# Quarter 1 report for Green Infrastructure Living Lab (GILL) project
# Report Period: **6/1/2017 ~ 8/31/2017**

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|---|---|
| Grant number: **1620003** | Contract number: **1620003**<br>Period covered: **6/1/2017 ~ 8/31/2017** |
| Principle Investigators:<br>**Dr. Franco Montalto, Dr. Mira Olson, Dr. Christopher Sales, Dr. Youngmoo Kim**<br>Drexel Team Member:<br>**Ziwen Yu, Babak K. Roodsari, Karly Soldner, Katelyn Johnson** | |

## 1- Brief executive summary

Major activities for the first quarter of 2017 include further elaboration of the Public Engagement App, site preparations at the Boys' Choir lot, continued improvements in data transmission, and investigation on new candidate monitoring sites. The Public Engagement App was improved by adding a Graphical User Interface (GUI) for entering the sensor and site maintenance information. Gravel was delivered to the Boys' Choir lot after cleaning the site. One pilot experiment was built at this site and more data loggers will be assembled for the future installations. A new approach for transferring data from data loggers to the cloud was developed.

Meetings between the Project Team and PWD team were held throughout the reporting period, from June 2 to August 25, 2017.

The main goal for the next quarter of 2017 is to finish ordering and deploying sensors for the existing and new monitoring sites. In addition, the research team will look for a new green roof candidate site for the following year's monitoring project. Furthermore, the structure of different tabs for the Public Engagement App will be finalized to ensure its effectiveness for public and maintenance team at PWD.

## 2- Project updates

### a- Existing monitoring sites

#### i. Boys' Choir lot

Major field activities at the Boys' Choir lot over the first quarter of 2017 include site configuration design, site cleaning, and prototype installations (Table 1). Detailed configuration of the site including soil depths, funnel surface areas, power outlet set ups, and outflow system were designed (Figure 1). The required soils for the twelve prototypes were transferred to the site, and rain barrels 1 and 2 were filled with the designated soil layers. For these two prototypes, soil moisture sensors were also installed inside the barrels and data loggers were shown to be successfully working. All design criteria remained unchanged based on the initial design (Figure 2), except for the approach to outflow measurement. The original outflow measurement approach featured a tipping bucket system, but the GILL team decided to modify the approach to include a deep plastic bucket with a pressure transducer inside a narrow PVC pipe.

Table 1- Summary of current and future site activities for the Boys' Choir lot

| **Fieldwork activity summary over this quarter (June 1-August 31, 2017)** | **Summary of next steps** |
|---|---|
| 1- The site was cleared, and gravel was delivered to the site.<br>2- Power output were ordered and Drexel facility installed them in Boys' Choir lot.<br>3- One of the pilots was built and started logging data. It includes two soil moisture sensors. Data is not logged into the cloud yet. | 1- Scales will be ordered.<br>2- The data transfer from scale to the logger will be tested.<br>3- All equipment and sensors will be deployed over the next quarter. |

