Low Cost Flood Sensors:

Urban Installation Guidebook

A partnership between Charlotte-Mecklenburg Storm Water Services and the U.S. Department of Homeland Security Science and Technology Directorate

DELIVERABLE 5.A

Contract 70RSAT18CB0000022

April 23, 2020

The research in this report was conducted with the U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) under contract 70RSAT18CB0000022. Any opinions contained herein are those of the author and do not necessarily reflect those of DHS S&T.

Table of Contents

List of Figures

List of Tables

Executive Summary

Purpose of Low-Cost Flood Sensors Guidebook

This guidebook presents CMSWS' experience deploying low-cost flood sensors (LCS) at locations in Mecklenburg County. It summarizes the steps taken in Mecklenburg County to install, operate and maintain LCS. It is intended to serve as a reference for communities nationwide attempting to mitigate hazards associated with flooding through the installation and monitoring of real-time water levels in areas at risk of flooding.

Background

Mecklenburg County is the most populated county in North Carolina and one of the fastest growing metropolitan areas in the country. There are over 370 miles of Federal Emergency Management Agency (FEMA) mapped streams and an estimated 2,800 houses and buildings in mapped floodplain areas. As part of its overall flood mitigation strategy, over 2018-2020, Charlotte-Mecklenburg Storm Water Services (CMSWS) partnered with the U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) to test low-cost flood sensors (LCS).

Year 1 (Base Year): CMSWS deployed and evaluated 75 alpha-stage (first generation) sensors from three vendors (25 sensors from each vendor)[1]. Upon completion of testing the 75 alpha sensors, DHS S&T selected a single vendor to move into Option Year 1 based on feedback from five (5) state and local stakeholders.[2]	**Year 2 (Option Year 1):** The vendor selected supplied an additional 98 beta (second generation) LCS to CMSWS for testing. CMSWS operated 98 beta sensors along with 20 alpha sensors (five alpha units were damaged and used for spare parts) during OY1 for a total of 118 LCS.	**Year 3 (Option Year 2):** CMSWS fully integrated the beta sensors with Mecklenburg County's existing Flood Information and Notification System (FINS) to provide autonomation of data and displays, to include real-time risk scoring, losses avoided and inundation mapping.

Summary of Findings

CMSWS operated the 93 beta and 20 alpha LCS through February 2020. The accuracy of the LCS units was excellent and met the needs of all use-cases monitored by CMSWS. CMSWS recognizes that, while maintenance is required, LCS deployments will result in an overall lower cost for these "commercial-grade" LCS compared to the significantly more expensive "scientific-grade" stream sensors.

In general, the units functioned effectively and any minimal disruptions in service were caused by communication (cellular) or firmware related issues. Some problems were encountered with the ability of the integrated solar array to effectively charge the units during periods of extended cloud cover (>72 hours) and at sites with dense tree canopy. Approximately 20% of the units suffered some sort of

[1] CMSWS' Base Year experience is documented in contract Deliverable 3.A (CMSWS, 2019) which details the preparations for installing and testing 75 alpha LCS in Mecklenburg County, North Carolina.

[2] Equipment from the 2 vendors not selected for beta production were sent back to the vendors or discarded.

physical damage during the testing period that prevented normal operation. The damage was predominantly caused by fallen trees, in-stream debris and vandalism.

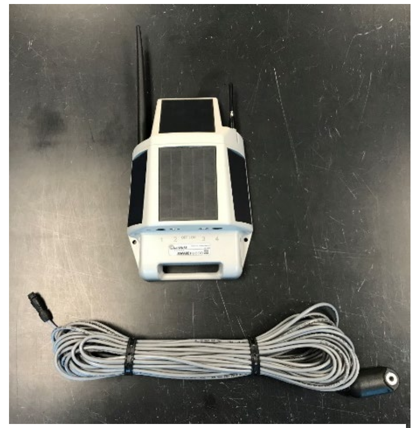

Figure 1: LCS Beta Unit.

The beta LCS sensors sites were distributed across the following use-cases and included both wet (in-stream) and dry (floodplain) installations:

- Unmonitored flood risk on residential and commercial buildings.
- Flood prone road crossings (bridges and culverts)
- Sanitary sewer lift stations, high hazard dams and other flood prone critical infrastructure
- Capital Improvement project sites (flood mitigation and stream restoration sites)
- Rapid Deployment (maintained in warm storage)
- USGS validation sites
- Public demonstration

Prior to installation of the LCS, CMSWS conducted site reconnaissance to determine site suitability, cellular service status and general installation needs. The alpha and beta LCS units are equipped with the capability to transmit data via radio or cellular modem. Testing in Mecklenburg County determined that the capabilities of the radio equipment limited transmission distance to <0.25 miles, which would severely limit the usefulness of the LCS. CMSWS opted to equip all of the LCS units with 4G cellular modems, which have been very effective. Once installed, most of LCS beta units failed to transmit data due to hardware or firmware defects. The vendor site visit and direction then resulted in the beta LCS to begin reliably collecting and transmitting data in December 2019.

An active and ongoing operation and maintenance program implemented by CMSWS has been essential to successful operations of LCS. Upon installation, CMSWS initiated a maintenance and operation protocol that consisted of several activities designed to monitor performance. The protocol included daily office checks via web-based monitoring on each sensor and site visits monthly and after one inch or more rainfall events.

Conclusions

The LCS tested by CMSWS present an extremely useful tool for storm water programs of all sizes. They are relatively simple to install and operate, but require an active maintenance program similar to other field equipment. They are highly versatile and can be permanently installed in a variety of settings including wet and dry sites or rapidly deployed in advance of storms at high risk areas. These “commercial-grade” LCS do not take the place of USGS gages and do not provide the same level of scientific accuracy or data. However, they offer a significant cost savings and can be quickly deployed almost anywhere a community needs reasonably accurate (0.10 feet), real-time flood data to warn citizens and first responders, and to support decision-making.

Through the integration of 118 LCS into the FINS network, CMSWS enhanced the existing flood information network to monitor 96% of the county’s flood risk.

1.0 Introduction

In April 2018, the U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) contracted with Charlotte-Mecklenburg Storm Water Services (CMSWS) to test low-cost flood sensors (LCS). This guidebook presents CMSWS's Option Year 1 (OY 1) experience deploying the 98 beta sensors at locations in Mecklenburg County, plus lessons learned from the deployment of the original 75 alpha sensors. It summarizes the steps taken in Mecklenburg County to install, operate and maintain LCS.

This guide is intended to serve as a reference for communities nationwide attempting to mitigate hazards associated with flooding through the installation and monitoring of real-time water levels in local streams. Using information collected from 18 months of operating LCSs in the local urban setting, CMSWS has developed this guidebook that can be used as a tool for other communities to develop and/or expand their own flood monitoring networks using LCS. This document builds upon lessons learned by CMSWS from its experience with the implementation of LCS and provides guidance/information that is scalable to other communities of different sizes, geographies, and allocated resources.

Therefore, the following sections will provide details pertaining to:

- Project Overview
- Pre-Deployment Activities, Project Overviewincluding functional assessments and preliminary site evaluations
- Testing through field deployment, installation needs/framework, and deployment planning,
- Deployment of 118 flood sensors through physical installation, ongoing evaluation, and modification to achieve optimal performance
- Operation and maintenance of the LCS network
- Cost considerations
- Value Proposition

2.0 Project Overview

DHS S&T Flood Apex Program

The LCS project is part of the DHS S&T Flood Apex Program, which is designed to reduce fatalities from flooding events, reduce property losses from future events, support community flood resiliency, and provide flood predictive analytics tools. It is a specialized program that develops and applies new and emerging technologies to improve community resilience from flood disasters. The project will further the goals of the DHS S&T Flood Apex Program through developing and documenting tools for flood risk management that can be leveraged and transferred to other communities to manage and reduce flood risk.

About Mecklenburg County, North Carolina

Mecklenburg County is the most populated county in North Carolina and one of the fastest growing metropolitan areas in the country. There are over 370 miles of Federal Emergency Management Agency (FEMA) mapped streams and an estimated 2,800 houses and buildings in mapped floodplain areas. CMSWS works to protect lives and property by reducing the potential for loss of life and property due to flooding while enhancing the natural and beneficial functions of the floodplain along FEMA-regulated streams throughout Mecklenburg County.

2.1.1 Flood Information and Notification System

The deployed LCS have enhanced Mecklenburg County's existing Flood Information and Notification System (FINS). To reduce future flood related losses, CMSWS' Flood Mitigation Program enforces floodplain regulations, conducts flood mitigation projects and operates FINS (finslive.mecklenburgcountync.gov) through a partnership between CMSWS and the U.S. Geological Survey (USGS) Cooperative Water Program.

The FINS network consists of 54 stream gages, and 72 rain gages all transmitting data to CMSWS base stations and servers. Figure 2 shows a screen capture of the FINS public website with the USGS stream gages activated. Using predetermined alarm thresholds, FINS software automatically recognizes the threat of flooding, sends flood warning messages to emergency management, CMSWS staff, and the USGS. CMSWS leveraged FINS to test the application of LCS in an urban flash flood environment. Through the integration of 118 LCS into the FINS network, CMSWS enhanced the existing FINS network to monitor 96% of the county's flood risk. CMSWS used this enhanced flood risk monitoring to evaluate communication, automation, and digital display of flood hazard information.

