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 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.

Metropolitan and the ICP funding partners do not endorse any particular product, service, or company, including those discussed in this report. The information provided within this report is not certified by Metropolitan and any party referencing this report should verify information as needed for its own purpose.

PG Water Consumption Monitoring and Savings System

FINAL REPORT

Innovative Conservation Program
2018 ICP – Agreement No. 181288
Project Green LLC - Highlands Ranch, CO
http://www.projgreen.com | brendan_muir@projgreen.com | 720.515.3394

Contents

Project Overview

The "PG Water Savings and Consumption Study" was conducted by Project Green LLC, a small startup venture located in Highlands Ranch, Colorado. Project Green is focused on bringing people together as a community to address the challenges inherent to the coming droughts and water shortages that lie ahead in the region and that, when coupled with concentrated population growth in urban areas, are heralding in a whole barrage of new economic, environmental, and social challenges.

With experts predicting that a significant gap between the supply and demand for water here in the Western United states will emerge sometime around the year 2030, we must act now. Educating people, bringing them together, and empowering them to take action seems the best solution, but will take time.

To further complicate the matter, water scarcity in this region negatively impacts the supplies of other natural resources. In fact, in terms of both the environment and our economy, nearly all the natural resources upon which we depend are part-of and directly-impact much larger systems, and are inherently connected. A great example of this interconnectedness is the nexus between water and energy here in The West. We need water flowing down our rivers to drive the hydroelectric dams that supply much of our power; if we don't have water, then our energy supply is significantly impacted.

Project Green was founded with the specific aim of addressing the coming challenges inherent to the emerging gap between the supply and demand for natural resources in the region, with a focus on community, demand-side management, and the environment. We believe that, if consumers are made aware of the coming challenges, and if we work together to leverage technology to help us use natural resources more efficiently, we can ensure future generations can live the same lifestyle we do today.

As a first step in educating people and companies about the coming water shortage here in the Western United States, and in an effort to engage and empower them to use natural resources in more efficient ways, Project Green has developed a technology platform that aims to eliminate water waste around the home. The platform is designed to track and log all the "water events" occurring at fixtures both inside and outside of a home in "real-time" using a single sensor, and has the ability to tag, categorize, and classify those events by "***fixture type***" and by "***specific fixture***".

Fixture Type: 'toilet', 'shower', 'bath', 'sink', 'dishwasher', 'laundry machine', 'lawn sprinklers', etc.

Specific Fixture: 'Master Bath - Toilet', 'Scott's Shower', 'Calgon-Take-Me-Away: Mom's Bath', 'Sprinklers - Backyard', etc.

The ICP-funded study described herein was aimed at assessing the effectiveness of the technology platform in its current state, and to see how end users would behave when presented with fine-grained information detailing their household's water usage as compared to that of their peers.

Specifically, the goals and objectives of the study were as follow:

Primary Goals

- To ASSESS the ACCURACY and RELIABILITY of the DEVICES when placed in RESIDENTIAL HOMES
- To EVALUATE whether the INFORMATION the system provides will MOTIVATE users TO TAKE STEPS to reduce their water consumption

Primary Objectives

- Demonstrate the system's ability to TRACK individual water events ('Start Time', 'End Time', Water Volume)
- Demonstrate the system's ability to IDENTIFY the FIXTURE TYPE / SPECIFIC FIXTURE responsible for a water event
- Demonstrate the system's ability to DETECT potential LEAKS, BREAKS, or UNDER-PERFORMING FIXTURES
- Demonstrate the system's ability to HELP end users MONITOR their CONSUMPTION and IDENTIFY WASTEFUL HABITS
- Demonstrate the system's ability to PROVIDE FEEDBACK to end users regarding CONSERVATION EFFORTS they make
- Collect FEEDBACK, SUGGESTIONS, and other QUALITATIVE information about the system from end users

While we were able to meet most of the goals and objectives of the study on a high level, there were significant and unanticipated technical challenges along the way that hampered our ability to meet them in as detailed a way as originally intended.

The following pages provide a discussion of the overall approach taken to carry out the study, including not only a discussion of the data collected, but also the technical issues encountered along the way and the fixes implemented to address them. It concludes with an assessment of the viability of this technology as it pertains to end user engagement, demand-side management, and the go-forward potential that it represents in terms of water savings.

The Approach

Devices were manufactured, tested, and installed in 12 homes for a little more than half a year, where they were configured to track and submit information detailing the **start-times**, **end-times**, total **pulse counts**, and unique "**flow signatures**" of water events occurring in and around the homes. Information was gathered and analyzed to assess the overall performance and accuracy of the data collected by the platform, and to assess the level of engagement and participation by end-users of the system.

As other sections of this report will detail, technical issues that arose with the devices significantly hampered data collection and aggregation efforts, thus negatively impacting the quality and quantity of data collected. Data was to be gathered to produce detailed, personalized consumption reports for each house, which would then allow homeowners to benchmark and understand their water usage habits in detail. While we were able to capture enough data to analyze individual water events occurring in homes, we were not able to come up with summary figures for each household or the full study group as an aggregate. The technical issues experienced with the devices were addressed to the best of our abilities given the time constraints of the study. Potential and permanent fixes are being fully vetted now, but we were unfortunately unable to get things working in full-function within a timeframe that would yield quality usage data for the ICP study.

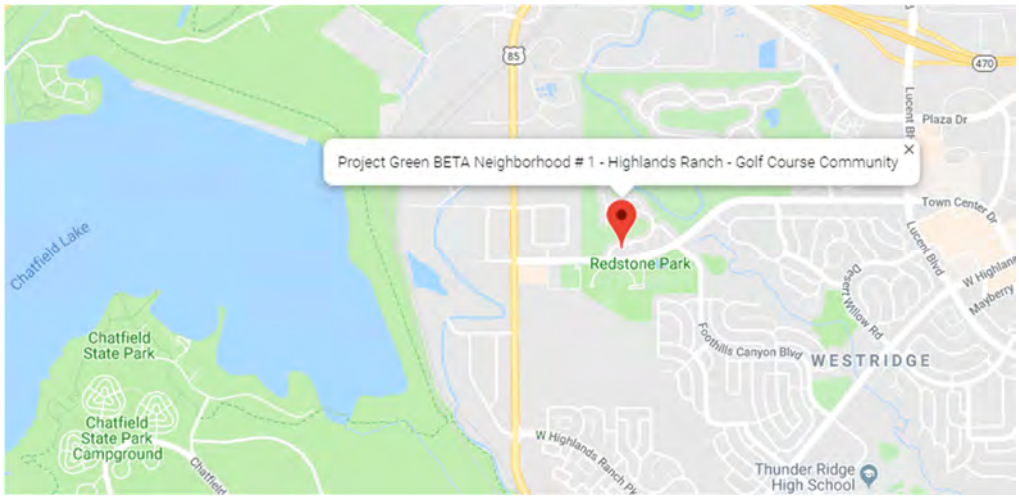
Finding Participants

Eligibility

To promote a sense of community, and to make it easier to visit homes for installations, fixes, and maintenance tasks, we limited the list of "eligible participants" in the study to **homes within a single neighborhood** (i.e. – a single, limited geographic locale of collocated homes).

This single-neighborhood strategy worked well. We discovered that participants naturally, and without prodding, helped to spread news of the study **via word-of-mouth** as they bumped into one another throughout the natural course of their days.

The graphic on the following page shows the neighborhood that was chosen, which is located in a golf course community in **Highlands Ranch, Colorado,** about **12 miles South of Denver** and in the heart of suburbia. Highlands Ranch is a **22,000-acre master-planned community** of around **100,000 people** and serviced by **Centennial Water and Sanitation District**.



Highlands Ranch Golf Course Community – (Highlands Ranch, Colorado)

Our initial outreach to find participants for the study relied on **four main modes of communication and advertisement** including: ***door-to-door*** inquiry, a geographically-targeted ***Facebook ad***, a series of postings in the local neighborhood's ***NextDoor.com*** forum, and a ***custom website*** that was created specifically for the study.

NextDoor

Much to our surprise, the **most fruitful** medium for finding volunteers for the study turned out to be **NextDoor.com**, which was a free listing. We made three posts on NextDoor over the course of four days, which connected us with 7 participant households.