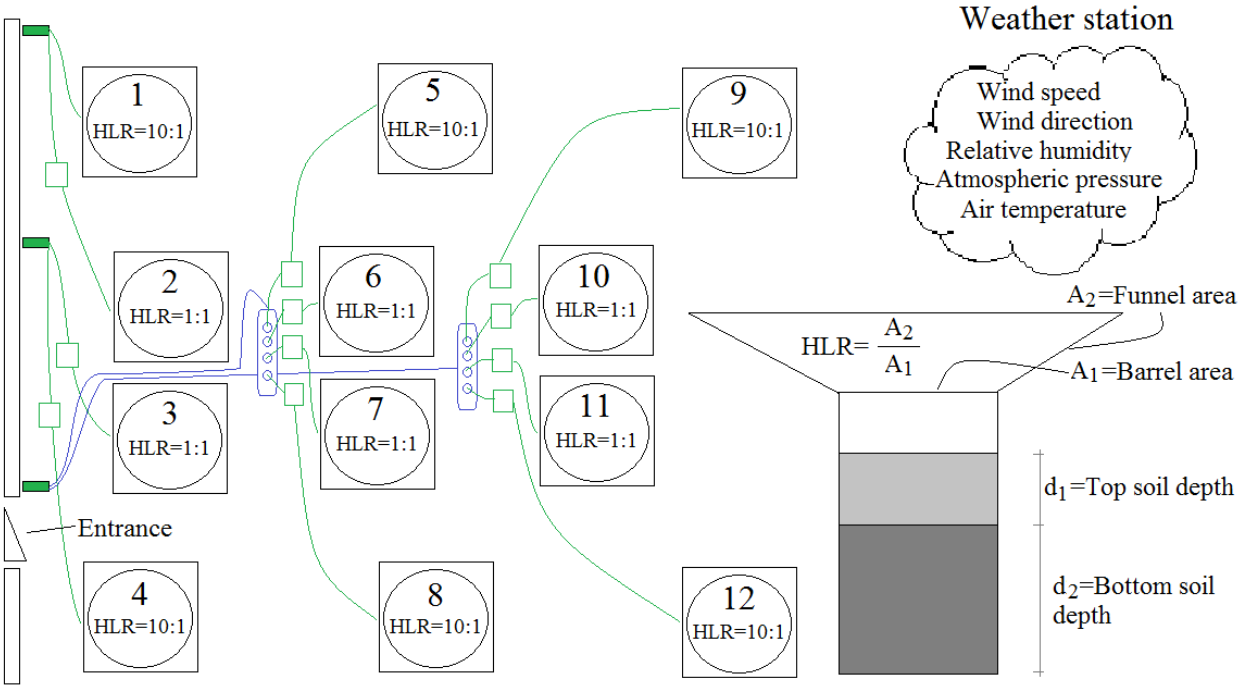



Figure 1- Design configurations for prototypes and power supply distribution at the Boys' Choir Lot. The bottom layer soil in all prototypes includes 18 inches of gravel AASHTO #57. The top layer soil for prototypes is 12 inches of high sand soil (prototypes 1, 2, 5, 6, 9, and 10) and standard stormwater infrastructure soil (prototypes 3, 4, 7, 8, 11, and 12). HLR values represent the Hydraulic Loading Ratio for the prototypes as defined on the diagram.

a)

b)

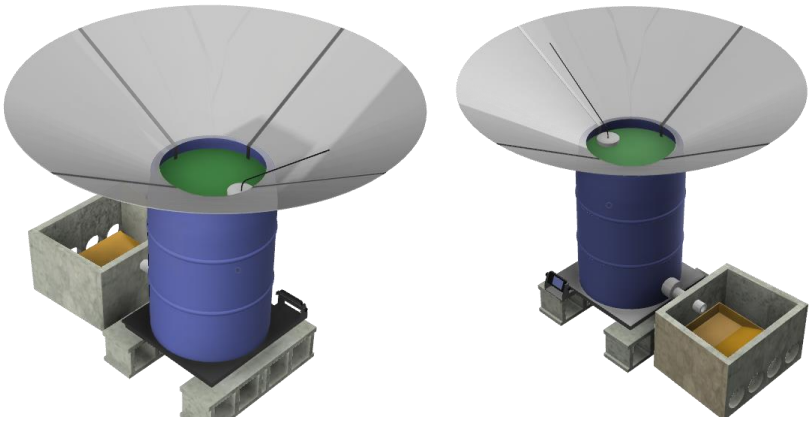


Figure 2- View of the site configuration at the Boys' Choir lot on November 9th, 2017 (a) and the initial design of the prototypes (b)

### ii. PISB

Major activities at PISB over the first quarter of 2017 include frequent calibration of EC5 and 10HS sensors at this site (Table 2). The Drexel research team regularly visited the to ensure the safety of the equipment and quality of the data. In addition, real-time transfer of data to a cloud-based server was accomplished over this quarter. The Drexel team will continue performing monthly and seasonal sensor calibration over the next quarters to ensure the quality of the calibrated data from the online database.

Table 2- Summary of current and future site activities for PISB.

| **Fieldwork activity summary over this quarter (June 1-August 31, 2017)** | **Summary of next steps** |
|---|---|
| 1- All sensors were calibrated regularly.<br>2- The data was successfully logged to the cloud database. | 1- Monthly and seasonal sensor calibrations will be performed for this site.<br>2- The quality of future logged data will be ensured. |

Real-time soil moisture data was collected using two different Decagon sensors: 10HS and EC5. To calibrate the sensor readings (millivoltage values), the volumetric moisture content of the soil was measured gravimetrically. Samples were extracted from the field, weighed wet, then dried, and weighed again, with the difference in mass used to establish the soil's moisture content. A linear regression was used to correlate the on-site soil moisture values with the raw voltage readings from each of the two sensors. The following chart shows the calibrated line for the two sensors (Figure 3). To date, only five soil moisture sampling visits have been performed, with 3 samples collected per visit. To improve the calibration, more on-site soil moisture measurements will be taken over the next quarter and the accuracy of sensor read outs will be examined for future data records.

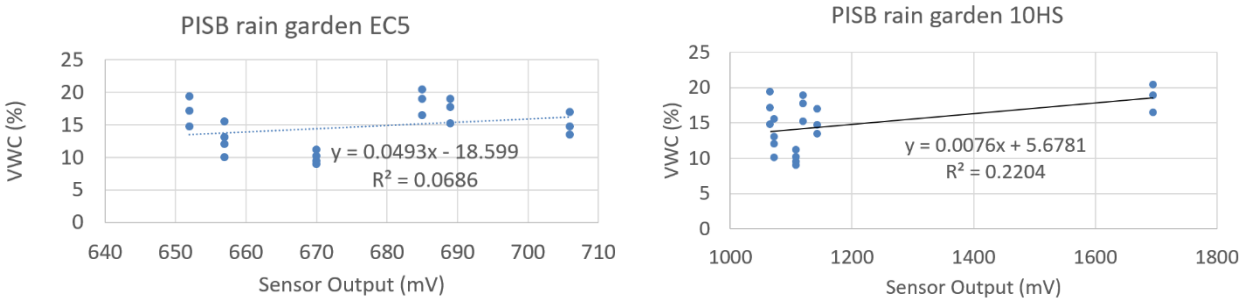



Figure 3- Calibration lines for the EC5 and 10HS soil moisture sensors at PISB.