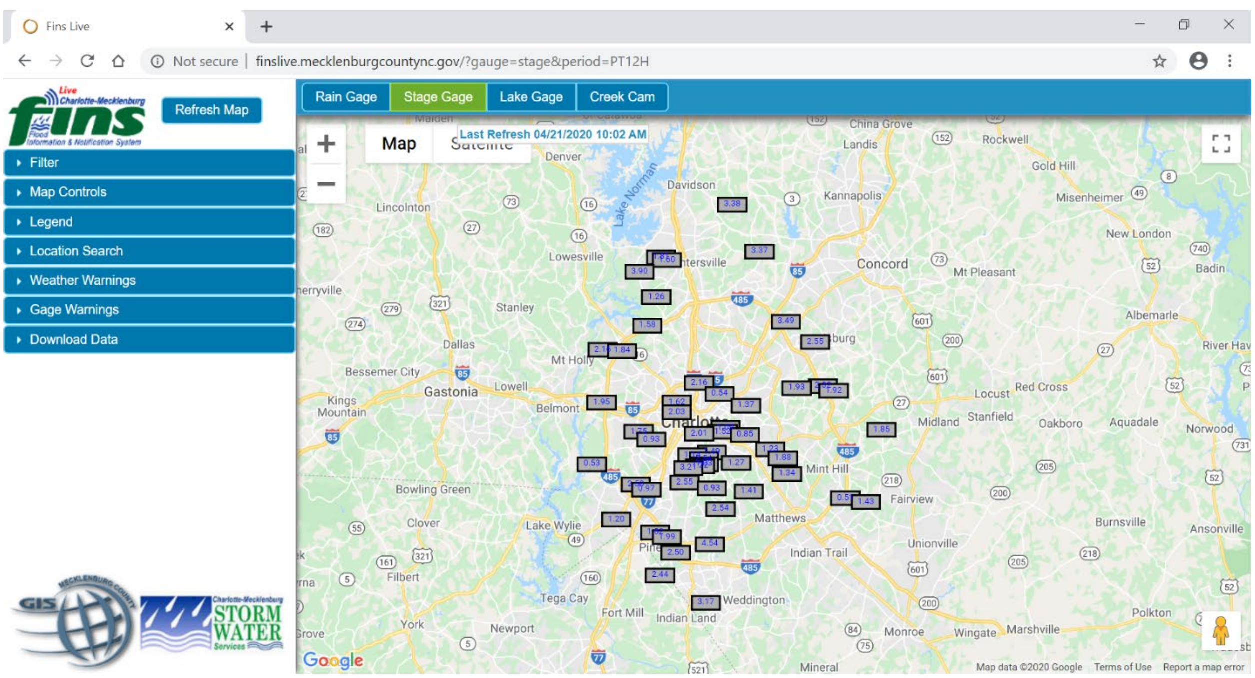

Figure 2: Screen capture of the FINS network showing the USGS stream gages.

During stream baseflow conditions, most gages in the network transmit data in 5-minute intervals using radio telemetry and the Alert2 protocol.[3] Gages in the Northern and Southern areas of the county transmit 5-minute data via GOES Satellites. During storm events, immediate transmitting of data occurs (2-minute interval) as thresholds are exceeded at any gage location. CMSWS uses a third party's hardware and software technology to manage all aspects of stream gage data for the FINS network.

Commercial-Grade vs. Scientific Sensors

Figure 3 shows the location of the USGS gages along with the alpha LCS and beta LCS sites. By co-locating the LCS with the USGS sensors, the project was able to test the "commercial-grade" accuracy and reporting capability of the LCS.

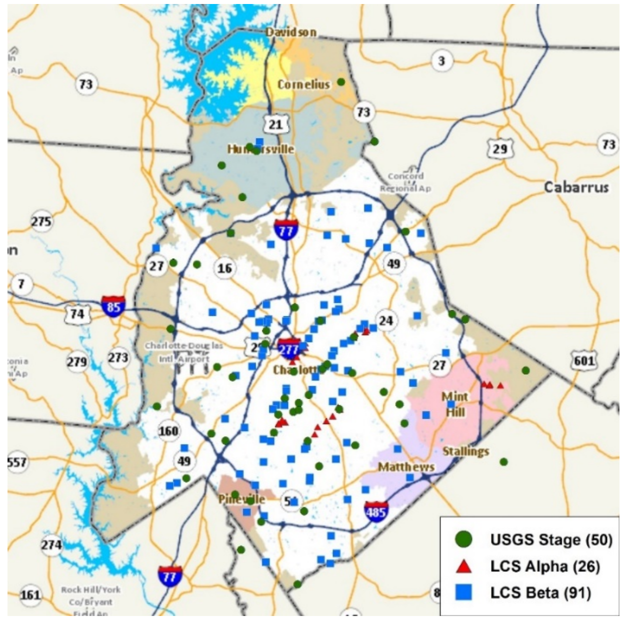

Figure 3: FINS stream gage network showing USGS, LCS-alpha and LCS beta sites.

The development of LCS technology is intended to provide storm water managers with a relatively low-cost tool for the collection of real-time water level information. LCS are similar to USGS stream gages, which also collect water level information, however they collect to a "commercial" level of accuracy (0.1 feet) compared to the USGS' scientific level of accuracy (0.01 feet). The USGS gages also have additional data associated with their capabilities (e.g. flow rate), are routinely calibrated, and whose associated rating curves are continuously updated to reflect changes to the stream channel needed to provide accurate flow data. Importantly, due to the fact that USGS gages require specific in-stream conditions to obtain necessary levels of accuracy and consistency, this prevents USGS gage installation in a number of settings.

The LCS are not intended to replace the scientific accuracy of the USGS gages. The LCS represent a supplement to existing, more costly USGS networks because of their ease of installation, ability to be installed in dry settings, lower cost for purchase and maintenance, and simplicity of operation. These benefits should be considered when flood monitoring locations with accuracies of 0.1 feet are suitable for monitoring purposes. Regarding maintenance, most storm water management programs are not able to support a staff of highly trained field technicians dedicated to maintaining the USGS stream gages. In contrast, LCS can be installed by most existing storm water personnel with a minimum of training.

Project Schedule

The LCS project was implemented over the course of three years with specific goals and deliverables associated with each year:

---

[3] Alert2 (2020). Homepage. https://www.alert2.org/. Accessed May 4, 2020.

- Year 1 (Base Year): Deploy and evaluate 75 alpha (first generation) sensors from three small business vendors (25 sensors from each vendor) and report the performance to DHS S&T.
- Year 2 (Option Year 1): Deploy and evaluate 98 beta (second generation) sensors from a single small business vendor. This vendor was down-selected by DHS S&T from the original three alpha sensor providers based on survey results from DHS S&T's five (5) stakeholder deployments.
- Year 3 (Option Year 2): Fully integrate the beta sensors with the existing FINS network to provide automation of data and displays to include real time risk scoring, losses avoided and inundation mapping. Additionally, Mecklenburg County will provide communication portability research to integrate sensor output with additional systems and technologies.

3.0 Pre-Deployment Activities

DHS S&T contracted with CMSWS to test alpha LCS from 3 vendors. CMSWS's Base Year experience is documented in contract Deliverable 3.A (CMSWS, 2019), which details the preparations for installing and testing 'alpha' LCS in Mecklenburg County.

Preparations for LCS deployment began in July 2018. The following tasks were completed as part of the preparation:

- Vendor Presentations July 2018.
- Property access negotiations, and encroachment agreements signed in August 2018.
- Sample equipment was received to develop installation requirements.
- A maintenance and operation database was developed to track field activities.
- Sites were selected and prepared for the installation, including in-stream mounting equipment and head unit mounting sites.

Functional Assessments of LCS

CMSWS received 25 LCS from three vendors for a total of 75 alpha (first generation) LCS. These 75 LCS were deployed at 25 sites split into 5 'mesh' networks of five sites each. Each site was configured with a single LCS from each of the three vendors. Two of the sites were co-located with a preexisting USGS stream gage for QA/QC purposes.

After an initial 'break-in' period lasting through January 2019, CMSWS began the testing period that extended initially from February 1, 2019 through April 1, 2019. The results of the testing were documented and a performance evaluation for each vendor was prepared (CMSWS, 2019b). DHS S&T selected a single vendor to supply 98 'beta' sensors to CMSWS for further testing during Option Year 1.

Site Selection

Site selection is a critical first step in developing a LCS network. A community may have identified flooding 'hot-spots' that have flooded in the past or knowledge of areas of high flood risk or critical infrastructure that may be compromised during a flood event. Direct knowledge of the local conditions is invaluable; however, without a systematic analysis of the available data, concentrations of flood risk could be overlooked. Additionally, development of a risk-based, site selection protocol will allow a community to prioritize resources, communicate with stakeholders and elected officials and develop a response plan based upon data generated by the LCS network. The "Flood Sensor Limited Field Deployment Plan (CMSWS, 2019a) was prepared during the LCS Base Year. This plan describes the site selection process to identify the location of the beta-LCS deployment sites in OY1. Using this plan,

CMSWS conducted a GIS-based tiered selection methodology that focused upon monitoring the most flood prone areas. The methodology scored sites in the following 7 categories:

- Unmonitored flood risk
- Stream Crossings
- Critical Infrastructure
- Existing Capital Improvement Project (CIP) Sites
- Rapid Deployment
- USGS Validation
- Public Demonstration Site

Based on this methodology the sites for OY1 were identified, as summarized in Table 1.

Table 1: LCS OY1 Selected Sites.

Category	Site Selection
Unmonitored flood risk	The existing FINS network monitored much of the existing flood prone areas of Mecklenburg County. The initial LCS deployment identified 35 additional sites where the current FINS network failed to provide adequate coverage for known flood risk.
Stream Crossings	Placement of 10 LCS at flood-prone road crossings provided additional information on overtopped roads and sites of frequent debris blockages.
Critical Infrastructure	Significant infrastructure assets are located in flood-prone areas. These assets include lift stations, high-hazard dams and previous mitigation sites. A total of 30 LCS were allocated to this category.
Existing Capital Improvement Project (CIP) Sites	Fourteen sensors were allocated to monitor newly constructed CIP sites and future sites.
Rapid Deployment	For deployment in advance of significant events, five sensors were maintained in the lab.
USGS Validation	Three LCS were installed in close proximity with existing “scientific-grade” USGS sites to test the “commercial-grade” accuracy and reporting capability of the LCS.
Public Demonstration Site	One LCS sensor was installed at a flood-prone area with significant public access and used to inform the public and direct them to a website where they could learn more about the project.

Examples of these locations include roads likely to be overtopped by flooding, culverts and bridges where debris blockages lead to flooding, waste water lift stations near streams, high-hazard dams, storm drainage capital improvement projects, flow dynamic monitoring sites, USGS validation sites, and flood mitigation buyout properties.

4.0 Approach to Field Deployment Testing

Installation Needs/Framework

LCS are generally comprised of three components: 1) Head Unit; 2) Cabling; and 3) In-stream sensor. Figure 4 shows a vendor’s complete LCS unit. In preparation for deployment, CMSWS ensured that the

preselected sites had space for both the head unit on the streambank and the in-stream sensor at the monitoring point.

