
| 7/31/2017 | 208,708 | 61 | | | 3,421 |
| 8/14/2017 | 98,768 | 47 | | | 2,101 |
| 9/11/2017 | 44,275 | 19 | | | 2,330 |
| **Total** | 4,812,474 | | 84,846,080 | | |
| **%** | 5.7% | | | | |

Table 8. Simulated Water Savings for Golf Course B. (Source: EYEON18)

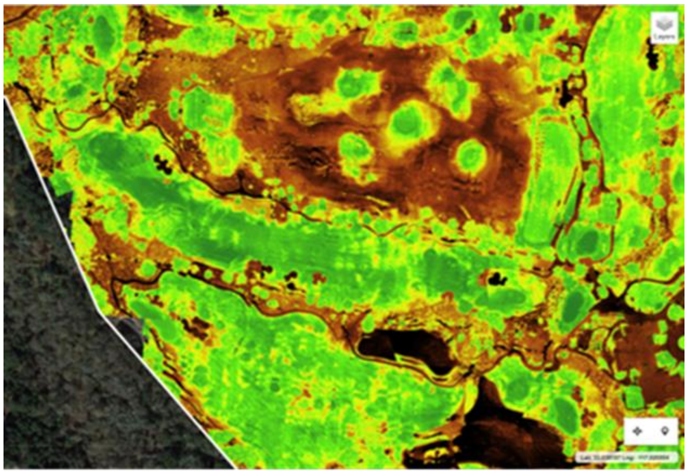
## Results - Golf Course C

### Study Site

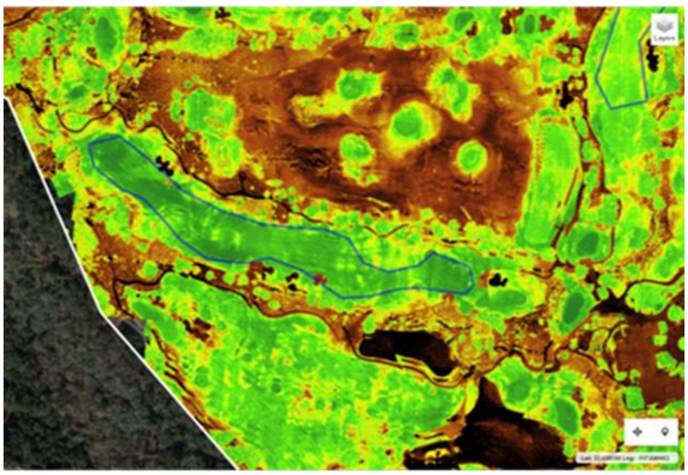
Golf Course C is a daily fee, privately owned facility in San Diego County approximately 16 miles inland in CIMIS Reference ET zone 9, "South Coast Marine to Desert Transition". The golf course was constructed using 419 hybrid Bermuda on all play surfaces except for the greens which are composed of Poa annua and Bentgrasses. The Bermudagrass growing season begins in early March and extends through the end of November. The golf course has 90 acres of irrigated turf and uses well and potable water sources. Management uses an older central control system (Site Pro) with 690 gear drive rotors to irrigate.

At the beginning of the study, there was insufficient chlorophyll to identify irrigation patterns due to challenges related to an excessive mat layer of old leaf tissue. The treatment required aggressive cultural practices and time to correct. Once the Superintendent's inputs were able to take effect, micro-climates were then identified and irrigation adjustments were then made. The progression of NDVI imagery at Golf Course C is shown in Figure 16.

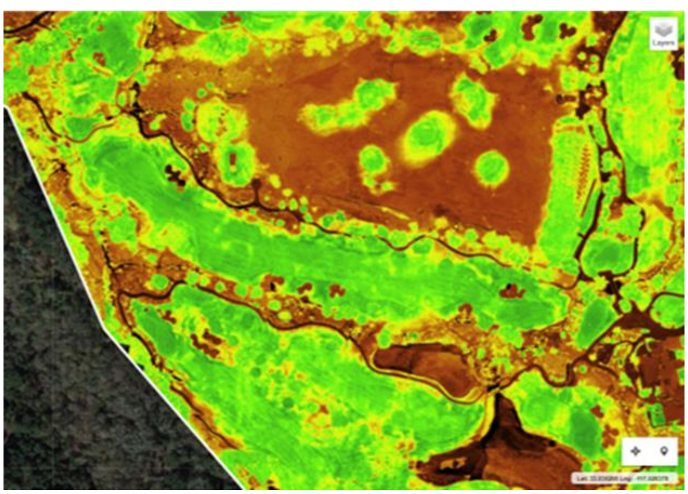
Figure 16. NDVI imagery at Golf Course C. Progression from unmanned aerial system (UAS) flights showing change in Normalized Difference Vegetation Index or NDVI imagery. (Source: EYEON18).