The calibration equations developed thus far were used to convert the raw sensor data into estimated soil moisture time series. Data collected from July 13 to August 31 for the 10 HS and 5EC sensors are shown in Figure 4 and Figure 5, respectively. Note that the soil moisture values are presented as a percentage of the soil's porosity. The variability in estimated soil moisture prior to August 3 for both sensors is due to the inspection activities after the installation.

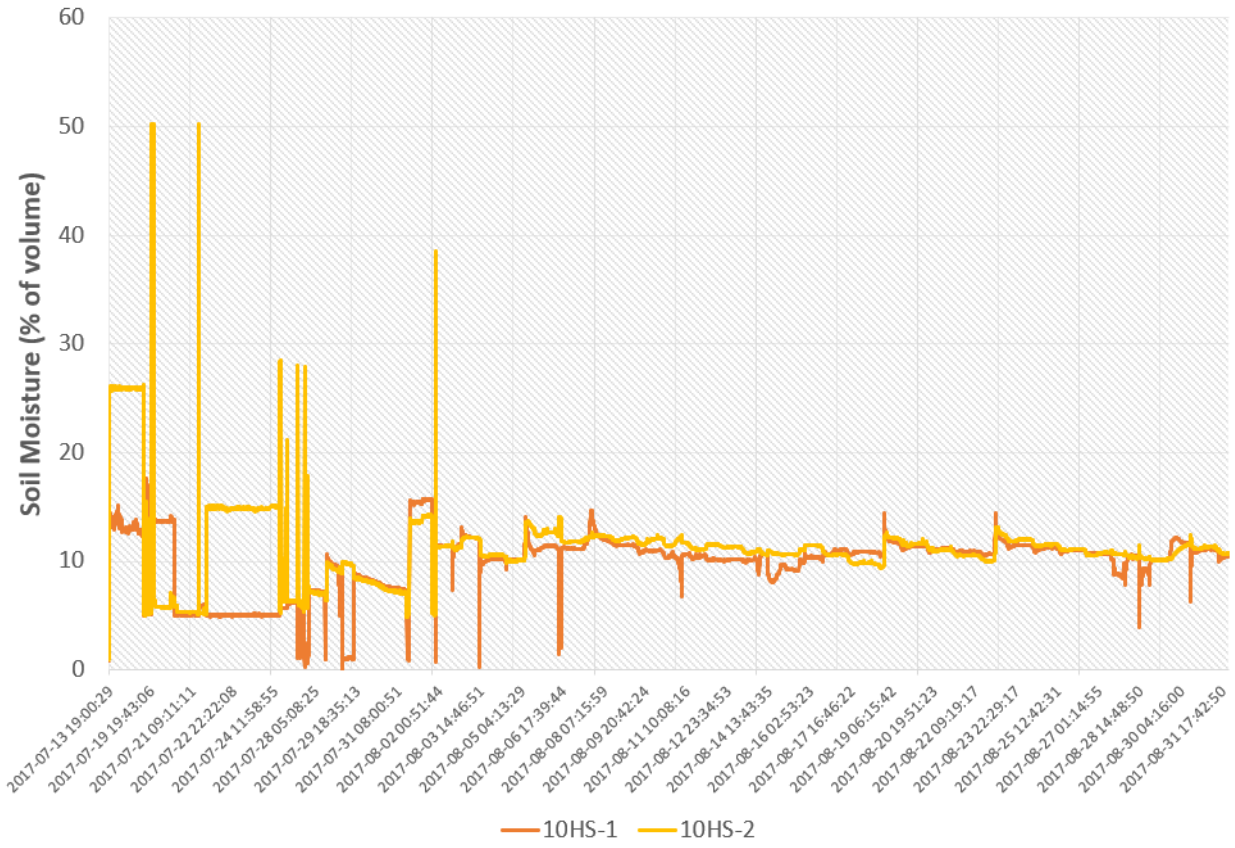



Figure 4- Calibrated soil moisture data from 10HS sensors over the period of July 13 to August 31