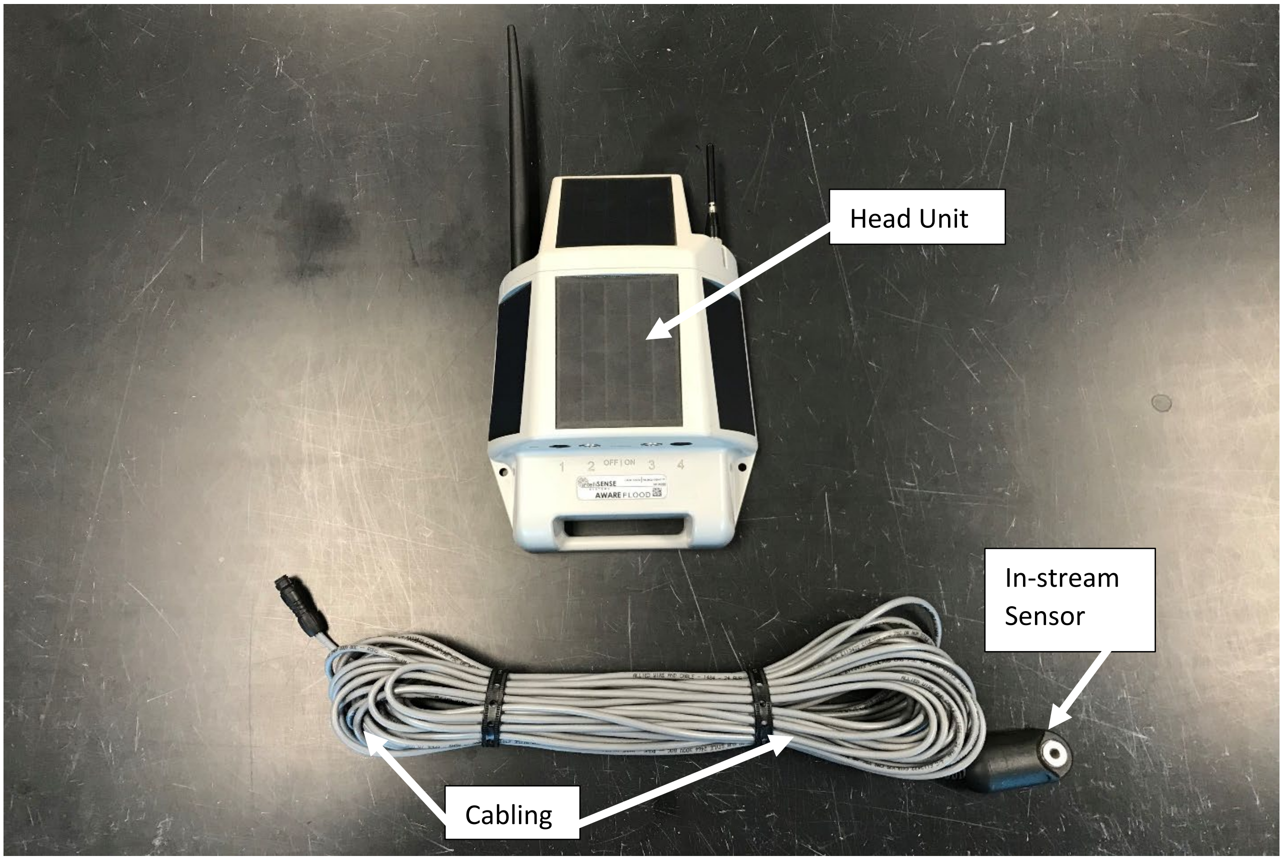

Figure 4: LCS Components that include Head Unit, In-stream Sensor and Cabling.

Deployment Planning

Once a community has determined potential locations for installing LCS(s), the following considerations should be made for each site:

- Encroachments and surrounding utilities
- Cell reception and communications requirements
- Accessibility for installation and maintenance
- Surrounding vegetation and sunlight availability year-round
- Creek depth and sinuosity
- Distance from head unit to in-stream sensor
- Flood elevations at the selected site

The following sections offer in-depth guidance for consideration.

4.1.1 Encroachments

Encroachments on Department of Transportation (DOT) right-of-way (ROW) - such as public footpaths, areas used for oil and gas pipelines - or private property can often be limiting factors for installing LCS. CMSWS developed a ROW encroachment agreement with the City of Charlotte's Department of

Transportation (CDOT) that gave CMSWS permission to install LCS at locations documented in the ROW agreement (see Appendix A: Right-of-Way Agreement). By utilizing the existing ROW that CDOT has on private properties, CMSWS was able to avoid obtaining permission from individual property owners.

CMSWS did install several LCS along privately-owned roads without municipal ROWs. CMSWS staff worked with property owners to obtain permission for the installation to occur. In general, by clearly communicating the intentions and the benefits of the LCS, most property owners were forthcoming with access for the installation of the LCS, particularly if they have the ability to access the data online and receive alerts.

4.1.2 Communication Reception

In Mecklenburg County, LCS with cellular modems were utilized to transmit the collected data to a local FINS server. Some LCS utilize radio frequency to transmit data within a mesh network and then use a single cellular gateway to transmit the information for the entire mesh network to a server. CMSWS tested this concept, but due to the variable topography and dense vegetation in Mecklenburg County, the maximum distance between LCS using radios was ≤0.25 miles, which greatly restricted the size of the mesh network. CMSWS opted to equip the entire network with cellular modems to ensure consistent data transmission and to maximize the flexibility of placement of the LCS. It is important to note that Mecklenburg County has consistent cellular coverage throughout the area.

Cellular communication of LCS sensor data requires each head unit to be equipped with a SIM card. SIM cards are generally provided by the LCS vendor. However, CMSWS decided to procure the SIM cards directly from its preferred cellular carrier because of an existing contract that provided discounted data transmission rates. Other communities may also have pre-existing cellular contracts they wish to leverage to lower costs and simplify billing. However, communities should test different carriers at their proposed sites to see if one carrier provides better overall reception for their network.

CMSWS strongly suggests other communities identify the desired location of the LCS based upon local flood risk and then select a vendor and product that can supply the needed communication protocols for the region. Most vendors offer a combination of radio, cellular, or satellite communication capabilities.

4.1.3 Sensor Capabilities, Alerts and Notifications

LCS are capable of transmitting several parameters in addition to water level. Varying by LCS type, some of the common parameters transmitted are: air temperature, water temperature, barometric pressure, battery voltage, date/time, GPS location, soil moisture (add on option), rain (add on option), etc.

With the LCS installed, CMSWS determined site-specific alarm thresholds using the data parameters discussed in the Communications section. Using detailed GIS data layers, predicted flood elevations and infrastructure data, CMSWS identified all property, people or structures in the general area of each sensor at risk of being impacted by flood waters. Once the flood threats were identified, CMSWS partnered with GIS staff to collect GPS elevation measurements (MSL) for each of the LCS pressure transducers, nearby structures and infrastructure. CMSWS imported this detailed elevation data into FINS allowing CWSWS to create site specific alarms to monitor areas at risk of flooding and monitor sensor performance (e.g. Set alarm to notify if sensor has a low battery voltage). Each alarm included target groups to be notified by email or text message and support the future notification by Wireless

Emergency Alerts. Options for custom alarms and notification messages will depend on the type of LCS (vendor-specific) and third-party software.[4]

4.1.4 Data Transmission and Storage

As discussed in Section 5.2.2, CMSWS utilizes cellular modems for LCS data transmission because of local conditions. The cellular modem on the LCS connects to a server's designated IP address and port, and uploads the most recent data. It is important to note that the LCS tested by CMSWS were only capable of pushing data to a single IP address. If a community requires the data to be available on multiple servers, custom scripts will need to be developed on the LCS destination server to push the incoming data to other locations. For example, FINS was designed with redundant servers to ensure data and alert functionality in the event of power loss or other emergency.

CMSWS has tested and utilized the following three options to store and display LCS data[5]:

1) Vendor Server: Initially, CMSWS used the LCS out-of-the-box functionality to store and manage data on the vendors server. In this case, all of the data was uploaded and stored on a vendor server and a vendor hosted website was then used to view and download the data. This option provided robust, basic functionality; however customization and ability to interact with the data was very limited.
2) Software Server: Because of CMSWS's need to integrate the LCS with the existing FINS network, the LCS vendor worked with its data hosting software company to integrate the two systems. The LCS vendor deployed their proprietary data translation protocols into the pre-existing FINS software to decipher incoming LCS data. Once deployed, these protocols allowed the LCS data to be injested into FINS. The LCS were still transmitting the raw data to a single IP address, which was the vendor's server. A continuously running script on the vendor's server pushed a copy of the newly arrived LCS data to the FINS server. This option provided the maximum redundancy and flexibility, however the LCS data still passed through the vendor's server. This increases the risk of failure if the vendor's server is compromised or is disabled. Additionally, vendor data hosting is provided at an additional fee, which will increase the cost of operating the LCS.
3) Customer Server: Lastly, CMSWS worked with the vendors to transmit the data from the LCS directly to the FINS servers. This option eliminated the need for vendor data hosting. FINS was constructed with a high degree of redundancy, which eliminated the need for outside hosting.

Each community should evaluate their specific needs for data storage, accessibility, and viewing. If a community has pre-existing software similar to FINS, the LCS may have the ability to transmit directly to an existing system. If integration into pre-existing software is not an option, it is critical that a community weigh a vendor's costs and ability to provide data hosting and visualization, alerts and notifications, system redundancy and security.

[4] Please reference Flood Sensor Limited Field Deployment Plan 3.b Section 5 for more detail.
[5] Please refer to CMSWS, 2019b Section 2.9 for more details.

4.1.5 Accessibility for Installation and Maintenance

Steep banks and other terrain considerations should be made when choosing LCS site locations. Due to the nature of flood prone creeks, large debris, rocks, and other materials can damage lower sensors. Accessibility for maintenance and the safety of employees should be a primary consideration.