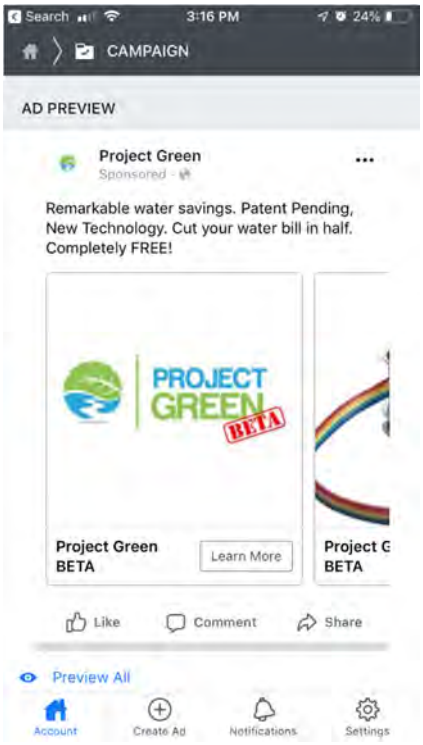
Facebook

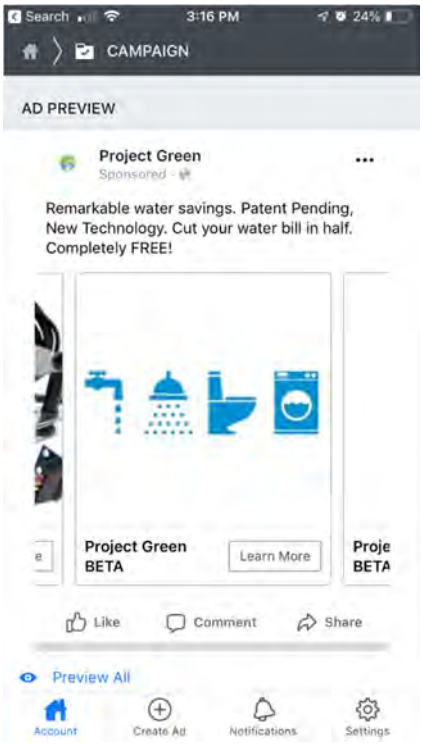
While we did pick up a single participant household from our **Facebook Ad**, we found the results of the campaign and its actual click-through rate to be lackluster. There were a lot of page impressions, but only three people actually clicked on the add. It's unclear whether our ad design was just a dud, or whether people aren't as prone to click on ads about things of this nature on Facebook as they are on community-specific pages like **NextDoor.com**. Perhaps their focus or mindset when browsing community pages is different than on Facebook, or perhaps the demographics reached via each medium differ.

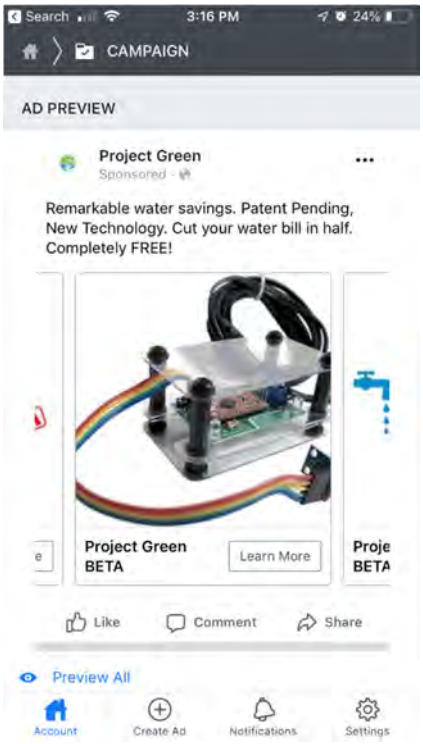
We limited the **Facebook campaign** to a geographic region within a **1-mile radius** of a centrally-located address in our target neighborhood, and to **men and women 25 years of age or older** (our assumption was that any Facebook users younger than 25 were not likely be homeowners or household decision makers). The screenshots below show the specifics of the campaign, the ad itself, and some of the statistics about how many times the ad was viewed by people in each demographic and via which medium.

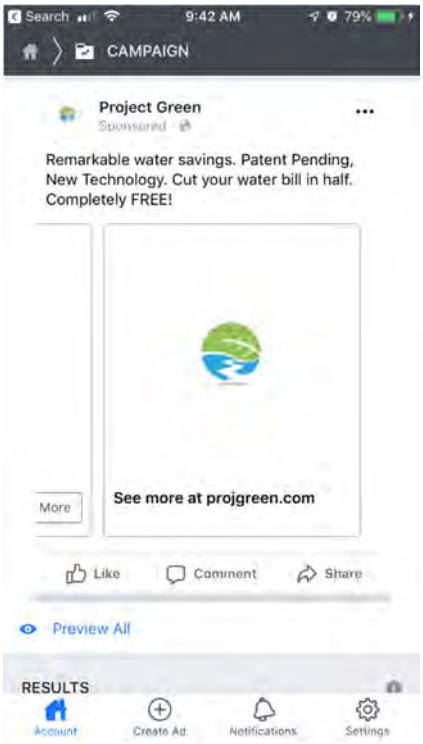
Screenshot of Facebook Ad Campaign – Target Demographic