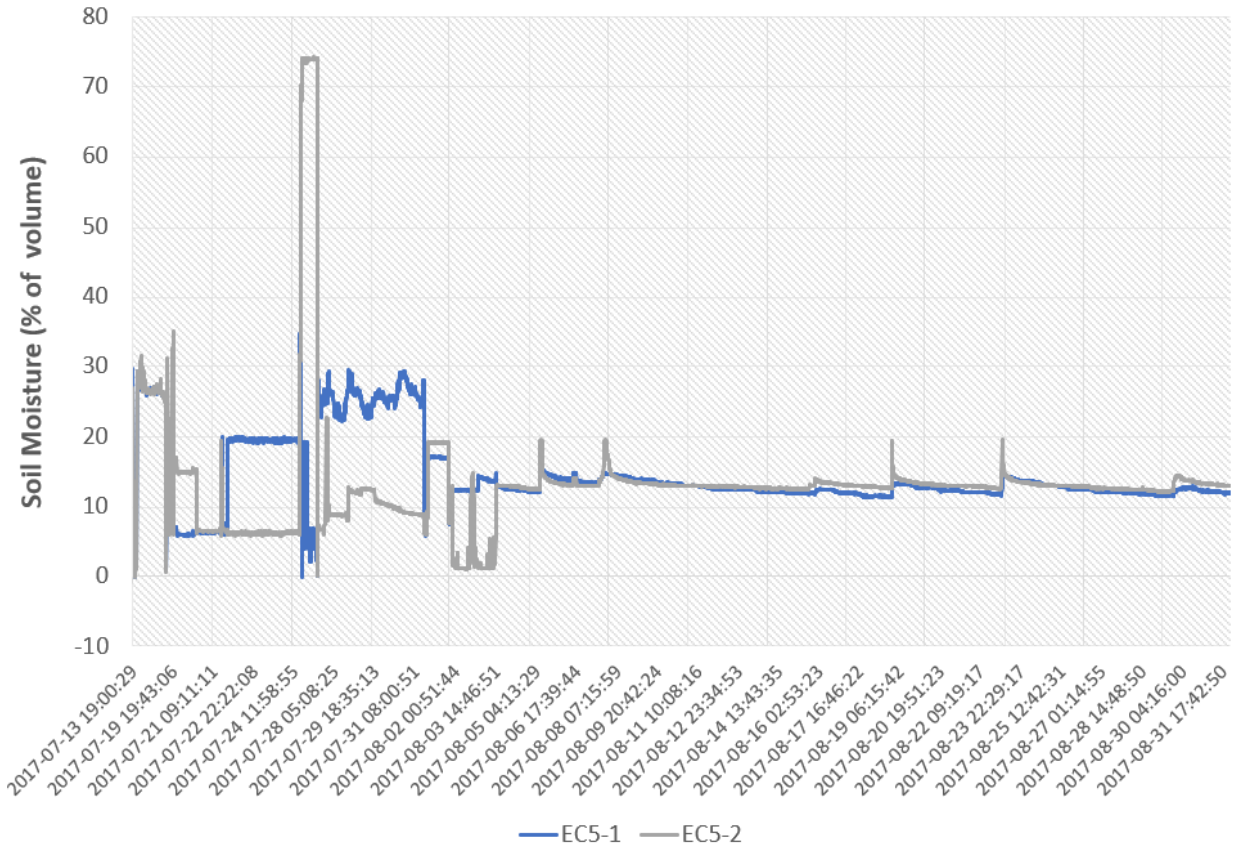



Figure 5- Calibrated soil moisture data from EC5 sensors over the period of July 13 to August 31

### iv. Rec Center

Research conducted at this site over the first quarter of 2017 includes continuous water level monitoring at the cistern using a HOBO U20L pressure transducer (Table 3). Analysis of the data collected from February to April 2017 suggests that the rate of discharge from the slow release pipe occasionally fell below its theoretical outflow discharge, 1.5 ft/hr (Figure 6). Preliminarily, the monitoring effort suggests that there are three different stages of water release that are possible for the cistern:

- Stage A: When the water level is below the invert of 3.1 ft of the slow release pipe, discharge is attributed completely to toilet flushing. The average observed rate of discharge is about 0.0017 cubic feet per second, corresponding to 298 flushes per day (assuming 1.6 gallons per flush).
- Stage B: When the water level is above the invert of the slow release pipe, water can also leave the cistern through the slow release pipe. The rate of discharge during periods when the water level fell in this range averaged about 0.0018 cubic feet per second. Based on the analysis above, about 95% percent of this flow is likely attributed to toilet flushing, with the remainder due to slow release.
- Stage C: When the water level is above 4.08 ft, the invert of the outflow pipe, water can also leave the facility through this second pipe. This condition was rare but resulted in higher total discharge rates, ranging from 0 to 0.0027 cubic feet per second.

As is evident from the data presented above, the Stage B discharge rate is not significantly greater than the Stage A flow rate, a condition that would be expected if the slow release pipe were functioning correctly. Moreover, the monitoring revealed a drop of 0.43 feet in water level over 4 hours on March 30, 2017. This rate of drawdown greatly exceeds that observed at other periods and is highlighted in Figure 6. Converted to a volumetric flow rate, this drawdown would have been approximately 0.0052 cfs, equivalent to 350 1.6 gallon flushes. Additional work is necessary to determine whether this drop in water level was indeed due to that many flushes, or if it were triggered by the partial clearing of a blockage in the slow release pipe.

The research team has requested that Drexel facilities inspect the slow release pipe to determine if it is clogged. Drexel facilities claims that they are lacking the funding to conduct this inspection, and inquired, in turn, as to whether PWD has any contractor who could help with this.

Monitoring of the water level with the pressure transducer is ongoing, and will be validated with manual measurements of water level made at a weekly time interval.