4.1.6 Sunlight Availability

LCS are generally configured to reliably function using vendor-supplied solar panels. In Mecklenburg County, there is a dense tree canopy and therefore ensuring adequate sunlight availability for the LCS to function is an important consideration. CMSWS staff ensured LCS were installed in locations where ample sunlight would be available year-round by orienting the solar panels to the South (see Figure 5). Local factors should be considered to maximize solar exposure during periods of extended cloud cover, shorter days (winter) or other local conditions.

Figure 5: Solar panels oriented in a southern direction from three vendors.

4.1.7 Vegetation

Sites should be assessed for any vegetation concerns to ensure successful installation and prolonged operation. Vegetation should be removed from the surrounding area where the head unit is proposed to be installed and a path created to where the in-stream sensor will be located. CMSWS staff conducted preliminary site preparation for vegetation through the application of herbicides and the physical removal of vegetation, where applicable. Vegetation management/removal was conducted as a means

to provide adequate sunlight availability, pathways for the cable/conduit, and a safe working environment for staff by removing trip hazards and/or health risks such as poison ivy.

4.1.8 In-stream / Wet Sensor Placement

Where site conditions required the placement of the LCS sensor under the water surface and continuously submerged (such as a stream or impoundment), two factors were considered most important: 1) the water level could be accurately measured, while minimizing debris accumulation; and 2) the t-post, survey pin or other mounting device could be safely and securely installed into the stream bed or bank.

In order to minimize debris accumulation, CMSWS staff planned for in-stream equipment installations in areas with the following considerations:

- Avoid installations in highly sinuous channels where undercut banks and point bar development are prominent, as these characteristics can lead to debris accumulation and unstable conditions for the in-stream sensor and subsequent sensor maintenance.
- Avoid installations where stream blockages are common due to decrease in flow velocity causing debris to be deposited or directly at the head of culverts where flow is constricted.
- Avoid installations that require the cabling to be suspended across the channel. The best installations have minimized the length of cabling in the creek. This reduces the likelihood of debris accumulation and/or damage that a longer amount of conduit and cabling could accumulate and potentially be damaged.

CMSWS staff also considered stream bed material during the site selection process. The stream substrate in Mecklenburg County varies in gradation between bedrock to sand/silt but is predominantly cobble/sand. The prominent cobble/sand substrate provided CMSWS staff with a suitable substrate to install the in-stream sensor. However, at sites where bedrock was prominent, the in-stream sensor mounting device was not able to be driven into the creek bed and alternative installation sites had to be located. At sites where unconsolidated (loose) sand was prominent, the in-stream sensor mounting device was not stable in the substrate and would easily wash away during a flood event. Depending on the dominant substrate in a given region, alternative in-stream sensor mounting techniques may need to be developed.

4.1.9 Dry Sensor Placement

Settings requiring placement of the LCS sensor above the water surface or in the flood plain adjacent to the stream are much less restrictive than placement in wet settings. In general, the sensor and head unit can be mounted to existing light or power distribution poles, on 4 x 4 posts set in concrete or on other pre-existing infrastructure. If mounting to existing poles, ensure permission is granted by the owner of the pole. Most utilities have a process for granting permission to mount equipment to their poles. Consideration should be made to protect the in-stream portion of the LCS from maintenance activities, such as weed trimming with line trimmers or mowing. Additional consideration should be given to the potential for vandalism at a given location.

4.1.10 Vandalism

Vandalism is possible with any field equipment. In order to minimize the likelihood of vandalism, many LCS have tamperproof hardware and locking mechanisms or cabling to deter removal or opening of the head unit. Also, if a head unit has a visible camera, then clearly pointing camera away from areas where

there's a perception of "public monitoring" should be practiced. These areas might include public trails, walkways, roadways, residences, public housing developments. CMSWS also attached signage to the head unit mounting devices clearly identifying the purpose of the equipment as flood monitoring.

1.1.1 Surrounding Utilities

Depending on how the head unit is to be mounted, utilities in the surrounding area should be located using an underground utility location service. CMSWS conducted preliminary site visits to determine a potential location for the head unit and in-stream sensor. During the visit, CMSWS marked the best location for an 8' galvanized fence post (when applicable) for the mounting of the head unit. An underground utility location service was then brought in to locate all underground utilities so the installers could avoid any possible damage.

1.1.2 Distance from Head Unit to In-stream Unit

At each site, measurements should be taken for the length of cable and conduit between the head unit and the in-stream sensor so that ample materials can be procured prior to beginning installations (see Figure 6). In Mecklenburg County, the maximum length of installation between the head unit and in-stream sensor was approximately 100 feet. During site selection, CMSWS staff attempted to keep this distance to a minimum to reduce the amount of exposed cabling, thus reducing the potential of damage during a storm event. CMSWS recommends consulting with LCS vendors to determine potential limitations of cables.

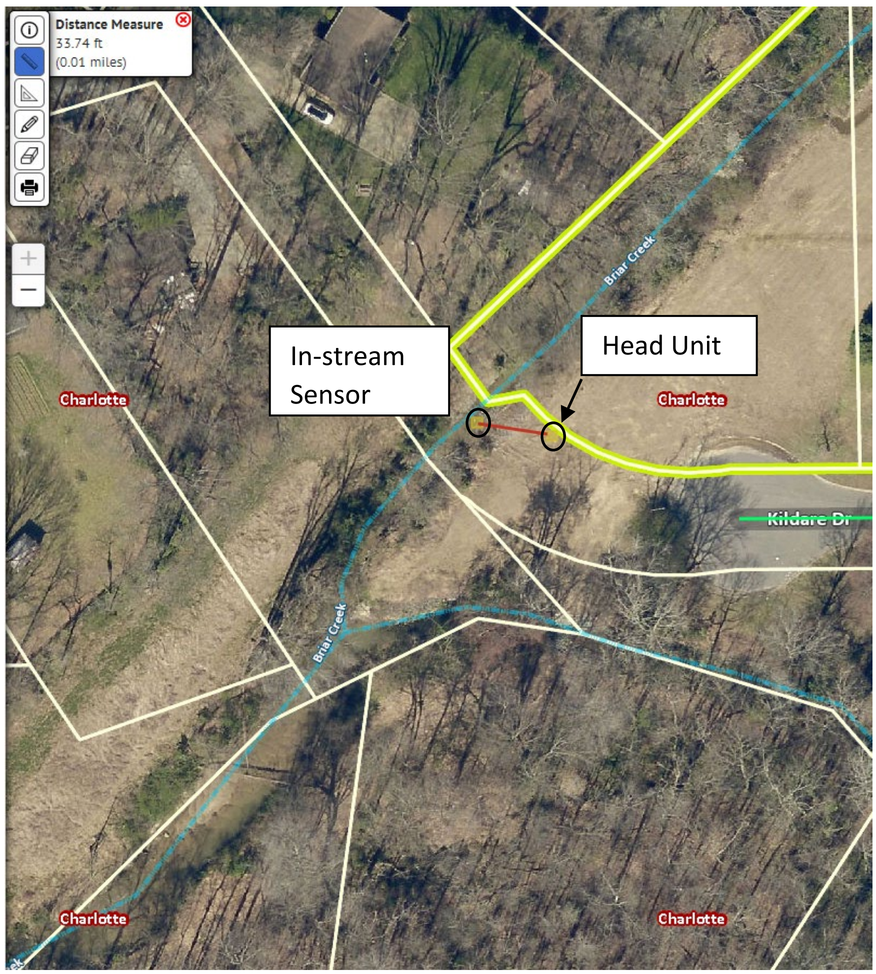

Figure 1: Distance estimation from head unit to in-stream unit using aerial photography to determine quantity of conduit needed.

1.1.3 Anticipated Flood Depth

Prior to installation, flood maps were consulted to determine likely flood depths at the installation site. Specifically, it is critical that the LCS head unit be installed above expected flood elevations. CMSWS chose to install all head units above the expected 1% annual chance (100 Year) flood elevation at the site. It is important to mount the head unit above anticapated flood elevations to prevent the

immersion of electronics (head unit, camera, solar panels), damage by floating debris, and data transmission failures while immersed.

5.0 Deployment and Evaluation of LCS

To evaluate the performance of the LCS beta sensors and provide other communities with firsthand experience and guidance, CMSWS installed the 118 LCS in a wide variety of settings throughout Mecklenburg County.

Installation of the LCS began in July 2018 and was completed in November 2018. Generally, installation of a single vendor's 25 LCS required approximately five field days to complete. Overall, radio communication proved problematic for Mecklenburg County terrain whereas 4G cellular communication was significantly more reliable. Upon installation, most of LCS alpha units failed to transmit data due to hardware or firmware defects. These alpha defects were subsequently addressed by the vendors through replacement of hardware and/or firmware updates. These challenges resulted in vendor re-visits to perform firmware updates and, in some cases, remove problematic equipment from the field.

Materials List

Figure 7 shows the set of tools and supplies used to install LCS in Mecklenburg County, listed here:

A. Post Driver (if installing post in ground)
B. Metal Banding and Clip (B & C, if securing post to preexisting structure)
C. Metal Banding Tool
D. Stake Driver
E. Round Steel Stake ¾" x 24"
F. 5-lb Hammer
G. ¾" Non-Metallic Flexible PVC Conduit
H. Head Unit of LCS – for harvesting and providing power, as well as processing and communicating sensor data *(these units can be found from various vendors)*
I. Water Level Pressure Sensor (pressure sensors are produced by various vendors)
J. Camera (if applicable)
K. Antennas for H
L. Head Unit Mounting Bracket (vendor specific)
M. Impact Driver
N. 2 ½" Conduit Cutter
O. Zip-Ties
P. Aluminum Angle Bracket (1" x 2" x 4")
Q. 1 ½" Hose Clamp
R. 5/16" Stainless-steel U-bolt
S. 9 Gauge Steel 9" x 1" x 9" Square Top Professional Grade Landscape Staples

Figure 7: LCS Hardware Components and Installation Tools

T. 5/16" SS Lock Nuts
U. ¼" x ¾" SS Hex Head Bolt
V. T10 Torx Mounting Screws
W. 1" Galvanized Self-Drilling Screws
X. Fence Post Cap
Y. Sign with Ownership and Contact Information
Z. Diagonal Snips
AA. T10 Torx Screw Driver
BB. Socket and Ratchet
CC. 5' or 8' Fence Post (Depending on Desired Size)

Physical Installation

Always refer to vendor-specific installation instructions for the LCS being deployed in the community. This guidebook is meant as a reference tool and steps may be altered depending on vendor-specific instructions.