a) NDVI image from UAS flight on 8/23.



b) NDVI image from UAS flight on 8/23 with polygon highlighting area of interest with high NDVI.



c) NDVI image from UAS flight on 9/13 showing lower NDVI and more consistent spatial distribution of NDVI values after irrigation adjustments.

**Measured Water Savings**

As with the other study courses, runtime adjustment flow was compared *before* and *after* changes were made. The result of 4% savings was estimated, but due to the late season start of runtime adjustments the total gallons of water saved for the study was greatly reduced compared to other test sites. A representative sample of measured water savings is shown in Table 9.

Total Flow was extracted from the irrigation report provided by the Superintendent. ETc was calculated using the 24-hour average ET acquired from a local weather station. On 8/23, before irrigation adjustments were made, ETc was 366,638 gallons, a bit below the Total Flow. This was likely due to the aggressive measures taken to rebuild a healthy turfgrass environment. After adjustments, the Total Flow was below ETc, indicating that tuning for micro-climate variations was likely underway. The difference in water volumes from *before* adjustments on 8/23 to *after* adjustments on 9/12 was -4%.

| MEASURED WATER SAVINGS | | |
|---|---|---|
| Golf Course C | | |
| | | |
| Irrigated Acres | **90** | |
| %ET / water budget factor | **100%** | |
| Date | **8/23** | **9/12** |
| ET, in/day | **0.15** | **0.22** |
| Total Flow, gal | **377,130** | **532,620** |
| ETc, gal | **366,638** | **537,736** |
| Above (below) Etc, gal | **10,492** | **(5,116)** |
| Above (below) Etc, % | **3%** | **-1%** |
| Net change above (below) Etc, % | | **-4%** |

Table 9. Representative sample of measured water savings at Golf Course C. Change in irrigation based on Project Team recommendations as a percent of ET is approximately 4%. (Source: Golf Course C Superintendent and EYEON18)

**Simulated Water Savings**

Simulated water savings for Golf Course C are shown in Table 10. Irrigation patterns were sufficiently distinguishable for the last two UAS missions in the study. The potential savings represented within an area of interest (polygon on the UAS imagery) was determined using the calculations outlined in the Analysis section: (acreage * heads/acre * gpm/head * runtime minutes * % reduction). Estimates for all polygons/recommendations for each of these flights were summarized, e.g., for 8/23, the simulated water savings was 2,180 gallons. Assuming the adjustments were made on 8/23 and held until the end of the study, the cumulative water savings would be: (savings per day) * (number of days remaining in the study), e.g., for 8/23, water savings of 2,180 gallons * 38 days remaining would be a potential water savings of 82,831 gallons by the end of the study period. Cumulative savings for both flights were calculated, the sum of which is 101,651 gallons for Golf Course C.

Simulated water use for the entire golf course on a particular was estimated using the same formula for 90 acres, e.g., 316,800 gallons per day. Cumulative water use using simulation assumptions would be: (use per day) * (number of days remaining in the study from the first day recommendations were implemented). The first irrigation adjustments were made on 8/23 with 38 days remaining, so the simulated water use for the entire golf course would be 12,038,400 gallons. As a result, the simulated water savings as a percent of total simulated water use for Golf Course C would be 0.8%.