Table 3- Summary of current and future site activities for the Rec. Center

| **Fieldwork activity summary over this quarter (June 1-August 31, 2017)** | **Summary of next steps** |
|---|---|
| 1- Water level data was collected for the first monitoring cycle.<br>2- We need to check the data for another cycle to confirm whether the slow release pipe is potentially clogged. | Keep doing the regular calibration measurement on the water level and collect data every season. |

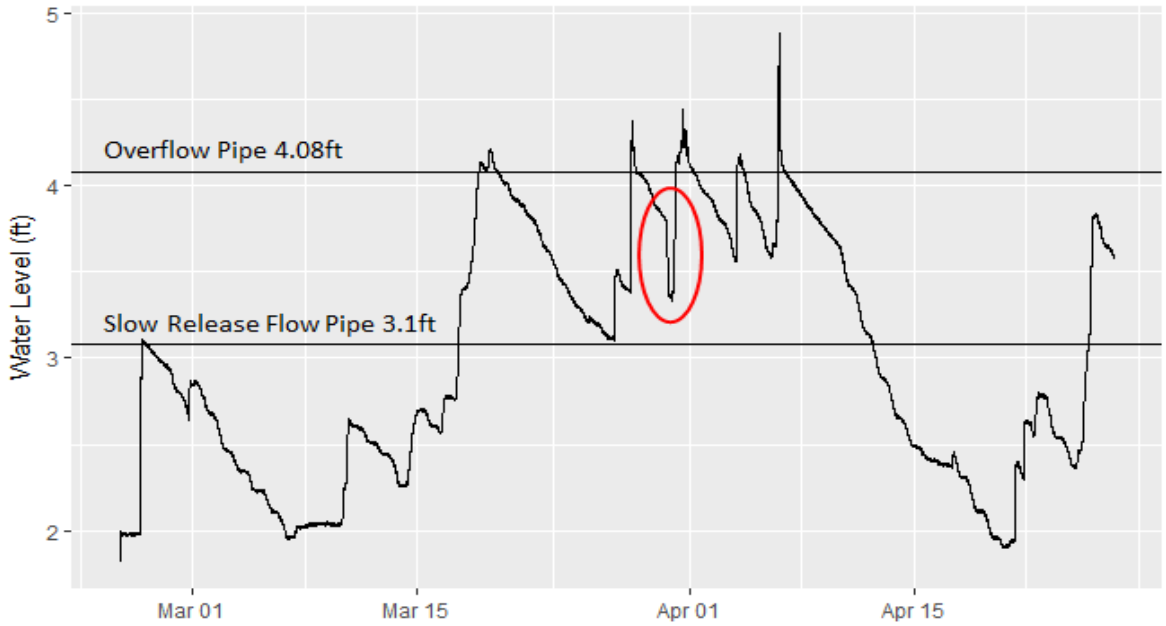



Figure 6- Water level in Rec Center from February to April 2017. (Red circle: a possible unclogging in slow release pipe)

## b- New monitoring sites

The Chestnut Square site, identified as a potential GILL monitoring site during Year 1, was repaired by Drexel facilities during this reporting period. During the next quarter, the team will propose a monitoring strategy for this site that addresses outstanding PWD research questions.

During the reporting period, the team also investigated two green roofs for potential consideration as new monitoring sites. The two sites under consideration by the team include the Cira Green and the CHOP green roofs.

Over the next quarter of the GILL project, the research team will also investigate other potential new monitoring sites with PWD

Table 4- Summary of current and future site activities for the new monitoring sites

| **Fieldwork activity summary over this quarter (June 1-August 31, 2017)** | **Summary of next steps** |
|---|---|
| Chestnut square site has been fixed by Drexel Facilities and is ready for monitoring. | We will continue to reach out to green roof (e.g. CHOP and Cira Green) and other sites to add new sites to our portfolio of GILL sites. |

## c- Public Engagement App:

Over the first quarter of 2017, the Public Engagement App was updated to include a webpage for maintenance activities such as adding new site, adding new sensor, changing status of existing sensors (Table 5). The site can be viewed at http://ec2-54-186-90-222.us-west-2.compute.amazonaws.com/sensor.php using the following credentials.

**ID**: admin

**Password**: ziwen

Table 5- Summary of current and future site activities for the Public Engagement App.

| **Activity summary over this quarter (June 1-August 31, 2017)** | **Summary of next steps** |
|---|---|
| A web page has been designed to the Public Engagement App to manage new site and new sensors. | 1- Further maintenance functionalities need to be added to the website and duplicate these into the mobile app.<br>2- A report function and live data view should be added into the web. |

The page used to deploy new sensors when adding a new site is shown in Figure 7. The user has to input the serial id of the sensor, its name, the associated measurement, and the corresponding site into the

database. Once a sensor is functioning, users can go to this page to change its status from active to others such as inactive or damaged. We need further discussion on what status needs to be added to this list as the project proceeds. The next step is to add more functionality to make this webpage more powerful and user friendly. This functionalities will also be duplicated in the mobile app so that users can use their smart phone to do all these activities on site. A report function and live data view will also be added.