The LCS provided by vendors working with CMSWS each required an in-stream sensor connected to a head unit via a data communication cable. This necessitated a 3-component design for the deployment of the LCS (see Figure 8):

1. Step 1: Attachment and positioning of the head unit
2. Step 2: Routing and protection of the cable
3. Step 3: Attachment and positioning of the in-stream sensor

Figure 8 : Three component design for the deployment of the LCS.

5.1.1 Attachment and Positioning of the Head Unit

The head unit is the device responsible for harvesting and providing power, as well as processing and communicating sensor data. LCS require a power source to process and communicate sensor data. To increase solar exposure and protect head units from being submerged during flooding and other sources of damage, CMSWS mounted the head units in various locations (See Figure 9). The head units should be mounted at a height above the 100-year flood elevation at the site. Depending on the

location of the installation, different procedures for installation were used, including galvanizing fence posts and methods to secure LCS to existing infrastructure.

Figure 9: Various upper node installation locations. From left to right, 8' galvanized fence post,

Galvanized Fence Post (see Figure 10)

- Prior to installing any fence posts, the area is marked for local utilities.
- If the area is free of utilities, a fence post can be driven into the ground using a post driver. Approximately 25% of the fence post's total length is driven into the ground (Figure 10).
- Once the fence post is secured in the ground, a vendor-provided mounting bracket is attached to the post with zip-ties or other specified hardware.
- The head unit is secured to the mounting bracket using vendor-provided mounting screws.

Figure 10 : Steps for installing galvanized fence post into ground and head unit onto post.

Securing to Pre-Existing Structures (see Figure 11)

At certain locations a fence post could not be driven into the ground. At these locations, pre-existing structures such as handrails, bridges, and light/telephone poles were used to attach the head unit. At these locations, a galvanized fence post can be attached to the pre-existing structure or the unit would be directly secured to the structure. The head unit was then secured to the mounting bracket.

Figure 11: Alternative installation techniques. From left to right, metal bonds, mounting brackets, zip-ties and metal bands.

5.1.2 Routing and Protection of the Cabling

The cabling is responsible for transmitting data from the in-stream sensor to the head unit. In Mecklenburg County, the distance from in-stream sensor to head unit ranged from 15 feet to 100+ feet, depending on the site. The following steps were taken to route and protect the cabling:

1. Determine distance from head unit to in-stream sensor: If the distance exceeded the standard cabling length of 10 meters, an extension cable (provided by the vendor) was attached and secured using electrical tape.
2. Cut conduit to length: CMSWS determined that the best means to protect the cabling was to run it through a length of ¾" non-metallic, flexible PVC conduit. Once the proper length of conduit was determined it was measured and cut using conduit cutters.

3. Feed cabling through conduit: A steel fish tape was fed through the conduit. Once fed through, the serial cable connector for the head unit was attached to the fish tape with electrical tape and pulled back through the conduit (see Figure 12).
4. Secure conduit: Using rip-rap, 9-gauge steel 9” x 1” x 9” square-top, professional grade landscape staples and other materials, conduit should be secured in the creek and on the creek bank to reduce the potential of debris and water from disturbing and/or damaging the sensor and/or cabling (see Figure 13).

Figure 12: Components and steps for routing and protecting data communication cable with conduit.

Figure 13: How to secure conduit in the stream and on streamband.

5.1.3 Attachment and Positioning of In-stream Sensor

To reduce the likelihood of debris accumulation around the in-stream sensor, CMSWS designed a mounting bracket for attachment of the in-stream sensors. An aluminum angle bracket (1” x 2” x 4”) was designed to be attached to a round steel stake with a stainless-steel U-bolt, and nylon lock-nuts (see Figure 14), with mounting holes for the in-stream sensor. One hole would be for the sensor, while the other was used to secure the conduit with a 1 ½” hose clamp and zip-ties.

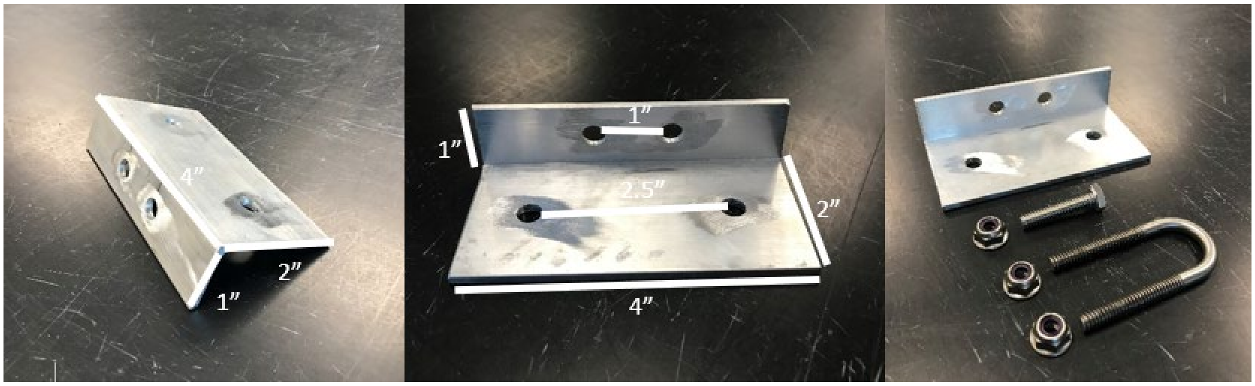

Figure 14: Aluminum angle bracket dimensions and associated mounting hardware for in-stream sensors.

The following steps were taken to install the in stream sensor:

1. Drive stake into creek bed.
   A ¾” x 24” round steel stake was driven into the creek bed using a 5 lb. hammer and a “stake driver”.
   The “stake driver” was fabricated from a piece of 1.25” square tubing welded onto a ¾” X 24” round steel stake. There is approximately 4” of the stake inserted into the tubing before it was welded (Figure 15).
   This tool allowed a stake to be driven into the creek below the surface level of the water and provided better ergonomic positioning for the installer.

Figure 15 : 3/4" x 24" round steel stake and "stake driver".

2. Attach in-stream sensor to mounting bracket (Figure 16).
   Using the ¼” nylon-lock-nut and ¼” X 1” hex head bolt, attach the in-stream sensor to mounting bracket. Secure the hose clamp to the conduit and secure hose clamp and conduit to mounting bracket with zip-ties.

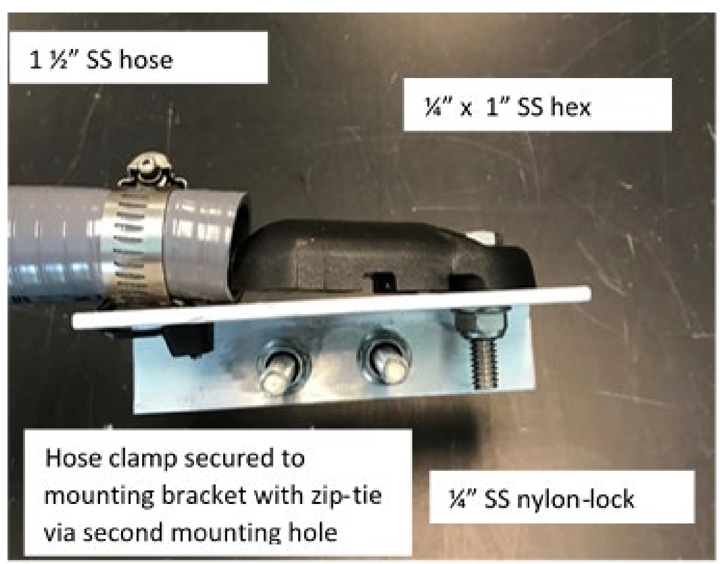

Figure 16 : In-stream sensor and conduit attached to mounting bracket.

3. Attach mounting bracket to ¾” x 24” round steel stake. Using a 5/16” stainless-steel U-bolt and 5/16” SS nylon-lock-nut, attach mounting bracket securely to the round steel stake (Figure 17).

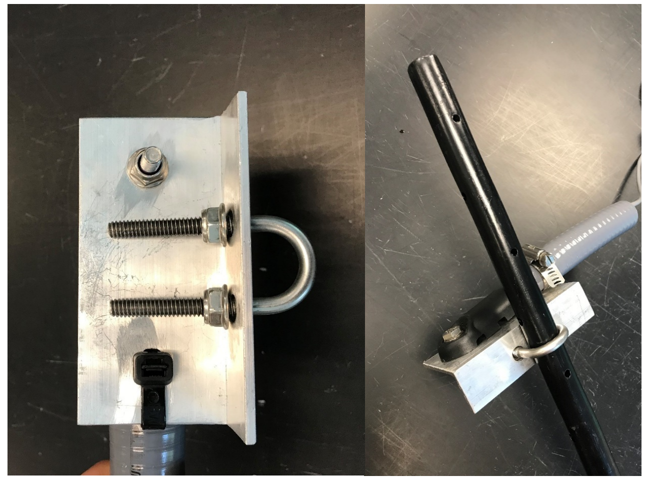

Figure 17 : 5/6" stainless-steel U-bolt and 5/16: nylon-lock nuts for attaching mounting bracket to 24" round steel stake.

5.1.4 Final Installation Steps

After the three main components of the LCS are installed (head unit, cable and in-stream sensor), the final installation steps can be completed. Always refer to the vendor-specific installation guidelines for instructions for each component of the installation. For example, one vendor may require the unit to be powered on prior to the in-stream sensor being submerged in the creek as part of its calibration process. In the final installation steps, ensure all vendor installation instructions have been properly followed, secure all conduits running from the in-stream sensor to the head unit with rip-rap, zip-ties and/or landscape stakes, and secure excess cables. If applicable, attach a sign indicating ownership of the equipment, a contact number and the reason for the equipment’s deployment (see Figure 18).

Figure 18 : Final installation of head unit and identification sign.