| SIMULATED WATER SAVINGS | | | | | |
|---|---|---|---|---|---|
| **Golf Course C** | | | | | |
| | | | | | |
| heads/acre | 16 | | 90 | irrigated acres | |
| gpm/head | 22 | | 316,800 | water use, total acres, gal | |
| runtime minutes | 10 | | | (simulated) | |
| date begin | 5/1/2017 | | | | |
| date end | 9/30/2017 | | | | |
| date of UAS flight | cum. water savings to end, gal | # days to end | water USE to end, gal | water USE per day, gal | water savings per day, gal |
| 8/23/2017 | 82,831 | 38 | 12,038,400 | 316,800 | 2,180 |
| 9/13/2017 | 18,820 | 17 | | | 1,107 |
| **Total** | 101,651 | | 12,038,400 | | |
| **%** | 0.8% | | | | |

Table 10. Simulated Water Savings for Golf Course C. (Source: EYEON18)

## Conclusions

The Project Team provided imagery and consultation on irrigation adjustments for all four study sites. Irrigation decisions were made at each site based upon the UAS imagery. Further, each site was able to refine irrigation practices towards optimal ETo watering regimes. NDVI can identify turfgrass growth habits that reveal irrigation patterns and the distinguishing irrigation patterns that register with higher NDVI values. Areas with high NDVI irrigation patterns represent areas where water savings can be realized. This provides a great wealth of information for the turfgrass manager's water conservation efforts. This pioneering project seeks to validate the use of UAS technology for producing valuable information for water conservation on turfgrass and golf courses.

### Water savings

Applying EYEON18 technology to the controlled study at the University of California, Riverside showed the potential to save up to 21% of ETo using information provided from NDVI imagery. Notably, the study golf courses which were running at 80% ETo, were also able to find additional measured water savings of 1-4% during the study period applying this technology. Further research is needed to determine the applicability of water reduction savings in the golf industry.

The simulated water savings for three golf courses over the study period equals approximately 6.2 million gallons or about 19 acre feet (Table 11). This is equivalent to 33 households in Southern California for one entire year (DWR 2011). If the recommended changes had been implemented, savings for the three golf courses over the study period could have totaled $41,114, assuming 100% of the water was potable purchased at water rates for a representative water district in San Diego County.

**SIMULATED WATER SAVINGS**
**Summary over study period, May to September 2017**

| Golf Course | simulated water savings, gal [A] | simulated water savings, $$ [B] | savings, % [C] | # heads | # acres | # adjustments |
|---|---|---|---|---|---|---|
| A | 1,316,941 | 8,689 | 5.0 | 610 | 38.1 | 75 |
| B | 4,812,474 | 31,754 | 5.7 | 2,557 | 159.8 | 71 |
| C | 101,651 | 671 | 0.8 | 184 | 11.5 | 7 |
| **Total** | 6,231,066 | 41,114 | | 3,351 | 209 | 153 |

A. Cumulative savings from date of recommendations to end of study
B. Savings = cum. savings over study period * representative water rates for San Diego County
C. Savings, %: (simulated water savings for Golf Course X) / (simulated water use for acreage)

Table 11. Summary of Simulated Water Savings for all Golf Courses based on recommendations made by the Project Team from May through September 2017. (Source: EYEON18)

## Cost-effectiveness

Project UAS missions were flown at no charge to Project Participants as part of this research. Commercial application cost of this technology is estimated as part of the EYEON18 business model. Cost estimates to collect and analyze UAS imagery for a 100-acre golf course is roughly $10 - $20 per acre per flight (2017). This cost estimate assumes a seasonal contract with 12 UAS missions flown over the course of a six-month irrigation season, including project planning and setup fees.

## Lessons learned

Extracting the most usable information and the most water savings from the UAS imagery requires coaching and education from experienced turfgrass managers and experienced NDVI analysts. Recommend continued interaction to educate the industry and build confidence in the UAS imagery and the irrigation tuning process.

Measuring water savings data is difficult to properly capture from irrigation system data logs. Each irrigation system has some level of customization with regard to irrigation programming. This programming is often tweaked and tuned at multiple points of the irrigation season to meet economic needs, turfgrass playing demands and extreme weather events. Tracking and comparing irrigation changes based on UAS information becomes challenging in this environment. Recommend supported partnerships with irrigation system manufacturers and turfgrass managers to capture and collect irrigation changes based on UAS imagery for future study.