*The screenshots below show the **Facebook Ad**:*

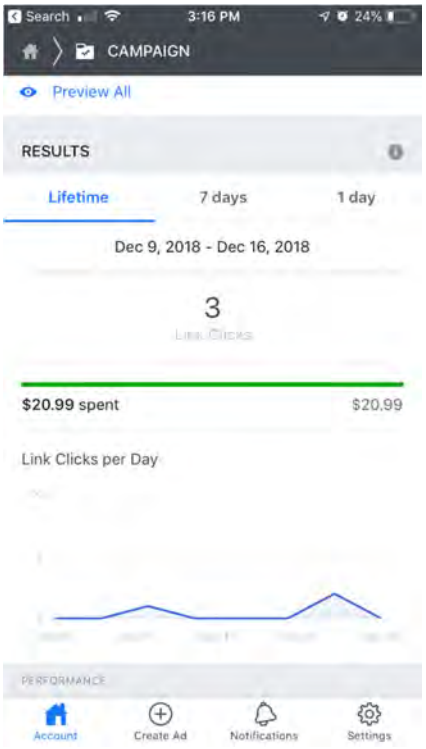


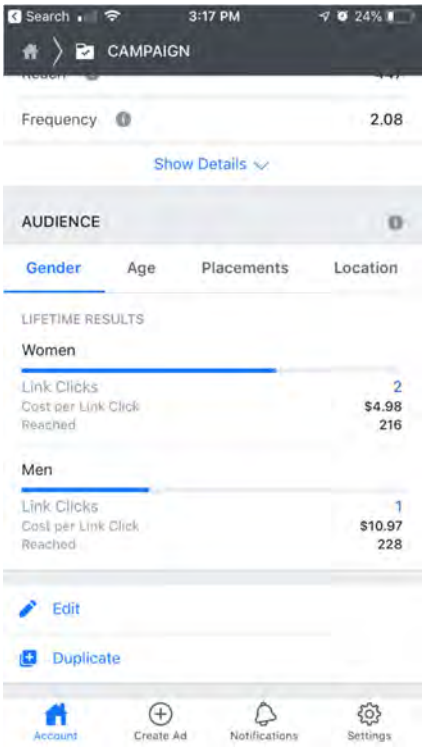


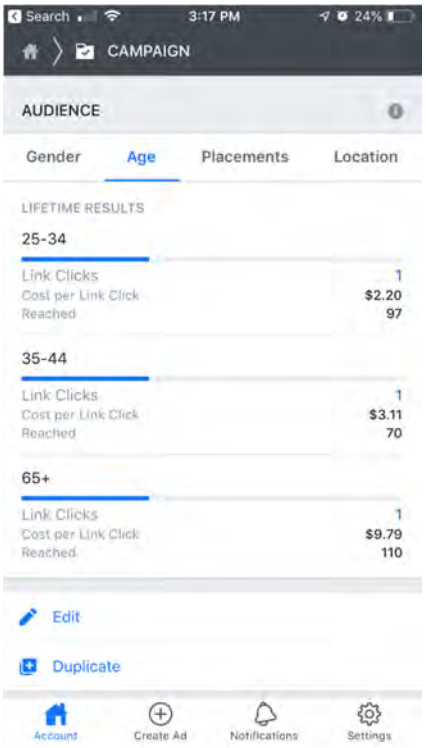


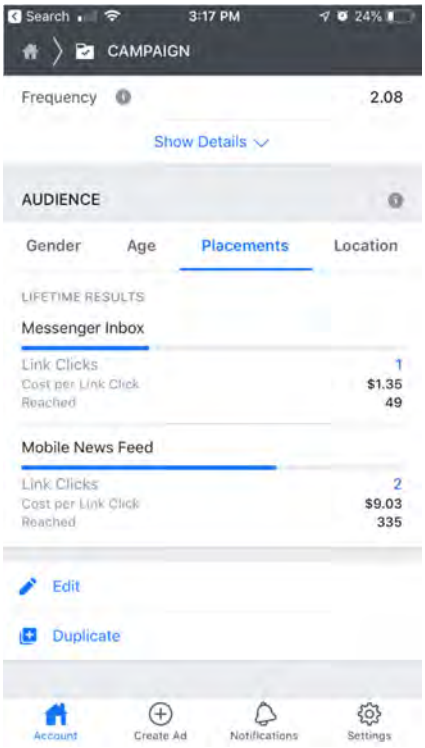


*The screenshots below show the **Facebook Ad <u>Campaign Results</u>**:*





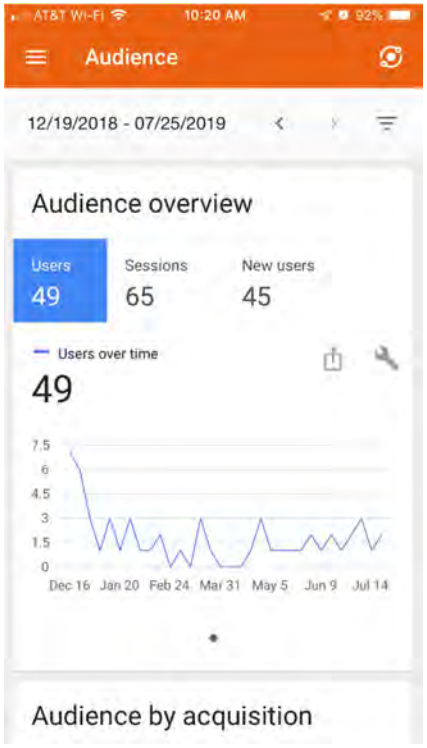


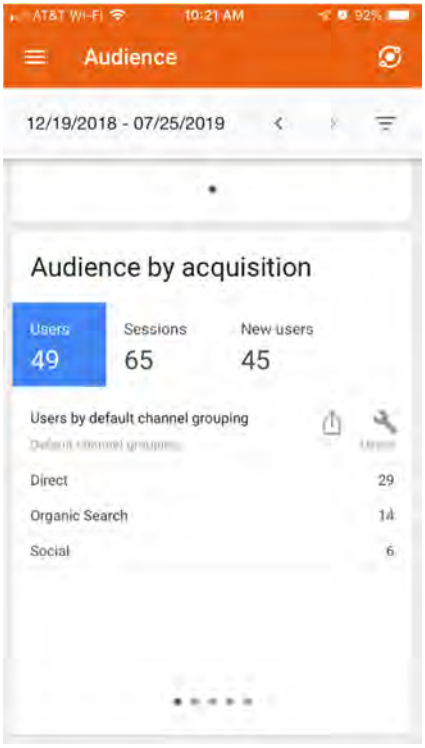


Study-Specific Website

A **website** was developed to provide information about the study, and to serve the **point-of-registration** for people interested in the study, which was branded as "**Project Green BETA**".

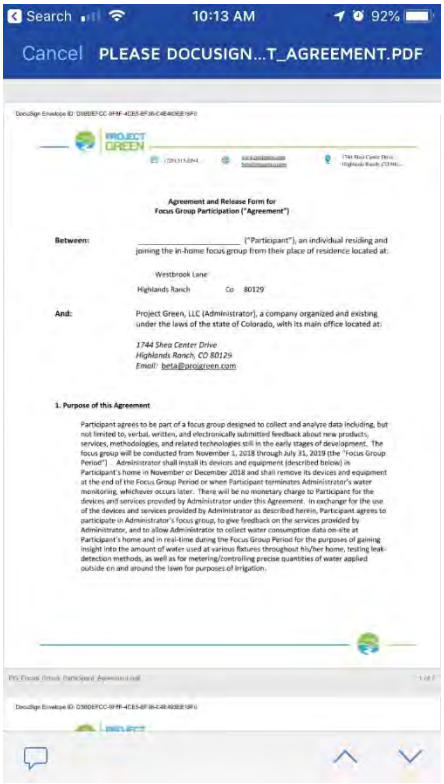
The website worked well, and attracted a decent amount of traffic. According to the **web traffic statistics** we gathered using Google Analytics, we had **45 unique visitors** to the site.





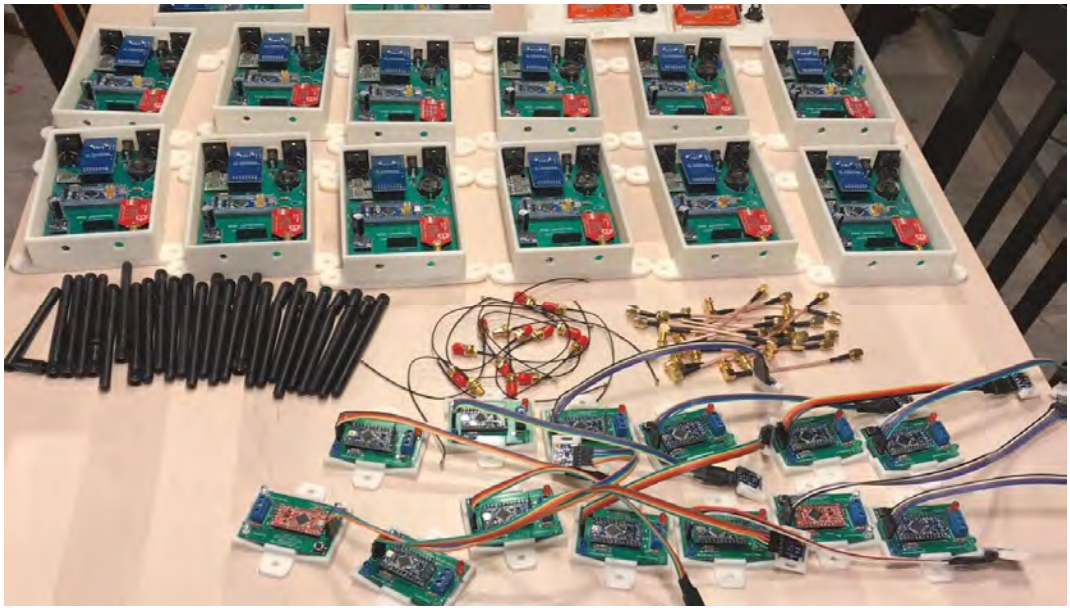
Participant Registration

After applying via the website, participating homeowners were required to execute a **legal agreement** detailing the terms and conditions of the study. It served as a formal release for the data collected, as well as a layer of legal protection for the entities and intellectual property involved in the study. The agreements were executed and signed electronically using DocuSign, which worked very well and for which we received positive feedback from participants.