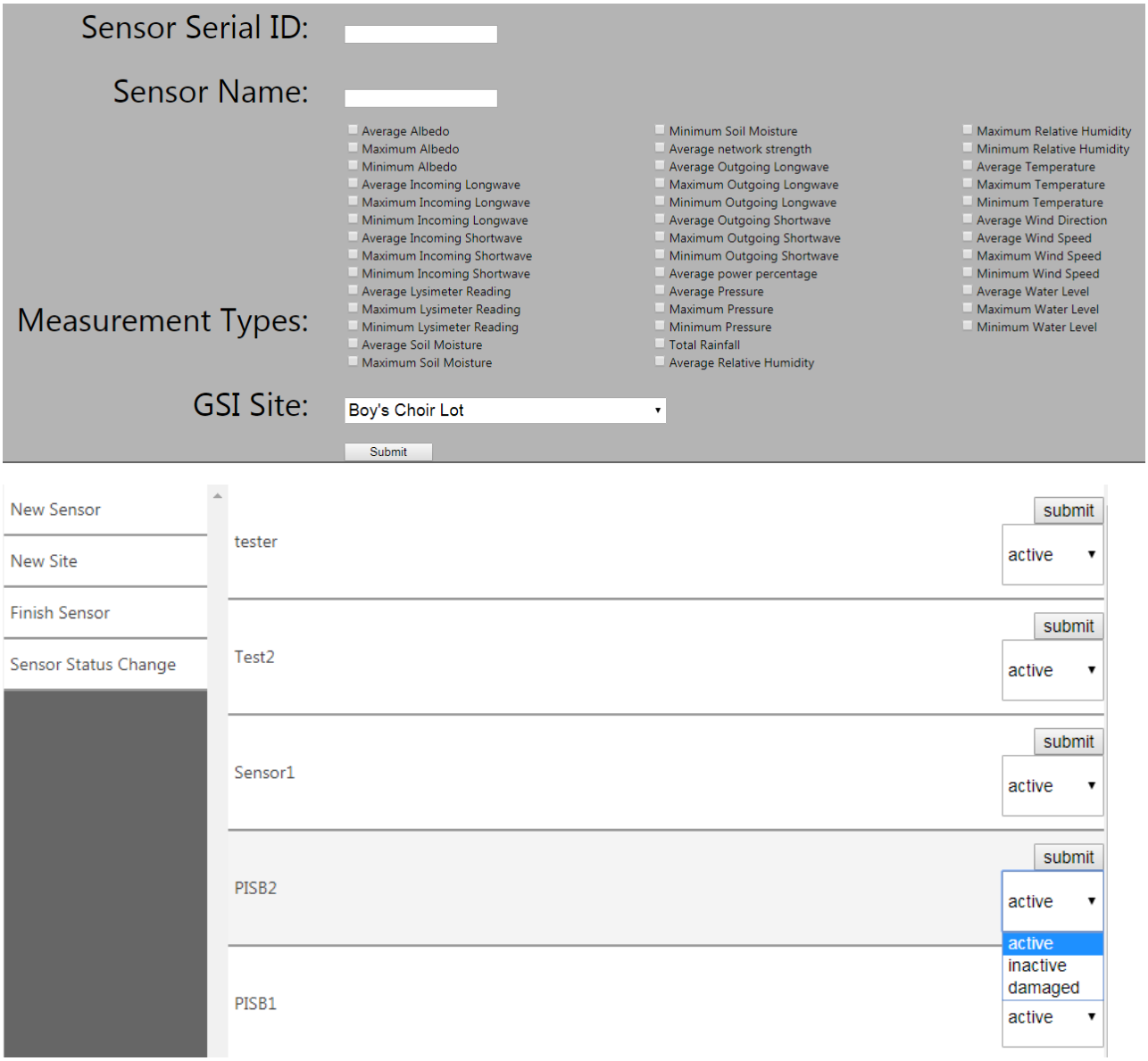



Figure 7- Graphical interface of new sensors page in the Public Engagement App.

## d- Sensor and data logger development

In the previous reporting period, a data transfer problem had been observed. Specifically, XXXXX. In the first quarter of 2017, the IoT data transferring problem was resolved (Table 6). The Drexel team checked

the JSON format of the transferring data and the web portal to pull the information. As we move on to other data loggers, we need to adjust the pull request to accommodate the format for different types of measurements. The real-time data from PISB data loggers are now logged to the MySQL database at the AWS server (Table 7). The next step is to build similar data loggers for the Boys' Choir lot, which log real-time data from scales, water level sensors, and soil moisture sensors.

Table 6- Summary of current and future sensors and data logger development activities.

| **Activity summary over this quarter (June 1-August 31, 2017)** | **Summary of next steps** |
|---|---|
| The data transferring problem has been resolved. The data loggers in PISB site is logging real-time data to the AWS database. | 1- Build the new data loggers for the Boys' Choir lot with different type of sensors.<br>2- Adjust the pull request to accommodate data format from future data loggers. |