Integrating soil moisture data can also help to better understand trends on the ground when producing recommendations. Further work must be done to tie the UAS imagery and soil measurements together to take advantage of the data. The use of soil moisture sensors was inconclusive, partly due to issues with aligning UAS imagery and soil moisture sampling locations. Suggest higher accuracy GPS unit for the soil moisture sensor and continued research into aligning moisture estimates with UAS imagery.

Commercial applications of UAS technology are new and evolving. As a reminder, FAA, safety and privacy concerns take time to address and cannot be ignored. In addition, weather conditions dictate when the UAS mission can be flown, especially precipitation and wind. EYEON18 operates with FAA certified pilots with adequate training. EYEON18 also developed and enforces a policy for safety and privacy. We recommend that all UAS missions do the same.

## Regional applicability

Given potential incremental savings of 1-4% of total volume per irrigation season, the potential savings for a golf course in Southern California with 100 irrigated acres on the low end could equal $8,600 over the course of a single irrigation season. This assumes a cost per acre foot of $2,150 (representative water district in San Diego County 2017) and water use of 4 acre-feet per acre per year (Lyman 2012). Based on this Project, the EYEON18 UAS-based system of imagery and recommendations can provide water savings and economic efficiencies to justify the implementation of the technology.

## Project Innovation

EYEON18 has pioneered the use of UAS technology to identify micro-climates in golf turf and, through decades of turf management experience, translate the information to increase irrigation efficiency on golf properties. Never before have Superintendents been presented with such detailed information enabling the fine tuning of their irrigation systems over the entire property. By identifying target areas with favorable conditions, irrigation systems can be increased and decreased to alter areas with lower and higher NDVI values to match the target conditions. By implementing the lessons learned above EYEON18 will continue to innovate and refine the implementation of this technology.

## Acknowledgements

EYEON18 greatly appreciates the efforts of Marcia Ferreira PE, Ph.D. with the Metropolitan Water District of Southern California (MWD), for coordinating the Innovative Conservation Program grant process.  Special thanks to the MWD, the U.S. Bureau of Reclamation, the Environmental Protection Agency, the Southern Nevada Water Authority, the Central Arizona Project, and The Southern California Gas Company for the funding of this project.

EYEON18 is grateful to Golf Course Superintendents Chris Erickson, Cody Layton, and Pat Reilly for their participation in evaluating this new, aerial approach to turf management.  Also key to the Project was the valuable assistance of the Research Staff at the University of California, Riverside Turfgrass Research Facility - Dr. James Baird, Dr. Marco Schiavon, Dr. Pawel Petelewicz, and University of California, Riverside FAA Part 107 pilots-in-command Sofia Koutzoukis and Holly Andrews.

Thanks to the Honeycomb Corporation, the AgDrone™ manufacturer, for data image processing and funding.  Finally, thanks to Mr. Richard "Stretch" Strautman, representative for Stevens Water Monitoring Systems, Inc. and Floratine Northwest.

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## Appendix A – EYEON18 SITE ASSESMENT

**GOLF COURSE B** PRIVATE
SURVEY CONDUCTED BY: Tyler Rowe / Tim Barrier / Gerald Ward
DATE: 4-3-2017
ADDRESS: [San Diego County], CA
COURSE SUPERINTENDENT: xxxxxx xxxxxx CELLULAR: (xxx) xxx-xxxx
ASSISTANT SUPERINTENDENT: CELLULAR:
PROSHOP NUMBER: (xxx) xxx-xxxx

Course areas for flight operations: Valley and lake nines.

Flights to be conducted on Mondays, grounds are closed due to maintenance

Gate Contact or entrance requirements: We have been granted access

FAA FSDO: SAN DIEGO
FAA CONTACT: No POI assigned at this time NUMBER:
GPS COORDINATES: [lat, long]
AIRSPACE: G Uncontrolled / Class B 6800 inside Mode C 30 NM Vail FLOOR OF AIRSPACE E 700 AGL
AIRPORTS: [xxx] Magnetic Bearing 9.3 NM
CONTROLLING AGENCY NUMBER: VHF FREQUENCY: xxx.x
COMMUNICATION REQUIRED PRIOR TO FLIGHT NO