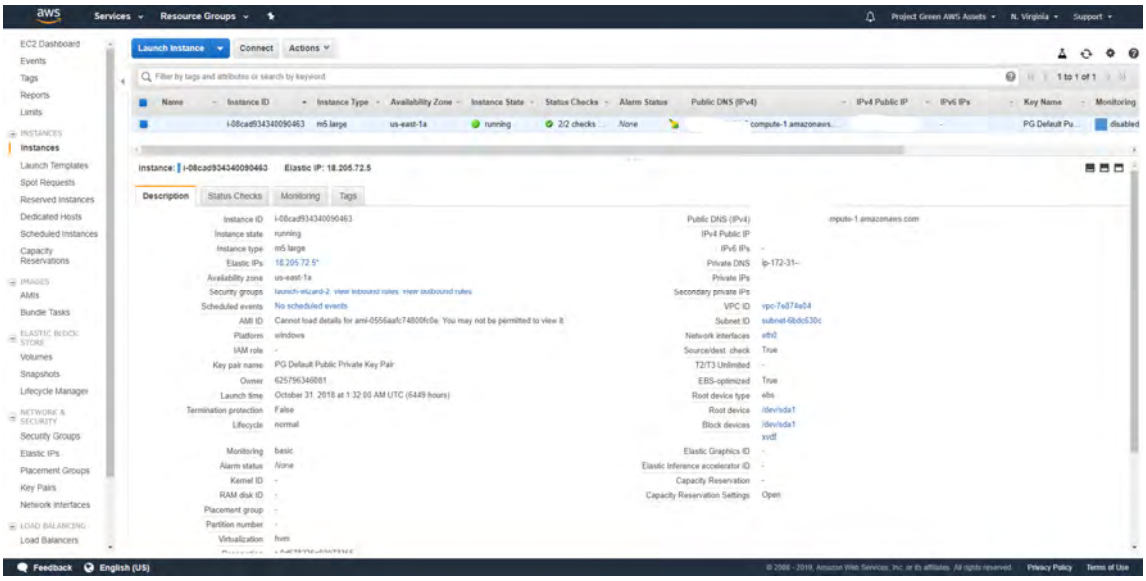
Device Manufacture

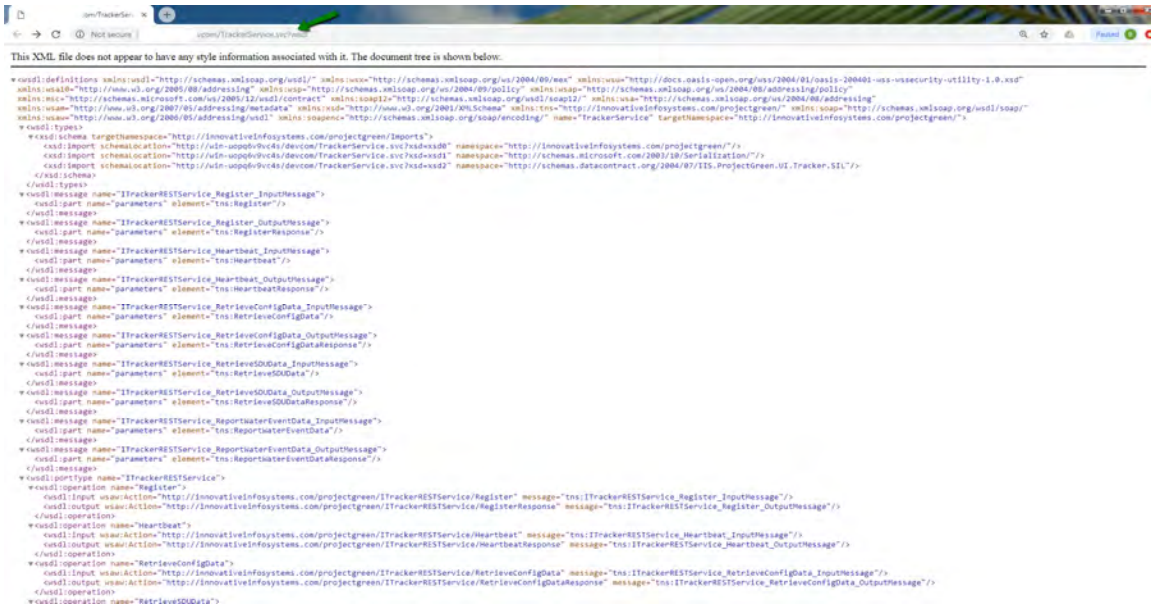
A batch of **16 electronic devices were manufactured specifically for the study**; parts were procured from China and then assembled and tested. **12** devices were used "**in the field**"; **2** served as "**backups**" and were eventually cannibalized for spare parts; and **2** were used in a **technical support** capacity for prototyping hardware fixes, software debugging, and regression testing.



Server Configuration

A **virtual server** was "spun up" on **Amazon's AWS EC2 platform**, and served as the host environment for the **RESTful web services that managed data communications between the devices and the centralized datastore** where all the data submitted by the devices was aggregated and analyzed. The instance data and settings configured and stored on the server were backed-up on a nightly basis, to protect against data loss arising from unforeseen technical issues in the cloud. Fortunately, the server and the web services proved to be very reliable and we experienced **100% uptime** on the server, REST interfaces, and the database.



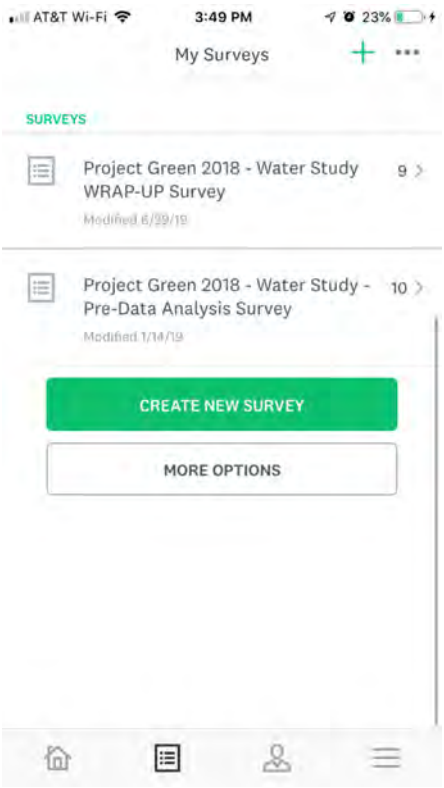


Surveys

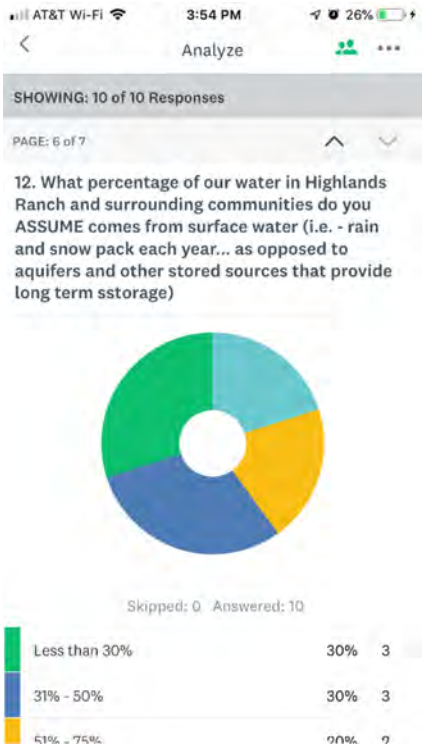
Before the devices were installed and before anyone saw their own consumption data, homeowners took a short survey geared at gauging how accurately they understand their consumption habits, the overall state of water supply and management here in the West, and to get a general sense of how they feel about conserving water. They were given a second survey at the end of the study, intended to gauge if their opinions had shifted over the course of the study.

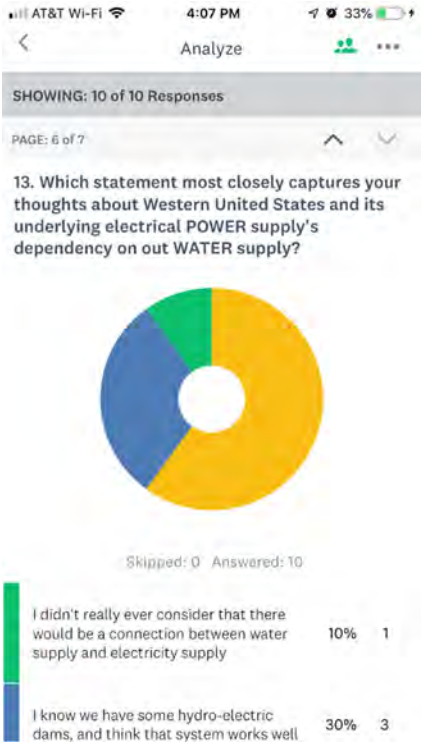
In reviewing the survey results collected, we found that most people did not trust that their the local water delivery authority here in Colorado has a good plan in place for the future and the coming droughts. We also found that study participants had very skewed views of the percentage of surface water that comprises our regional water supply, and that more generally, they didn't seem to know much about where their water comes. Similarly, most participants did not seem to know that there is strong nexus between water and energy in this region.

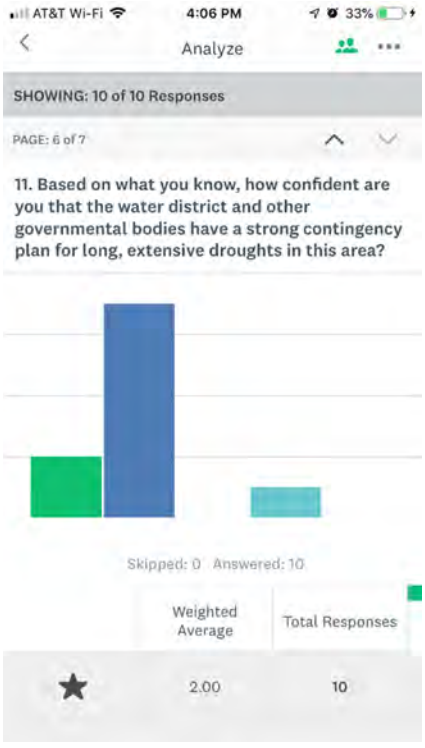
The surveys were **conducted electronically** using **Survey Monkey**. It took quite a bit of bird-dogging and incentivizing to get some of the participants to complete the surveys, despite the fact that we had made the question lists short, thinking that would encourage completion. If we had it to do over, we would conduct more thorough surveys with more questions, and would offset the burden on the survey taker with more significant incentives to encourage completion. We would have liked to have delved into some areas more than we were able to via the short surveys.