Table 7- screenshot of the measurement table for PISB sensots at the AWS server

| datetime | value | measure_type_id | QAQC_flag | sensor_id |
|---|---|---|---|---|
| 2017-08-30 23:56:42 | 68.000 | temp ave | 0 | PISB2 |
| 2017-08-30 23:56:42 | 552.000 | moist ave | 0 | PISB2 |
| 2017-08-30 23:56:42 | 899.000 | temp max | 0 | PISB2 |
| 2017-08-30 23:56:42 | 61.000 | netwk ave | 0 | PISB2 |
| 2017-08-30 23:56:40 | 68.000 | temp ave | 0 | PISB1 |
| 2017-08-30 23:56:40 | 700.000 | moist ave | 0 | PISB1 |
| 2017-08-30 23:56:40 | 1140.000 | temp max | 0 | PISB1 |
| 2017-08-30 23:56:40 | 59.000 | netwk ave | 0 | PISB1 |
| 2017-08-30 23:47:54 | 68.000 | temp ave | 0 | PISB2 |
| 2017-08-30 23:47:54 | 560.000 | moist ave | 0 | PISB2 |
| 2017-08-30 23:47:54 | 903.000 | temp max | 0 | PISB2 |
| 2017-08-30 23:47:54 | 61.000 | netwk ave | 0 | PISB2 |
| 2017-08-30 23:47:52 | 68.000 | temp ave | 0 | PISB1 |
| 2017-08-30 23:47:52 | 702.000 | moist ave | 0 | PISB1 |
| 2017-08-30 23:47:52 | 1139.000 | temp max | 0 | PISB1 |
| 2017-08-30 23:47:52 | 59.000 | netwk ave | 0 | PISB1 |
| 2017-08-30 23:39:06 | 68.000 | temp ave | 0 | PISB2 |

## 3- Summary of meetings

A summary of meetings over the first quarter of 2017, including key meeting topics and important outcomes for each meeting is provided in Table 8.

Table 8- Summary of all meetings in the first quarter of 2017.

| Date | Key Meeting Topic | Important outcomes |
|---|---|---|
| **6/2/2017** | Public Engagement App updates | 1- Contract renewal is underway and should go quickly for signing<br>2- A real-time logging at the Boys' Choir lot for the Public Engagement App will be needed in the future.<br>3- Final and Public Engagement App reports is received by PWD.<br>4- PISB site is installed and everything is working well. |
| **6/16/2017** | discussing site updates and IoT problem | 1- Some obvious trends seen in the rec center graphs were discussed.<br>2- As Aaron is setting up the AWS, a documentation of what he did will be helpful since AWS is new.<br>3- summer plans was explained to the Drexel team. |
| **6/30/2017** | updating site activities and problem in Rec center data | 1- Rec center data indicates a clogged slow release pipe. These can be verified or disputed by conducting another survey the next time we retrieve the data loggers.<br>2- The Boys' Choir lot needs a cleaning to remove the boxes. This request has been send to Drexel facility.<br>3- We potentially will have a presentation about the IoT technology as an example of smart city in DC in Sep. |
| **7/14/2017** | updating site activities and lab space | 1- The IoT real-time data transferring problem has been solved.<br>2- Boys' Choir lot is cleared and the gravel is delivered.<br>3- Chestnut square, as a potential future site, is not fixed yet.<br>4- Consider new sites and implementation of the Public Engagement App as part of an environmental class at Drexel. |
| **7/28/2017** | discussing power problem in Boys' choir lot, plan for work on Rec center, and engagement app development | 1- For Boys' Choir, the funnel design was changed to be a form of tarp that is fortified using brackets and a metal frame.<br>2- Chestnut Square site is finally fixed and is a very possible new site as we had the agreement from Drexel Facilities regarding sensor placements and power source in a meeting a while back.<br>3- Cira Green is also desirable, but we received no response so far. |
| **8/11/2017** | updating site activities, app functionality expanding, candidate for post-doc | 1- Based on a theoretical water balance model in Rec center, the water level should not go over the slow release level for a substantial amount of time. This means that real time control isn't viable for this site.<br>2- We should get a water-tape to manually measure the water level at the Rec. Center's cistern to validate the data.<br>3- For Boys' Choir, plants aren't going to be used anymore as it is past the planting season. Monitoring through the winter should be possible as the scales are advertised as being functional in the lower temperatures. |
| **8/25/2017** | updating the project schedule and site activities, and discussing data logger at Boys' Choir lot and the engagement app functionality | 1- Weather station is cleared of wasps and can be worked on.<br>2- A live visualization is needed to let the public see the monitor data through the Public Engagement App.<br>3- To accurately determine what form of catch basin is needed for the discharge at Boys' Choir, we should manually test the volume by measuring how much water is poured into the barrel vs how much is released. |

## 4- Presentations, communications, and/or papers

A summary of presentations, communications, and conference abstract submission over the first quarter of 2017 is provided in Table 9.