6.0 Operation and Maintenance

Always refer to vendor-specific operation and maintenance instructions for the LCS being deployed in the community. This section is meant as a reference tool and steps may be altered depending on vendor specific instructions.

In developing an Operation and Maintenance (O&M) plan for the LCS deployed in Mecklenburg County, CMSWS developed several guidelines for the four CMSWS staff tasked with conducting routine maintenance. The basis of the O&M plan enacted by CMSWS consisted of office-based activities and field-based activities. Refer to Appendix C: Operation and Maintenance (O&M) Plan for a complete checklist used by CMSWS personnel during both office-based O&M and field-based O&M.

Office-Based O&M

While it is important to note that this office-based work was conducted by CMSWS as part of the requirements of the DHS S&T grant contract, this effort will be extended after the grant is completed. Some of these tasks could be supplemented or replaced by establishing warnings based on battery voltage or other parameters, setting up alerts in the software.

Each day, CMSWS staff logged onto a data collection and visualization platform used by CMSWS to review data from the LCS network (see Figure 19). CMSWS personnel reviewed their assigned sites (approximately 29 sites per staff member), checking both battery voltage and stage readings. Personnel noted any irregularities, such as a low battery voltage, lapses in data transmission and/or stage readings not representative of the site's expected conditions. This in-office data analysis was used by staff to prioritize field site visits, document potential problems, and prepare for field work that might include the replacement of batteries or in-stream sensors.

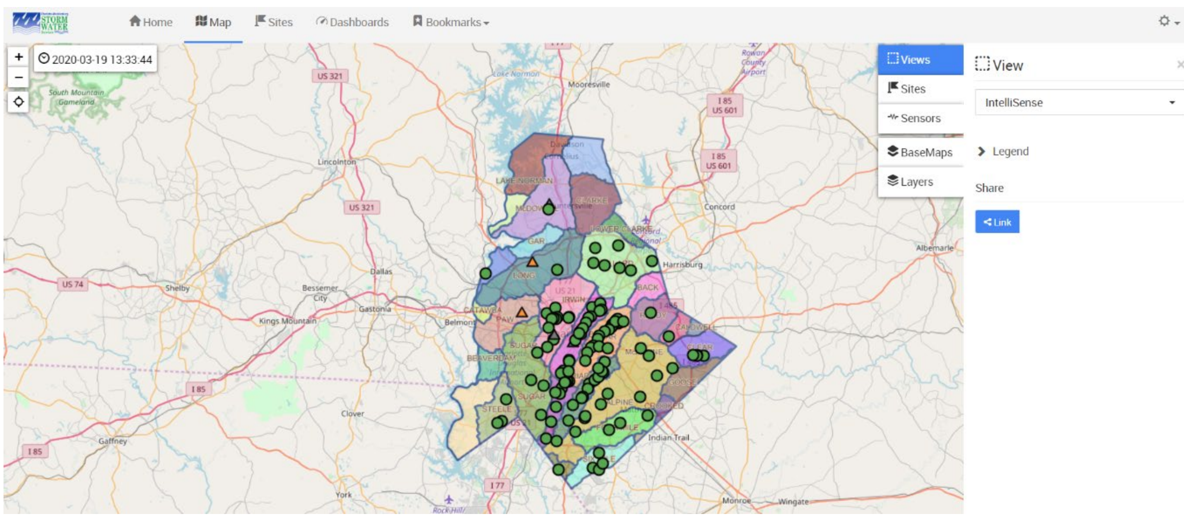

Figure 19 : Screenshot of data collection and visualization platform, showing 118 LCS in Mecklenburg County.

In addition to the use of the FINS software and website, CMSWS personnel used an in-house data management program developed by CMSWS called the Environmental Data Management System (EDMS) to report and document office-based and field-based findings from O&M activities (see Figure 20). EDMS provided a platform for CMSWS to document installation dates, problems identified with the LCS, validation measurements, corrective action taken to resolve issues and any other activities surrounding the LCS. All activities surrounding the LCS project were documented in EDMS for internal and external data sharing purposes.


Environmental Data Management System

Welcome storomg ! [Log Out]

Flood Sensors | Cityworks | Program Measures | Volunteers Programs | SRRS | My Tools

New	Insp #	Site	Sensor	Notes	Depth	Insp Date Time	Inspector
Edit Delete	1542	FMB41 (Little Sugar Creek @ W side of Brevard St)	IntelliSense - IoT41	Cleared debris; re-drove pin w/ lower sensor into ground	1.10	03/16/20 03:00 PM	Barnes Iva
Edit Delete	1544	FMB43 (Little Sugar Creek @ Alexander St Park walk bridge)	IntelliSense - IoT43	Cleared debris	0.35	03/16/20 01:35 PM	Barnes Iva
Edit Delete	1546	FM23 (Little Sugar Creek @ Seigle Ave)	POC-N41	Cleared debris	0.25	03/16/20 01:30 PM	Barnes Iva
Edit Delete	1545	FM22 (Little Sugar Creek @ Belmont Ave)	POC-N2	Cleared debris; replaced missing antennae	0.47	03/16/20 01:25 PM	Barnes Iva
Edit Delete	1543	FMB42 (Little Sugar Creek @ S side of E 18th St)	IntelliSense - IoT42	Cleared debris	0.42	03/16/20 01:15 PM	Barnes Iva
Edit Delete	1540	FMB37 (Little Sugar Creek @ Between Wellingford St and Used Tires Express)	IntelliSense - IoT37	Cleared debris	0.47	03/16/20 01:00 PM	Barnes Iva
Edit Delete	1539	FMB36 (Little Sugar Creek @ End of Mellow Dr on sanitary sewer ROW)	IntelliSense - IoT108	Cleared debris	0.27	03/16/20 12:55 PM	Barnes Iva
Edit Delete	1541	FMB38 (Derita Branch @ N side W Craighead Rd)	IntelliSense - IoT38	Cleared debris	0.24	03/16/20 12:45 PM	Barnes Iva
Edit Delete	1538	FMB35 (Little Sugar Creek @ NE side of Hidden Valley Rd)	IntelliSense - IoT35	Cleared debris	0.44	03/16/20 12:30 PM	Barnes Iva
Edit Delete	1537	FMB40 (Little Sugar Creek @ End of Cullman Ave at train tracks)	IntelliSense - IoT40	Cleared debris, no blockage observed	0.69	03/12/20 04:00 PM	Barnes Iva
Edit Delete	1523	FM8E (Briar Creek @ Purser Dr)	Evegia - SensiFlood2	Sensor reinstalled after repairs conducted by Evegia.	14.00	03/12/20 12:50 PM	Storosh Matthew
Edit Delete	1529	FMB12 (Stewart Creek @ S side of Southwest Blvd)	IntelliSense - IoT12	Cleared debris, unburied	0.07	03/12/20 12:20 PM	Barnes Iva
Edit Delete	1530	FMB15 (Irwin Creek @ W side of floodplain on Andrill Terrace)	IntelliSense - IoT104	All good	0.00	03/12/20 12:15 PM	Barnes Iva
Edit Delete	1524	FM9E (Briar Creek @ USGS Bridge)	Evegia - SensiFlood1	Sensor reinstalled after repairs conducted by Evegia. Issues observed with reporting stage. Consulting with Evegia personnel.	3.90	03/12/20 12:00 PM	Storosh Matthew
Edit Delete	1521	FM6E (Briar Creek @ Shannonhouse Dr)	Evegia - SensiFlood4	Unit 4116 installed at site, was 4118 prior to 3/12/20. Sensor reinstalled after repairs conducted by Evegia.	3.50	03/12/20 11:35 AM	Storosh Matthew
Edit Delete	1522	FM7E (Briar Creek @ Galway Dr)	Evegia - SensiFlood3	Unit 4118 installed at site, was 4116 prior to 3/12/20. Sensor reinstalled after repairs conducted by Evegia.	3.00	03/12/20 11:15 AM	Storosh Matthew
Edit Delete	1520	FM5E (Briar Creek @ Perth Ct)	Evegia - SensiFlood5	Sensor reinstalled after repairs conducted by Evegia.	3.00	03/12/20 10:45 AM	Storosh Matthew
Edit Delete	1527	FMB9 (McIntyre Creek @ W side of Beatties Ford Rd)	IntelliSense - IoT9	Cleared debris	0.30	03/12/20 10:25 AM	Barnes Iva
Edit Delete	1528	FMB11 (Stewart Creek @ E side of Barlowe Rd)	IntelliSense - IoT11	Cleared debris	0.24	03/12/20 10:00 AM	Barnes Iva
Edit Delete	1532	FMB17 (Stewart Creek @ Norwood Dr and Coronet Way)	IntelliSense - IoT106	Cleared debris, no blockage observed	0.48	03/12/20 09:50 AM	Barnes Iva
Edit Delete	1533	FMB18 (Stewart Creek @ W side of Parkway Ave)	IntelliSense - IoT107	Cleared debris	0.37	03/12/20 09:45 AM	Barnes Iva
			Count=1,530				

Page 1 of 39 (1530 items) [1] 2 3 4 5 6 7 ... 37 38 39

Figure 20 : Screen shot of O&M Activity Documentation in EDMS

Field-Based O&M

As noted above, each staff member was assigned approximately 29 sites to maintain and inspect. Sites were assigned using geographical proximity to increase the efficiency of potential site visits that could be conducted in a single day (see Figure 21). To comply with grant requirements and internal standards set for the project, CMSWS personnel conducted monthly site visits or after a 1-inch or more rainfall event.

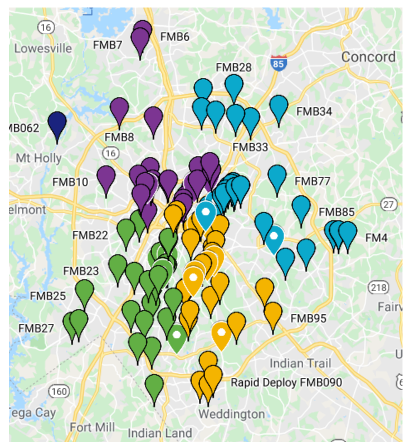

Figure 21: LCS sites geographically color coded for CMSWS staff.