AIRPORT: [xxx] Magnetic Bearing 7.6 NM
COMMUNICATION REQUIRED PRIOR TO FLIGHT NO

HELIPORTS:
HELIPORT CONTACTS: NUMBER:

TOTAL ACRAGE: 257 AVERAGE ESTIMATED FLIGHT TIME 18 MINUTES BATTERY USAGE 40%
COURSE ELEVATION: 15 below msl
HIGHEST OBSTICLE: 50
POWERLINES: NA

TAKEOFF COORIDOR 2 WIDTH 300 VERTICLE OBSTICLES trees 30: left right
SLOPE: SLIGHTLY DOWNHILL
TAKE OFF AND LANDING AREA COLOCATED: YES
UTILIZING AN OPEN SPACE NON GOLF HOLE OR DRIVING RANGE IS MOST DESIRABLE NO

LANDING AREA 1: 2 WIDTH 300 LANDING PREVAILING WIND WEST

SLOPE: SLIGHTLY DOWNHILL

LANDING AREA 2: 3 WIDTH 300 ft LANDING PREVAILING WIND
SLOPE flat

WATER CONCERNS: NA

LOIDER LOCATION: Hole 8 285 AGL

ALTERNATE LOIDER LOCATION: Hole 4 285 AGL

Verified or none verified: Verified 300 ft

CART REQUIRED FOR VISUAL CONTACT: NA

MULTIPLE OBSERVERS REQUIRED: NA

Pilot Flight Platform Location: Hole 11

RADIO COMMUNICATIONS REQIRED BETWEEN CREW: YES

MULTIPLE FLIGHTS PLANS REQUIRED IRREGULAR LAYOUT: NO

DRONE POSTING LOCATIONS LISTINGS: Clubhouse / PILOT & Observer's Location

MARSHALLS UTILIZED: NO

NOISE SENSITIVE AREAS: NA

HOME DENSITY PERIMETER: NA

COURSE MANAGEMENT CONCERNS: NONE

EYEON18 SAFETY CONCERNS: gusty wind valley circulation many lakes low ceiling and fog occasionally

EYEON 18 AREA DIRECTORS: TIM BARRIER NUMBER: (858) 775-7051

LOCAL LAW ENFORCEMENT: NUMBER:
LOCAL MEDICAL: NUMBER:

**EYEON18 NO FLIGHT RULES**
WIND GREATER THAN 15 MPH
TFR
500 FT. CEILING
POOR LIGHTING CONDITIONS
NO FLIGHT OPERATIONS PRIOR TO 9 AM.
PRECIPITATION
TEMPERATURE EXCEEDING 105 F.
MANAGEMENT RESRICTIONS

# Appendix B – DroneLogBook

Shown below is an entry in the cloud-based software used by EYEON18 to document and manage UAS Flight Data. Flight log data for every full or partial flight is transferred from the AgDrone™ System to DroneLogBook to help record FAA-required flight parameters including date, latitude and longitude, flight personnel, etc. plus relevant notes such as anomalies or issues encountered during the flight. One flight log is maintained by EYEON18 for each UAS in operation.

EYEON18

DroneLogbook Operations Report
28 October 2017

EYEON18

**Period**: 2017-01-01 to 2017-10-28
**Customer**: MWD Grant
**Name:** EYEON18 **Email:** *info@eyeon18.com*

FLIGHTS (45 in the period)

**Flying time on this period**: 34:35:25

| Date | Flight name | Drone | Type | Time | Location |
|---|---|---|---|---|---|
| **2017-09-13** | **Flight 2017-09-13 16:58:06** | AGDRONE HoneyComb /Ag Drone | Commercial - Agriculture | 00:18:10 | **Golf Course C, City, latitude, longitude** |

**Project/Job Reference:**Maderas

Personnel: Tyler Rowe [Pilot], Tim Barrier [Visual Observer], , **Pilot info:**
**Equipment onboard:**
**Nb landing:** 1 **Distance:** 17696 m **Max altitude:** 162 m
**Conditions:**
**Cloud cover:** 3 % **Temperature:** 75 F **Wind:** 8.85 miles/hour **Humidity:** 60 %
**Notes:**