*The screenshots below show some of the **survey questions and their response summaries**:*

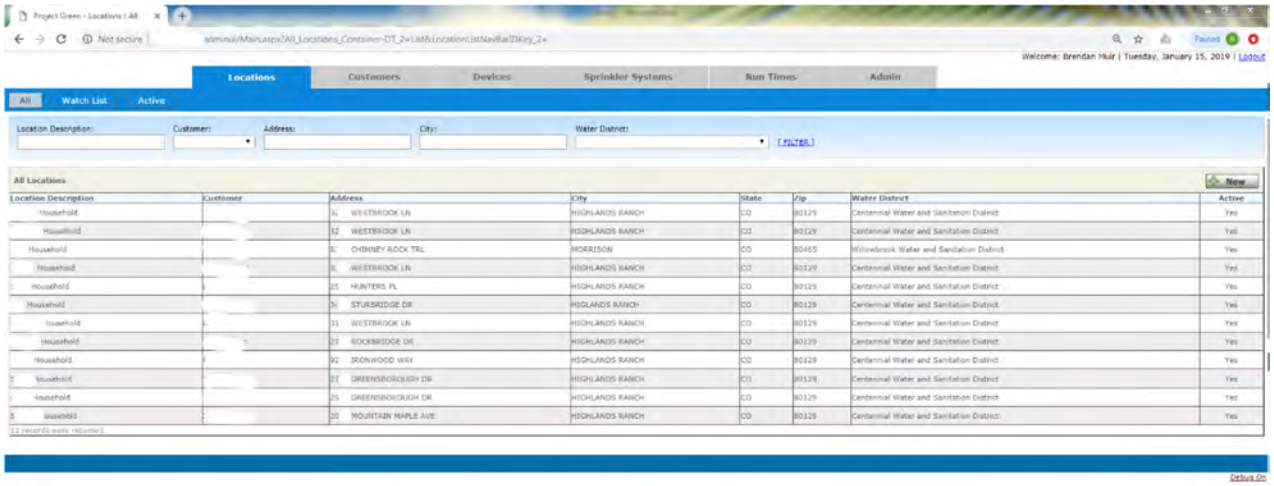




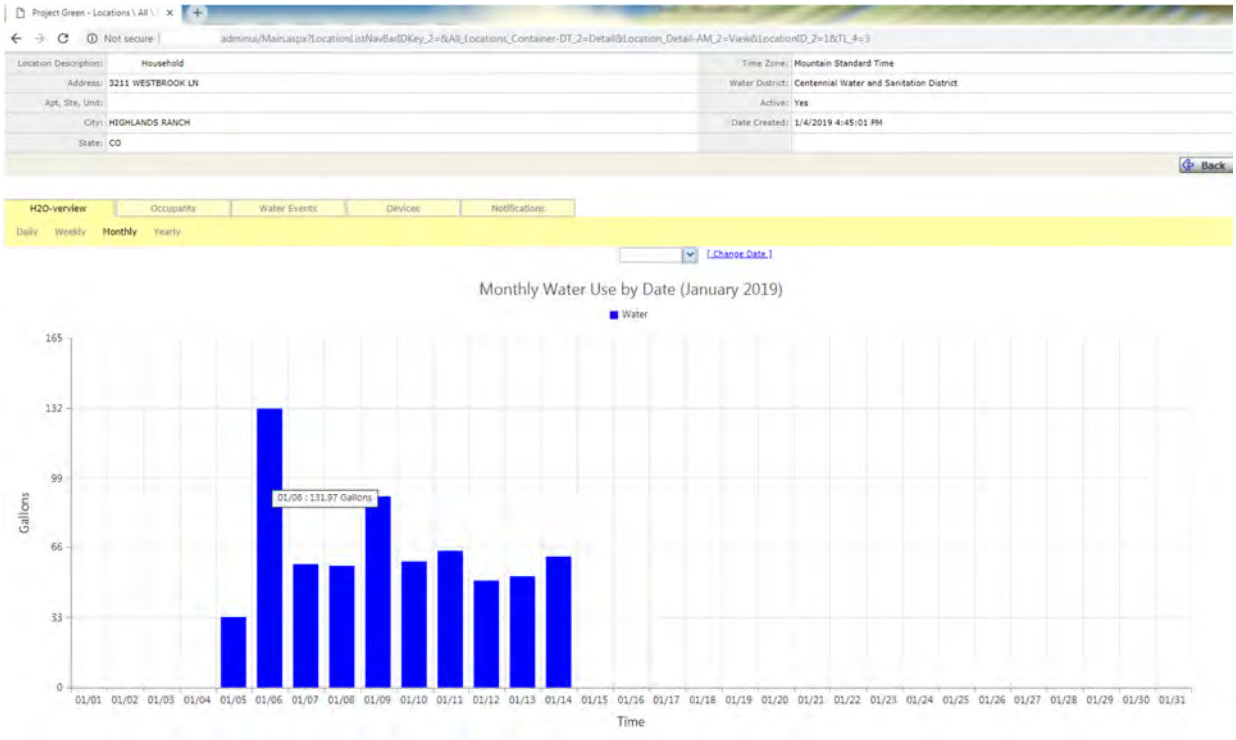


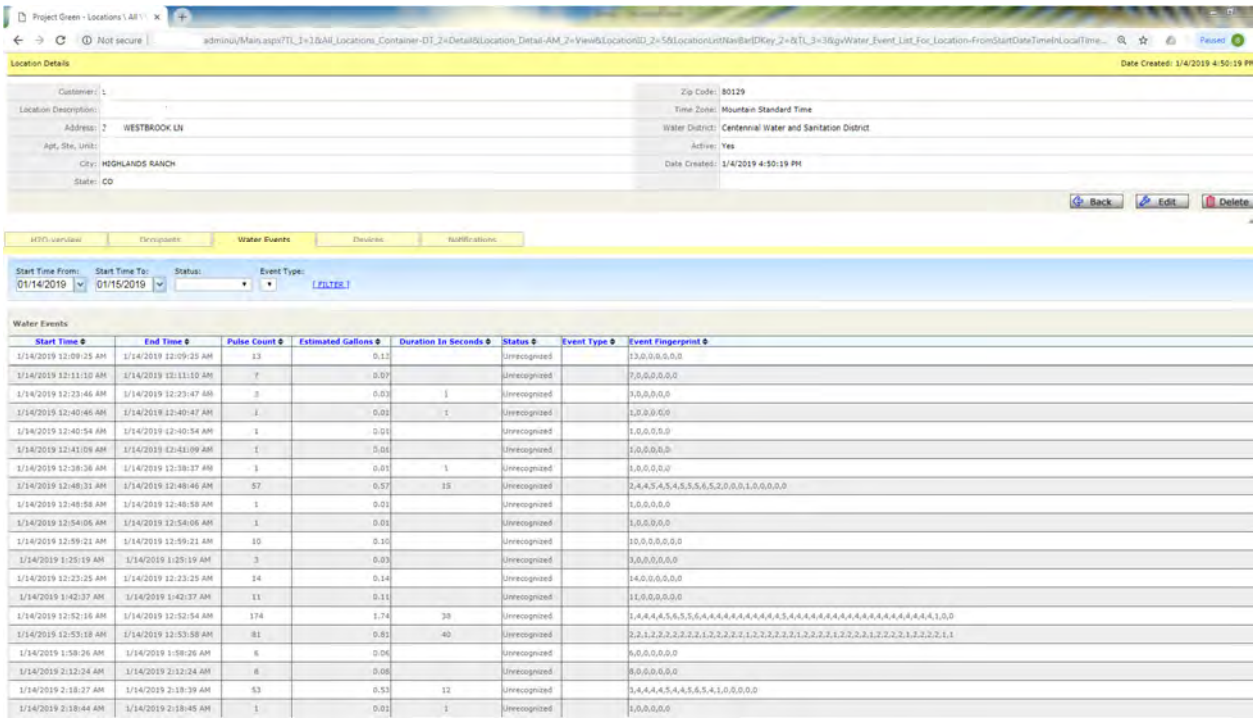
Device Installation, Data Collection and Reporting

Devices were installed in twelve homes. Installation consisted of attaching the sensor to the outside of the water meter with Velcro and then running a Cat5 network cable from the sensor to the main board, which was mounted on a wall and plugged into a power outlet. The sensor monitored for water event data which the main board forwarded on to the server where it could be aggregated and analyzed.



Usage data was not made available to end users upon install since the devices were set to run in "Silent Data Collection Mode", meaning that they were configured to track and classify water events outside the purview of end users. The intent behind silent mode was to develop a baseline picture of the monthly water usage habits of each household before participants were provided with information detailing their consumption, since seeing their personal and detailed information might have caused them to alter their normal habits before we had a relative baseline measure for any behavioral changes they might make.





As was mentioned previously, the original plan was to deliver fine-grained, personalized reports to each homeowner detailing their consumption. The reports would have allowed participants to benchmark their usage figures and habits against those of others in the study, and would have included a formal list of recommended savings strategies derived from their usage habits and analysis of their data. The intention was to also give users access to their consumption data in real-time, and to send them notifications via email and text message as leaky or maladjusted fixtures were detected or as their household reached significant consumption milestones relative to their personal historical use and/or budgeted targets. Unfortunately, due to several global issues caused by hardware defects and firmware bugs with the electronic devices placed in homes and described in the next section of this report, there wasn't enough quality data to provide homeowners with helpful information about their habits. The communications between the server and the devices were inconsistent and were not reliable enough to perform any real-time monitoring. Much of the data detailing water events occurring in participant homes was never reported to the server due to communications issues. The silver lining is that is that end users seemed engage and were looking forward to seeing their data. In fact, a number of them have asked for us to return to reinstall the devices once our fixes have been fully-proofed, sometime beyond the end of this study.