During site visits, personnel took validation measurements (to compare reported stage levels vs. actual stage levels), inspected all components of the LCS, conducted any vegetation maintenance as needed, and made any necessary repairs to the site. If repairs could not be conducted at the time of visit, notes were taken and reported in EDMS to ensure corrective action was taken as soon as possible. All actions taken during a site visit were documented by CMSWS personnel and later input into EDMS[6].

7.0 Cost Considerations

Hardware Expenses

Beyond the LCS purchase price, there are other cost considerations for installation. Typically, CMSWS spent approximately $75 per site for additional hardware, installation materials, and signage. This number varies by site and is dependent upon the length of conduit, head unit mounting technique

[6] See Reference List (CMSWS 2020) for full documentation of LCS maintenance, failure rates, reliability and durability.

(fence post, existing post, railing, etc.), and if a sign was installed for education or anti-vandalism purposes. See Table 2 for summary of expenses. The additional costs detailed here do not include the purchase of tools needed for the installation of this hardware. The assumption is the installer would have the necessary tools required.

Table 2: Additional Hardware Expenses Incurred by CMSWS for the Installation of LCS.

Hardware Expenses	**Expense**
1-⅝" Galvanized Fence Post	$12.00 (ea)
¾" x 24" Steel Stake	$3.78 (ea)
¾" Flexible Conduit	$0.65 / ft
Angle Brackets (1"x2"x4")	$8.00 (ea)
Signage	$10.75 (ea)
Fence Post Pipe Clamp	$4.75 (ea)
Landscape Staples	$0.22 (ea)
Band-It SS ¾" Banding	$1.43 / ft
Band-It SS ¾" Buckles	$0.44 (ea)
Misc. Mounting Hardware	$5.00 / site

Labor Expenses

Staff time and expense to install and maintain the sensors is presented in Table 3. After installation of all LCS, CMSWS determined that a site installation required approximately 2.5 labor hours per site. This labor expense includes all the detailed installation steps outlined previously in this document. In addition to the labor of the installation, planning should be made for monthly checks and validation measurements of the equipment, approximately 0.5 hours per site, per month. CMSWS currently conducts routine monthly site visits and after a 1-inch or greater rainfall event. During these site visits, all components are checked for secureness, any vegetation is maintained, and a stage validation measurement is collected.

Table 3: CMSWS Labor Expenses for the Installation and Maintenance of LCS.

Labor Expenses	**Labor Hours**
Sensor Installation	$\bar{x} = 2.5$
Monthly Checks & Validations	$\bar{x} = 0.5$
Repairs	Dependent upon repair type

8.0 Value Statement

Value of LCS to a Storm Water Management Program

Comprehensive storm water management programs often include diverse responsibilities, including surface water quality, permitting and inspection of land development and building activities, maintenance and improvement of drainage systems, flood mitigation, environmental restoration, support of emergency responders, and floodplain mapping. The capabilities presented by LCS can be leveraged by programs to collect real-time water level data in a variety of settings. Data from LCS can be used on activities ranging from determining permit compliance to alerting first responders to the possibility of road or structure flooding. The LCS are intended to be used where flood monitoring

networks do not exist or as a supplementary resource to existing community flood monitoring or USGS networks.

The LCS technology was deployed by CMSWS in a number of settings or use-cases intended to test the equipment in real-world situations typically encountered by an urban storm water program. The site selection and deployment of the LCS was documented in CMSWS (2019a). The list is in no way comprehensive. The LCS could be deployed in most situations where real-time water level information of surface water is needed. Table 4 presents the list of use-cases tested by CMSWS along with a brief description.

Table 4: Use-cases for LCS testing

Use-Case	Description
Unmonitored Flood Risk	LCS were installed to monitor flooding on structures not currently covered by the existing USGS network. Sensors needed to accurately measure water level and drive alerts. Installations were typically in-stream (wet) and could be located away from existing crossings. Installation sites were often shaded and could be installed on poles, railings or treated posts. Long battery life and solar efficiency were important along with the ability to locate the sensor at a specific location.
Stream Crossings	LCS were installed to monitor road crossings at risk of overtopping during flood events. Road crossings are typically subjected to significant debris accumulation, which required the LCS to be very durable and able to be removed and reinstalled for maintenance activities. Installations were typically performed on existing infrastructure, such as handrails. Head units were usually installed in full sun, which reduced the need for long term battery capability and solar efficiency.
Critical Infrastructure	LCS were installed to monitor flood risk to critical infrastructure, such as sanitary sewer lift stations. Installations were typically performed on posts specifically installed for the head unit. Installations could be wet or dry but were generally wet and there was some degree of flexibility in site selection, which limited the importance of solar efficiency and battery life. There was a secondary need for camera capabilities with reasonable resolution.
Water Quality Restoration Sites	LCS were installed at water quality stream restoration sites to determine water levels during the construction and warranty period. Installations were variable but generally wet. Sensors were subjected to significant debris and sediment accumulation, which accentuated the need for durability and the ability for the in-stream sensor to continue to operate when buried. There was flexibility in the specific installation location, which minimized the importance of battery life and solar efficiency.
Flood Mitigation Sites	LCS were installed at flood mitigation sites to collect data used to calculate financial losses avoided. Installations at these sites were typically dry and located on posts installed specifically for the LCS. It was important that the sensor be able to sit idle for extended periods of time but accurately measure water level when inundated. Head units were typically installed in full sun, which reduced the need for battery life and solar efficiency.

Use-Case	Description
Rapid Deployment	LCS were installed at various locations to test the ability of the sensors to be rapidly deployed ahead of expected flood events. The sensors needed to be easy to install in a variety of settings. The ability to install the LCS by a single staff member was also important. Rapid deployment units were stored in the shop until needed, which required the capability for the units to be maintained when not in the field.
Operational hotspots	LCS were installed to assist operations group with the detection of blockages or other maintenance needs at pre-existing hot spots, which are usually located at road crossings. Road crossings are typically subjected to significant debris accumulation, which required the LCS to be very durable and able to be removed and reinstalled for maintenance activities. Installations were typically performed on existing infrastructure, such as handrails. Head units were usually installed in full sun, which reduced the need for long term battery capability and solar efficiency. There was a secondary need for the LCS to have a camera so that maintenance personnel could visually inspect the accumulation of debris remotely, thus eliminating the need for a site visit.

Each of the use-cases presented in Table 4 were tested throughout OY1 of the contract. Table 5 presents the results of the testing and effectiveness of the LCSs at meeting the needs of the use-case.

Table 5: LCS Effectiveness for Use-Cases

Use Case	Needed sensor capabilities	Effectiveness of LCS for Use-case
Unmonitored Flood Risk	• High degree of reliability • Efficient solar recharging • Accuracy to 0.5 feet • Battery life >72 hours	Highly effective • Units functioned as needed
Stream Crossings	• Durability • Accuracy to 0.1 feet • Increased transmission frequency during rising water levels • Variable installation capabilities	Effective • In-stream equipment occasionally damaged from debris • Units needed to be removed for blockage removal
Critical Infrastructure	• High degree of reliability • Wet or dry install • Accuracy to 0.1 feet	Highly effective • Units functioned as needed
Water Quality Restoration Sites	• Durability • Camera • Wet or dry install • Accuracy to 0.1 feet	Effective • Camera resolution not sufficient to monitor construction activity
Flood Mitigation Sites	• Long term dry installations • Post installation • Accuracy >0.1 feet	Highly Effective • Units functioned as needed Note: CMSWS continues testing of long-

	• Long-term reliability	term dry installation
Rapid Deployment	• Ease of installation • Variable installation • Ease of stand-by maintenance • Ease of integration with existing network	Highly effective • Units are quickly installed in a variety of settings • Units equipped to be maintained in warm storage • Quickly integrated with existing network
Operational hotspots	• Camera • Durability • Variable installation • Ease of removal/reinstallation	Effective • Camera resolution not sufficient to replace field inspection • Units needed to be removed for blockage removal
Illicit discharge detection (not included in CMWSW, 2019a)	• Accuracy 0.1 feet • Measurement frequency minimum of 15 minutes • Ease of installation • Camera	Effective • Units provided data for rises in water levels not associated with storm events that could be related to illicit discharges such as sanitary sewer overflows • Camera resolution not sufficient to replace field inspection Note: CMSWS continues testing alarms for rises in water levels not associated with storm events

Sensor Utilization Beyond Flood Warnings

During the evaluation period, CMSWS utilized the LCS beyond their intended use. The Water Quality Program within CMSWS utilized the LCS network to retroactively identify when a large, sanitary sewer

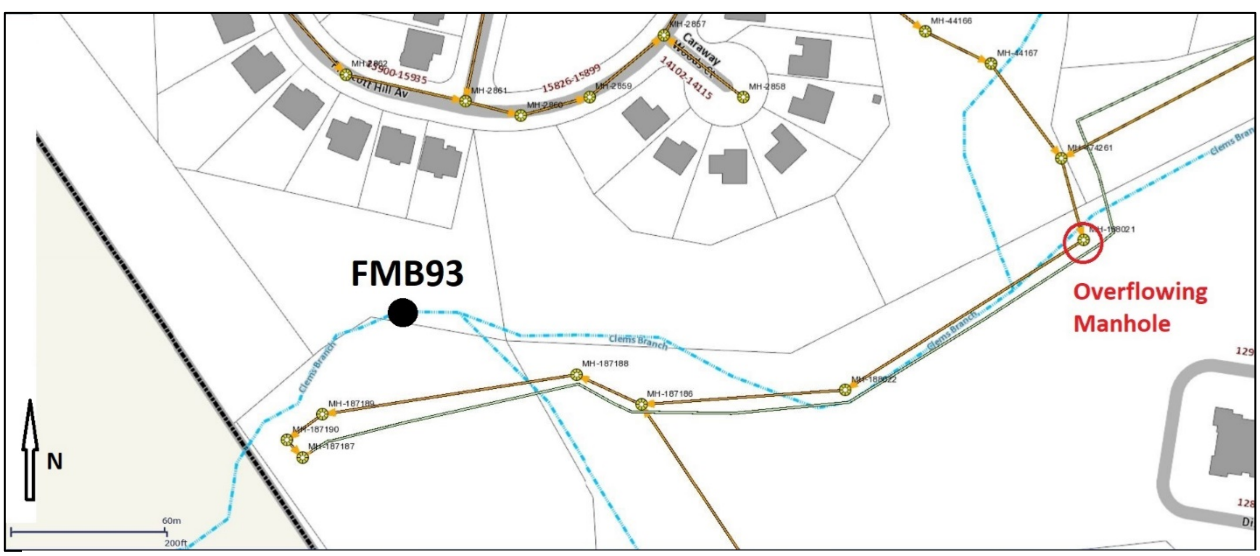

Figure 22: Map of sanitary sewer manhole that was overflowing upstream of FMB93.

overflow began. Charlotte Water, the local utility company, notified Water Quality staff of a large overflow that was impacting Clem's Branch (see Figure 22) . Charlotte Water was notified of the spill by a local resident on January 8, 2020. The stage data for Clem's Branch confirms that the spill began impacting Clem's Branch on January 8, 2020. During this time period, the watershed did not experience any rainfall and the stage raised by 0.18 feet. This post-hoc confirmation is a good indicator that the LCS can be used to help identify potential illicit discharges to surface waters. With the development of rules and notifications in FINS, illicit discharges such as this could be detected and eliminated.