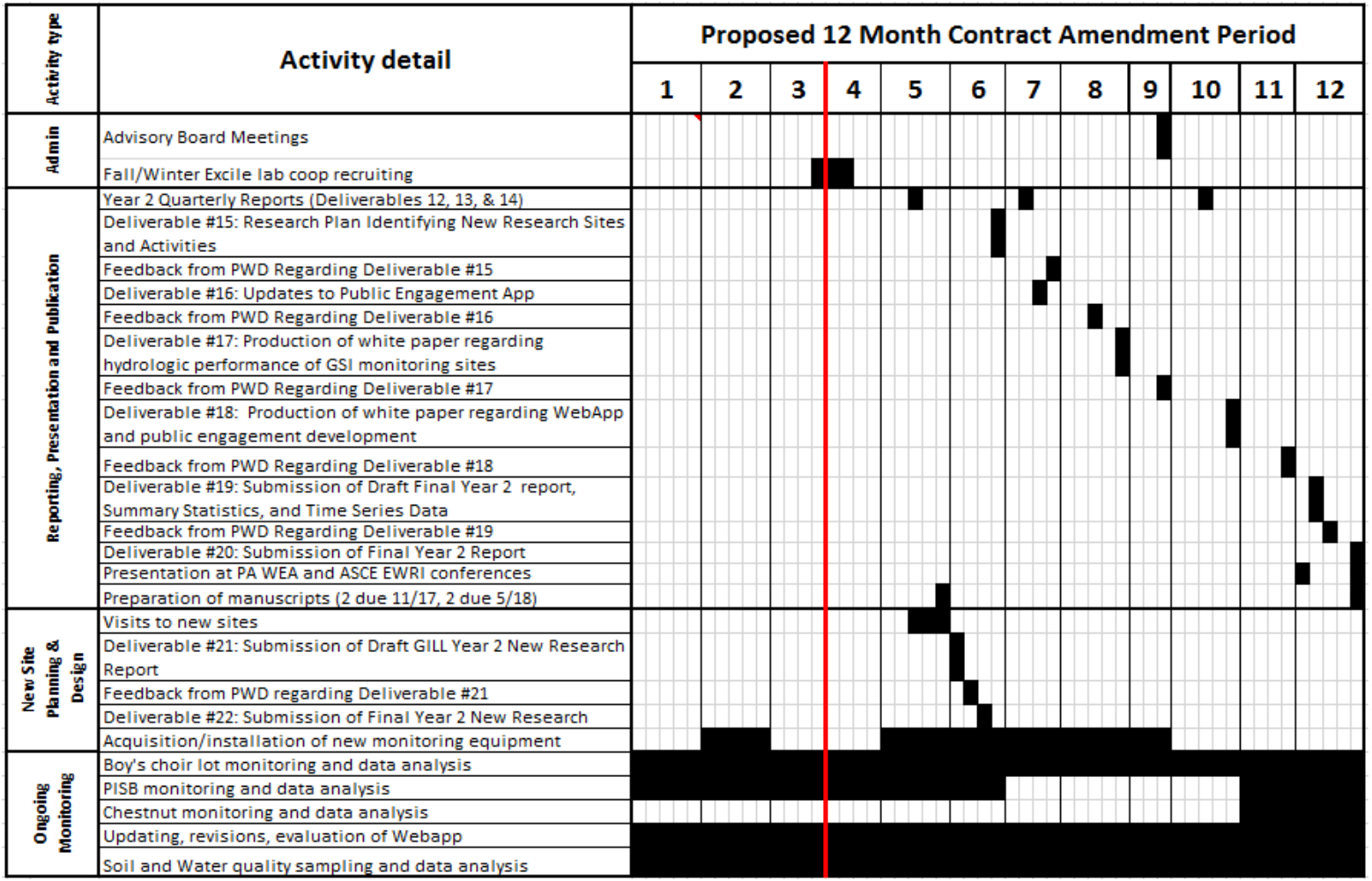
Table 9 - Summary of presentations, communications and conference abstract submissions

| **Activity** | **Date** |
|---|---|
| Preparing for the presentation at the Villanova University Symposium | Oct 11 |
| Preparing for the brown bag meeting at PWD | Oct 16 |
| Preparing for two abstract in AGU<br>• Franco Montalto (Using Amazon Web Services (AWS) to enable real-time, remote sensing of biophysical and anthropogenic conditions in green infrastructure systems in Philadelphia, an ultra-urban application of the Internet of Things (IoT))<br>• Ziwen Yu (Quality control of the soil moisture probe response patterns from a green infrastructure site using Dynamic Time Warping (DTW) and association rule learning) | Dec 7 |

## 5-Revised timeline and status on deliverable completion

An updated project timeline is shown in Figure 8. The red line separate the first quarter from the remaining period of the project. As can be seen, there is no deliverables due in the first quarter and most activities in this quarter focus on field monitoring activities. Based on this timeline, Drexel research team has met all the project deadlines for the first quarter of 2017.

Figure 8- Revised timeline for the second year of the GILL project.



A summary of the GILL project deliverables current status is provided in Table 9.

Table 10- Summary of the project deliverables status for the second year of the GILL project.

| Deliverable | Due date | Status |
|---|---|---|
| **Deliverable #15: Research Plan Identifying New Research Sites and Activities** | 11/30/2017 | An initial draft of this deliverable was completed and received comments from Franco. Further edits are needed before the final submission. |
| **Deliverable #16: Updates to Public Engagement App** | 12/21/2017 | Step-by-step tasks were defined for the Coop to facilitate preparing the final product. Different tabs of the app are already designed and need to be digitalized by the Coop. Next step is to write the methodology. |
| **Deliverable #17: Production of white paper regarding hydrologic performance of GSI monitoring sites** | 2/1/2018 | NA |
| **Deliverable #18: Production of white paper regarding WebApp and Public Engagement App development** | 3/29/2018 | NA |
| **Deliverable #19: Submission of Draft Final Year 2 report, Summary Statistics, and Time Series Data** | 5/17/2018 | NA |
| **Deliverable #20: Submission of Final Year 2 Report** | 5/31/2018 | NA |
| **Deliverable #21: Submission of Draft GILL Year 2 New Research Report** | 11/9/2017 | NA |
| **Deliverable #22: Submission of Final Year 2 New Research Report** | 11/23/2017 | NA |