Technical Issues, Hardware Defects, and Firmware Bugs

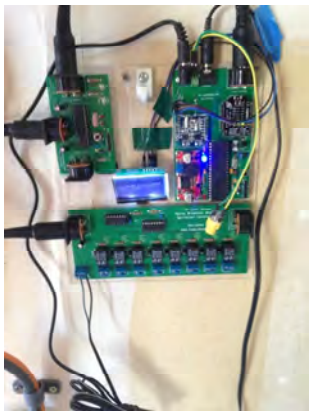
Data collection efforts throughout the duration of the project were hampered due to unforeseen issues with the electronic devices manufactured for the study. The net impact of the issues prevented the devices from staying online, and from logging data consistently and accurately. The descriptions and pictures provided in this section discuss the issues, their impacts, and the fixes we came up with to try to remedy things.

Wifi Connectivity Issues

Home networks, routers, and the devices connected to them do not always maintain solid, uninterrupted communications to one another. In fact, it is not uncommon for connected devices to experience minor and very temporary variations in Wifi signal strength and connectivity throughout the course of a day. When that happens, connected devices can inadvertently get "bumped" offline for what should be very short moments, before they quickly reestablish a connection to the router and thereby the Wifi network. This re-connection behavior is a function commonly referred to as "**connection management**".

While the firmware running on the Project Green main board was programmed to perform "connection management", **we inadvertently omitted the "Wifi Reboot" circuit from the physical circuit board schematic** when we sent it to China to order the boards used for the study. The printed circuit board and schematic design had been proofed and refined previously in four generations of devices used in a few homes prior to the study, but a "new" schematic was created to accommodate a modification to the physical size and shape of the board itself, so that it could fit nicely inside a protective, 3D-printed plastic enclosure. We didn't want to hang bare printed-circuit-boards on people's walls as we had done in a few primary test homes with the previous generations of devices, and so we opted to mount them inside of custom enclosures. Due to an oversight when copying the circuits from the old schematic to the new one containing the layout that fits the enclosure, the Wifi reboot circuit didn't make it on to the new schematic.

Bare circuit boards

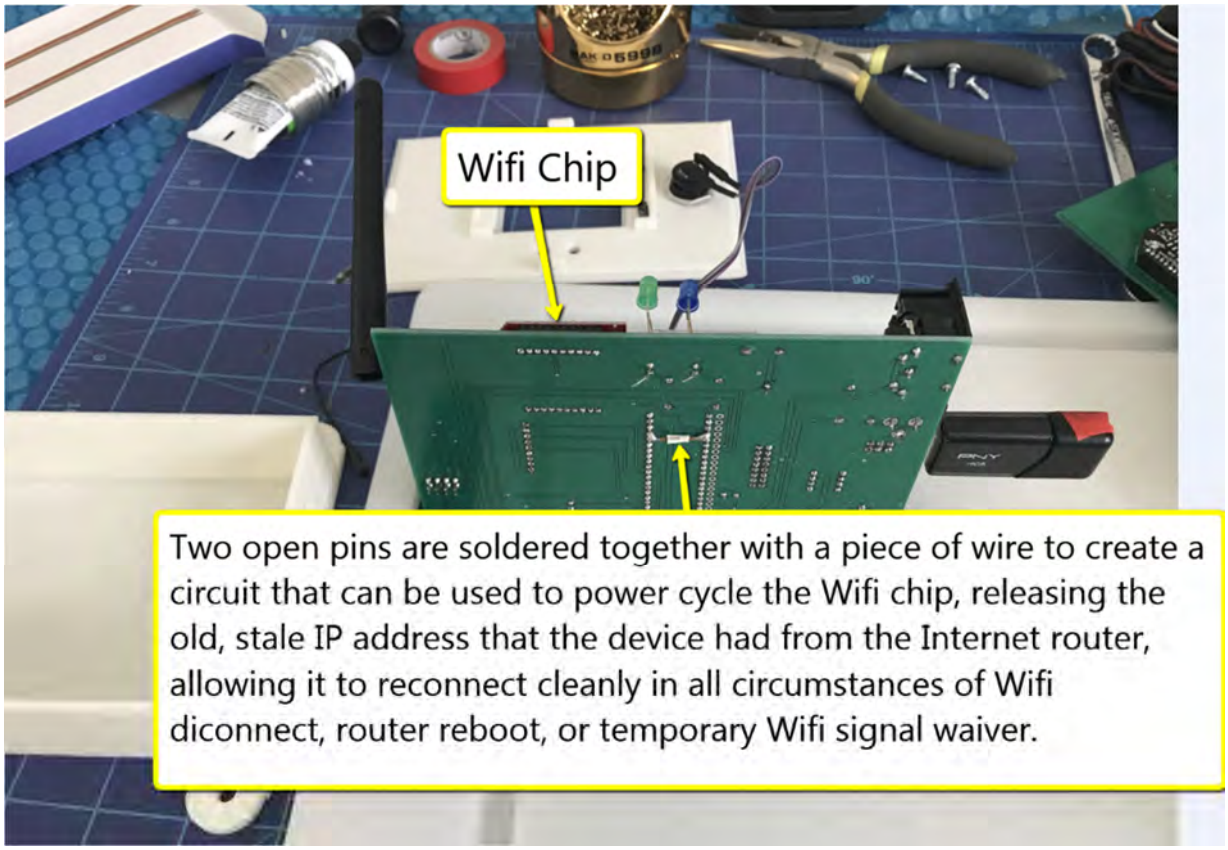


vs.

Enclosed circuit boards

The missing circuit prevented the devices from releasing and renewing the IP addresses they were assigned by the router, a step required for them to be able to reconnect to Wifi under most conditions. What that means is, as soon as the device lost connection to the network the first time, it was unable to reconnect. It took about five weeks to specifically diagnose, recreate, and determine that the connectivity issues were caused by a missing circuit.

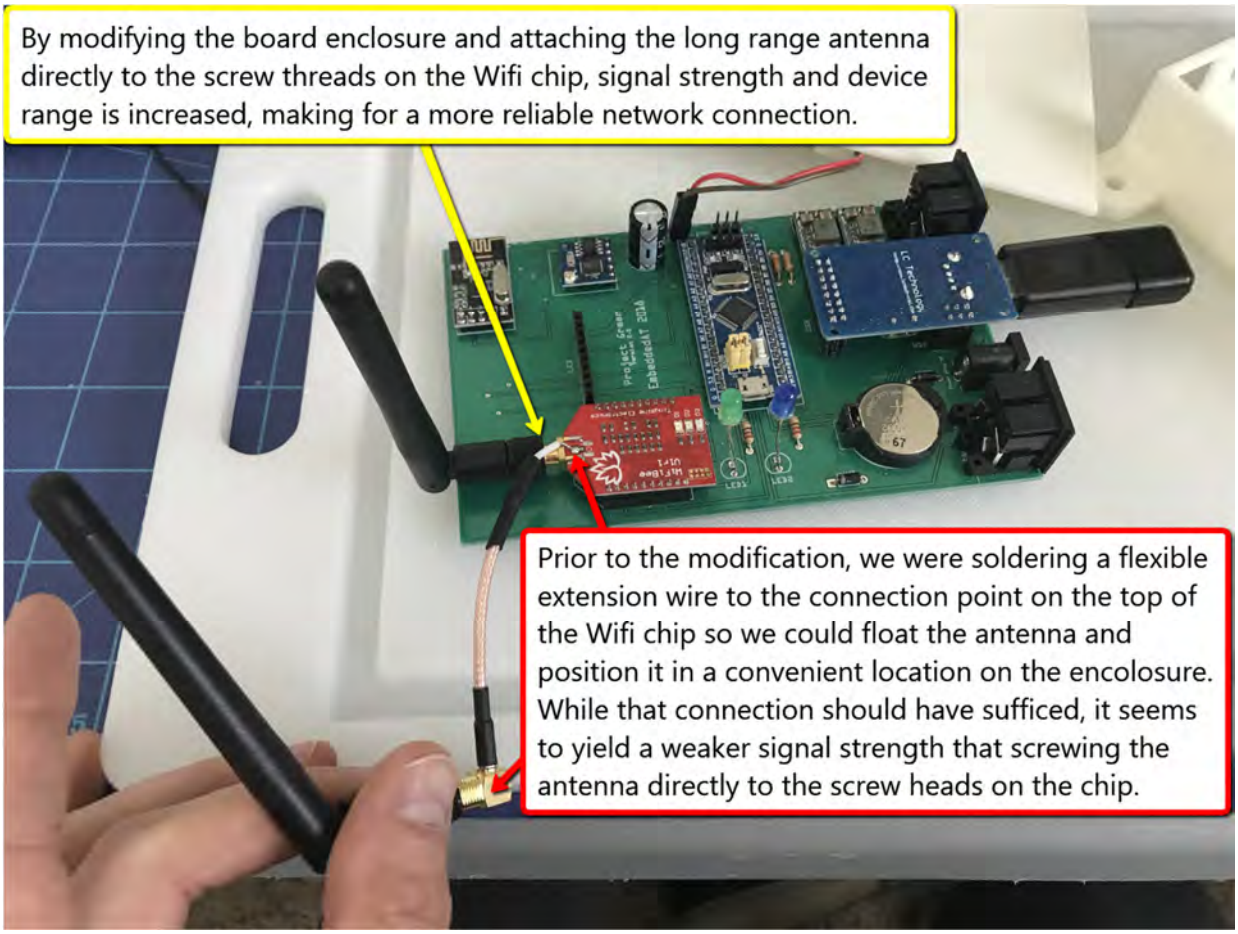
As the following picture reflects, we were able to come up with a fix for the missing circuit, which consisted of soldering a wire between two open pins that are located on the underbelly of the board. Doing so creates the missing circuit, and allows the devices to reconnect to Wifi after the initial connection is lost.



Wifi Antenna and Signal Strength Issues

While the root cause to the Wifi connectivity issues was the “missing circuit” described above, we also had to adjust the way that we affixed the long-range antenna to the Wifi chip, in order to maximize signal strength and reliability. Even with the Wifi Reboot circuit in place, we observed an abnormal number of disconnects and cases where the devices were dropping offline. Although the specs for the antenna indicate that either of the two connections points on the chip can be used, we found that using the

threaded-coupler attachments resuls in a stronger, and thereby more reliable, signal between the device and the router.

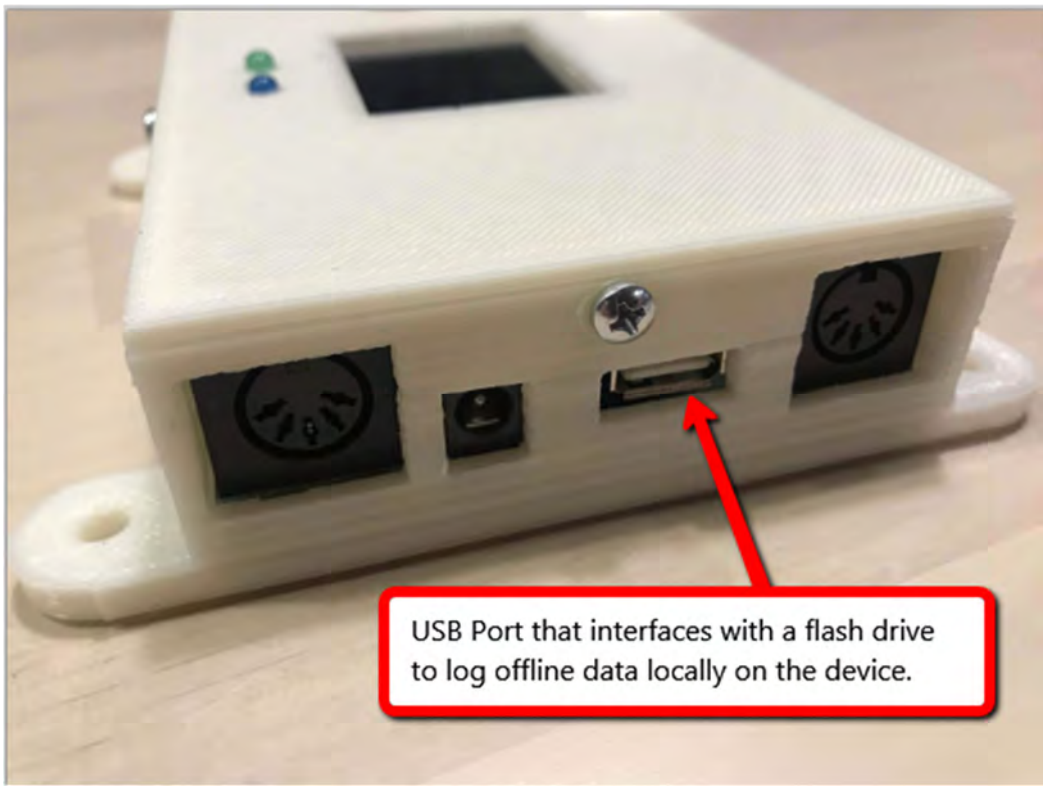


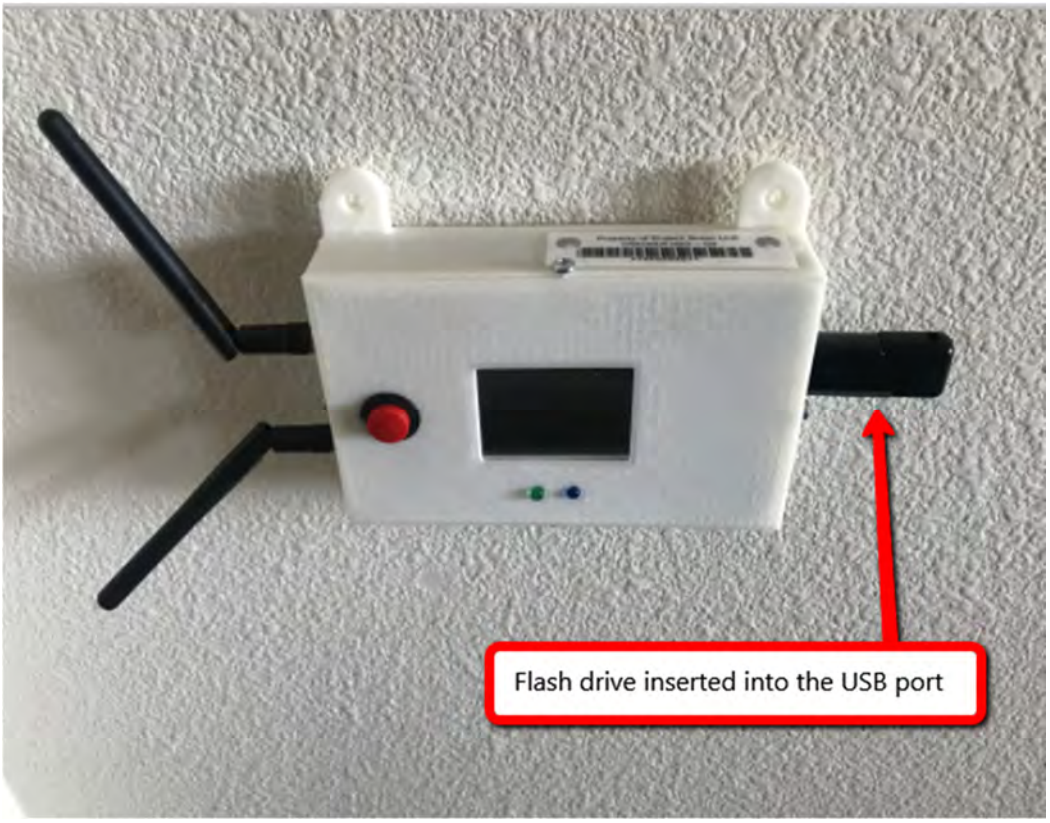
(Yellow arrows indicate the new, improved antenna connection; red arrows show the old approach)

USB Drive Issues

There's a USB drive built into the main board (shown in the screenshots appearing on the next page). When a Wifi connection is not present and a water event is sensed, the water event data is written to a flash drive that is plugged into the USB port, which saves the water event data so that it can be sent to the server once a connection is reestablished or once someone manually pulls the data off the flash drive.

Unfortunately, there was a bug in the firmware that caused the "write" operations to the flash drive to halt unexpectedly, preventing the device from storing water event data for events sensed while the device was offline. The writing of water events to the local flash drive was our fail-safe backup strategy for Wifi communication issues, but it also failed.





The firmware bug that caused the USB write operation failures was traced to an issue with the driver created by the part's manufacture, and was resolved by reaching out to the manufacturer to obtain a library file that contained the fix, which was eventually incorporated into a new version of the firmware and flashed to the devices.

Issues Summarized

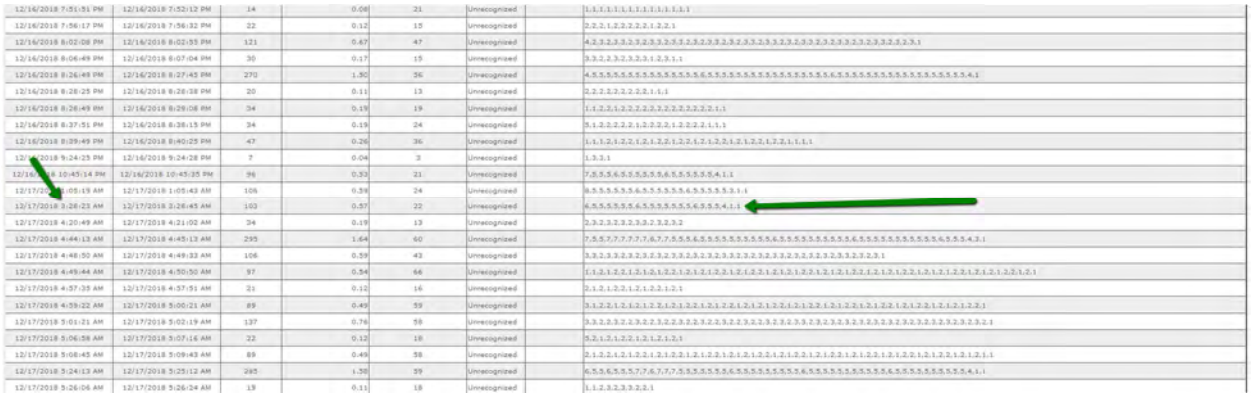
The overall impact of all three bugs and defects that that both our primary and secondary methods for capturing water event data failed; a worst-case scenario. Reliable data collection is a keystone in the performance of the platform, and we missed the mark.

Data Analysis

While the data collected from homes was too patchy and incomplete to arrive at any broadly-scoped conclusions about individual households and all the participant homes as an aggregate, we were able to collect and analyze more narrowly-scoped data about individual water events. In doing so, we **confirmed** that the platform **accurately senses the duration**, **number of gallons used**, and **flow signature** of water events. We also confirmed the devices ability **to identify the fixture and fixture-type responsible for most water events**, in everyday homes and existing plumbing systems. (Prior to this study, testing had only been done under "laboratory-type" conditions, and in too small a number of homes to make a determination with any degree of confidence as to whether the results would hold up in the average home with a common plumbing system).

The screenshot below shows a list of water events that were sensed in the home of a study participant starting on December 16th. While the technology used to sense and determine the flow signature of each event is considered proprietary and will not be discussed in this report, we can take a look at some of the data output, to demonstrate how the system correlates events of the same type and belonging to the same fixture.

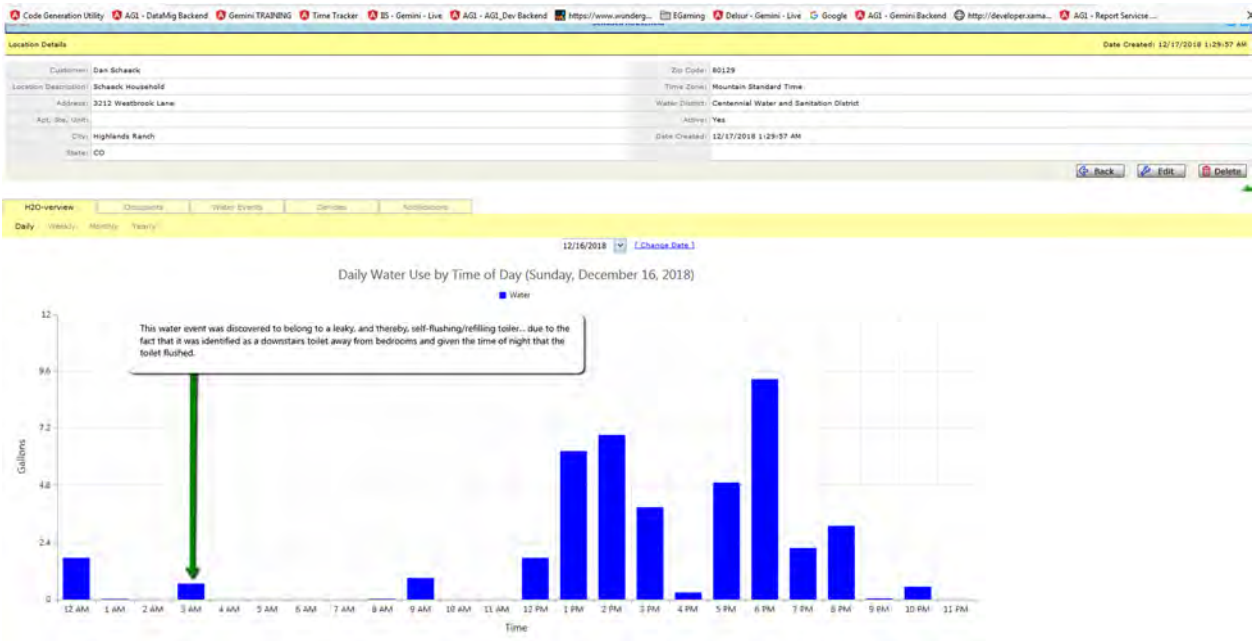
The green arrow in the screenshot below calls out a water event that occurred at ***3:28 am***, and that had a flow signature of '***6,5,5,5,5,5,5,5,5,6,5,5,5,5,5,5,5,5,6,5,5,5,5,4,1,1***' and ran for **22 seconds**. The event in the list just above that event occurred at **1:05 am** and belonged to the same fixture. Its flow signature was '**8,5,5,5,5,5,5,5,6,5,5,5,5,5,5,5,6,5,5,5,5,5,5,3,1,1**' and ran for **24 seconds**. Events originating at the same fixture and pertaining to the same type of water event have similar flow signatures and can therefore be correlated. The water event matching algorithm takes into account a bunch of different variables when trying to identify the originating fixture and fixture type of an event, but the flow signature is one of the more vital pieces of information used in many cases.



To demonstrate the contrast of an event that occurred at a different fixture, we can compare the flow signatures of the two events belonging to the same fixture discussed above, to the event that occurred at **8:37 pm** earlier that night, and ran for **24 seconds** and had a flow signature of "**5,1,2,2,2,2,2,1,2,2,2,2,2,1,2,2,2,2,2,1,1,1**"

If an end user opts to formally train the system by manually triggering and tagging a series of water events, future events of the same type and originating at the same water fixture can be "automatically" recognized, tagged, and classified. Once events are classified, they can be compared over time and the corresponding fixture's performance can be monitored to identify any leaks, mal-adjustments, or material changes in the amount of water consumed per-use. Additional performance evaluations of each fixture can be made if the classified events corresponding to that fixture are compared to known industry standards or known baseline figures for fixtures of that same type in other homes.

During the course of the study, and in test driving the training feature, we encountered a few cases where the platform was able to successfully identify leaky and underperforming fixtures. One such example occurred fifteen hours after our first installation. Upon reviewing the training data from the day prior and comparing it to events that had occurred earlier that morning, we noticed a data anomaly that we believed was a faulty toilet in a participant's home. The water event stuck out, because it corresponded to a toilet located on the downstairs floor of the home, where no one slept and that was not normally used during nighttime or early morning hours. The amount of water registered with each flush was odd as well.



As shown in the screenshot above, several flushes of that toilet were sensed and reported throughout the course of that first night. The homeowner confirmed that no one used the toilet during those hours and upon investigating things, confirmed that the toilet was "leaking" in such a way that it was "sort of flushing on its own" multiple times "throughout the day". The toilet was fixed that same day, representing an immediate estimated water savings of about 3 to 5 faulty flushes per day (or 15-18 gallons/day).

Conclusion

While the technical stumbling blocks we hit along the way prevented us from meeting all the goals and objectives we set out to achieve in the ways that we had planned, we were able to refine and proof the technology in a way that we feel indicates that this platform can be used as a conservation tool to eliminate water waste in and around homes and to combat coming water shortages.

Based on what we observed and based on feedback from participants, the most innovative aspect of the new technology seems to be its ability to provide real-time consumption data by-use and by-fixture, using a single sensor that attaches quickly and non-invasively to existing water meters.

With some small fixes and tweaks to enhance device reliability, we believe that the information collected by the devices can be enriched and delivered to end users in a way that empowers them to understand and curtail their consumption habits. Over time, the hard data that the system will deliver to consumers will allow them to benchmark their consumption over time and against other households of similar demographics and can also calculate and provide homeowners with actual ROI (Return On Investment) figures derived from their conservation efforts.

Additionally, and in thinking toward the future, it's safe to assume that aggregating and analyzing more detailed consumption data in real-time on a cloud-server will allow us to improve the algorithm and the approach used to tag, classify, and "fingerprint" water events. We may even be able to improve things through the increased use of machine learning techniques, which would yield an improved classification algorithm and an larger dataset which could be shared with a larger audience and may have a number of applications in the future.

Note: Both the method and the apparatus/system discussed herein and comprising the water savings platform are "Patent Pending".

Thank you to ICP

We wanted to extend our gratitude to the ICP and its partners. While things didn't go exactly as planned, this project has proven an invaluable step in moving forward with efforts to vet and refine this technology. The feedback we received from homeowners and the system's ability to classify individual water events provides us with momentum enough to continue forward. There aren't many funding opportunities out there for parties in the private sector and who aren't considered a water delivery authority. We firmly believe that challenges deriving from coming droughts and water shortages are problems best tackled as a community. The ICP is unique in that it allows individuals and small businesses, comprising an important part of that community, a chance to participate in the process and to be part of the solution from the demand-side. We are very appreciative of the ICP and all of its partners.