9.0 Conclusion

Overall, the LCS functioned as intended and were effective or highly effective at meeting the requirements of each use-case tested. Their ease of installation, simplicity of operation, and lower cost of operation and maintenance allow for storm water management programs of all sizes to use them when accuracies of 0.1 feet are suitable for monitoring purposes.

LCS Strengths:

- Ease of installation: CMSWS was able to devise an approach to install the LCS in every setting encountered. The simplicity of the equipment and mounting hardware was relatively easy to adapt to any setting. An experienced crew of two technicians were able to complete an installation in approximately two hours. Installation is possible with a single technician.
- Accuracy: The LCSs tested by CMSWS met or exceeded the accuracy requirements for each use-case.

LCS Characteristics to be Improved:

- Cameras: The cameras provided with the LCS did not meet the needs of several of the use-cases. It is important to note that higher resolution cameras produce larger image file size, which requires significantly more power and time to transmit.
- Durability: In particular, the in-stream units were susceptible to damage.
- Susceptibility to Pest Damage: The head units were not fully enclosed. Ants and other pests were often found inside of the head units, which resulted in failures to report data to CMSWS and the need for repairs to be made by the vendor.

10.0 Reference List

Charlotte-Mecklenburg Storm Water Services (CMSWS) (2019a), "Flood sensor limited field deployment plan – Deliverable 3B; Milestone 5". Report prepared for U.S. Department of Homeland Security Science and Technology Directorate under Contract 70RSAT18CB0000022.

Charlotte-Mecklenburg Storm Water Services (CMSWS) (2019b), "Flood sensor deployment plan – Deliverable 3A; Milestone 4". Report prepared for U.S. Department of Homeland Security Science and Technology Directorate under Contract 70RSAT18CB0000022.

Charlotte-Mecklenburg Storm Water Services (CMSWS) (2020), "Low Cost Flood Sensors: Performance Analysis – Deliverable 5B; Milestone 10". Report prepared for U.S. Department of Homeland Security Science and Technology Directorate under Contract 70RSAT18CB0000022

APPENDIX A: Right-of-Way Agreement

Drawn by / Pick Up: __________________________
Ruff, Bond, Cobb, Wade & Bethune LLP
R. O. D. Box 24

STATE OF NORTH CAROLINA

RIGHT OF WAY
ENCROACHMENT AGREEMENT

COUNTY OF MECKLENBURG

THIS RIGHT OF WAY ENCROACHMENT AGREEMENT (this "Agreement") is made and entered into this the _____day of _____________, 2018, by and between the **CITY OF CHARLOTTE**, a municipal corporation (hereinafter "City"), and **MECKLENBURG COUNTY**, a political subdivision of the State of North Carolina (hereinafter "County").

WITNESSETH:

THAT WHEREAS, County desires to encroach on the rights-of-way of certain public roads in the locations listed at Exhibit A attached hereto, for the purposes of installing flood sensors (the "Sensors") within the said rights-of-way as more particularly shown on the diagram(s) attached hereto as Exhibit B and incorporated herein;

WHEREAS, it is to the material advantage of County to effect these encroachments, and City, in the exercise of authority conferred upon it by statute, is willing to permit the encroachments within the limits of the rights-of-way as indicated, subject to the conditions of this Agreement.

NOW, THEREFORE, IT IS AGREED that the City hereby grants to County, its successors, contractors, vendors, and assigns, the right and privilege to make these encroachments, upon the following conditions, to wit:

1. That County binds and obligates itself, its successors, contractors, vendors and assigns, to install and maintain the encroaching Sensors in such reasonably safe and proper condition including aesthetic appearance, that such Sensors will not interfere with, or endanger, travel upon said highways, nor obstruct nor interfere with the proper maintenance thereof, and if at any time the City shall require the removal of or changes in the location of the Sensors, that County binds itself, its successors, contractors, vendors, and assigns, to promptly remove or alter the said items, in order to conform to the said requirement, without any cost to the City.

2. That County agree to comply with the provisions of CDOT's Work Area Traffic Control Handbook (WATCH) should any roadway or walkway, or portion thereof, need to be blocked or closed during construction. Further, County agree to provide advance notification to, and obtain a Right of Way Use Permit from, CDOT for any such roadway or walkway closure in accordance with following:

Travel lane(s) and/or sidewalk(s) – 5 working days (minimum)
Street Closure – 10 working days (minimum)

Construction, installation, and maintenance activities are further restricted from blocking or closing a roadway or walkway at certain times of the day. These activities cannot occur during the following times:

7:00-9:00am, Monday – Friday
4:00-6:00pm, Monday – Friday

3. That County agree to provide notification to, and obtain a Street Cut Permit from, the Street Maintenance Department at least 24 hours prior to performing any construction that involves the cutting or breaking of any roadway or walkway pavement.

4. That the City retains the right and privilege to remove or alter the Sensors whenever an emergency or other situation requires prompt action and the City may recover the cost associated with removing or altering said encroachments.

5. That County, its successors and assigns agree to indemnify and hold harmless the City, its officers and employees, from and against all damage, including injury to persons or damages to property, expenses or other liability which may result from, arise out of, or be brought by reason of the encroachments.

6. That County, its successors and assigns, further agree, to the extent permitted by law, to defend any lawsuits which may be brought against the City, its officers and employees by reason of the installation and operation of the above-mentioned encroachments and pay any claims or judgments resulting from or preceding such lawsuits. Such agreement as to indemnification and defense shall be construed to the end that the City, its officers and employees, will suffer no liability or expense because of such claims or legal actions.

7. The County, its successors, contractors, vendors and assigns, each at their own expense, shall purchase and maintain for the duration of this Agreement Comprehensive General Liability Insurance and contractual liability assumed under this Agreement. Such policy or policies of insurance shall be for limits of not less than $1,000,000 bodily injury and property damage liability and will be subject to future review and adjustment at the request of the City. Certificates of Insurance shall be furnished to the Director of the Charlotte Department of Transportation containing the provision that 30 days written notice will be given to the City prior to cancellation or change in the required coverage. The provision of such insurance shall in no way replace or otherwise limit the obligation to defend and pay claims described previously.

8. Intentionally Omitted.

9. That County understands that power companies, CATV television franchise holders, and other holders of easements in City rights-of-way have or may have rights paramount to those of County to use of lands under the City rights-of-way at the locations specified in this Agreement.

10. That County waive any and all claims for damages or other relief which it may now or hereafter have against the City for interference with or damage to its Sensors located within the City rights-of-way way arising out of negligent act or omission.

11. City and County agree that this Agreement (including the exhibits attached hereto) may be amended and/or modified at future date(s), provided both City (by the Director of the Charlotte Department of Transportation) and County (by the Director of the Mecklenburg County Land Use and Environmental Services Agency, provided the approval of the Mecklenburg Board County of Commissioners is not required) consent to and approve in writing any such amendment or modification.

IN WITNESS WHEREOF, City and County have hereunto caused this Agreement to be executed by their duly authorized officers as of the day and year first above written.

CITY:

CITY OF CHARLOTTE,
a municipal corporation

By: ______________________________________
Name: ______________________________________
Title: Director, Charlotte Department of Transportation

ATTEST:

_____________________________________(seal)
City Clerk

APPROVED AS TO INSURANCE:

____
Insurance and Risk Management

COUNTY:

MECKLENBURG COUNTY,
a political subdivision of the State of North Carolina

By: ___________________________________
Name: ___________________________________
Title: County Manager

Approved as to Form:

____
County Real Estate Attorney

This instrument has been pre-audited in the manner required by the Local Government Budget and Fiscal Control Act.

____
Finance Director

Approved as to Insurance Requirements:

____

Director, Charlotte-Mecklenburg Division of Insurance Risk Management

STATE OF NORTH CAROLINA
COUNTY OF MECKLENBURG

I, _________________________________, Notary Public for said County and State, certify that
(Name of Notary)

______________________________ personally came before me this day and who, being by
(Name of Secretary)

me sworn, acknowledged that (s)he is the Secretary of the _____________________________
(Name of Corporation)

knows the Common Seal of the ______________________________, and is acquainted with
(Name of Corporation)

___________________________Who is the ________________________ of the name of the
(Name of Officer) (Title of Officer)

_______________________ and that (s)he saw the said _______________________ sign the
(Name of Corporation) (Name of Officer)

foregoing instrument and that (s)he affixed said seal to said instrument and that (s)he signed

her/his name in attestation of said instrument in the presence of ________________________.
(Name of Officer)

WITNESS my hand and notarial seal, this _______day of _____________, 200___.

____
(Notary Signature)

Notary Public

My Commission Expires: ___________________________
(Date)

APPENDIX B: Deployment Installation Check List

REFER TO LCS VENDOR SPECIFIC INSTRUCTIONS AND MODIFY DEPLOYMENT CHECKLIST AS NEEDED

1. **Head Unit:**
    a. Fence Post:
        i. Driving fence post into ground: use 8' post
        OR
        ii. Attach fence post to preexisting structure: 5' or 8' fence post using zip-ties
    b. Attach mounting bracket to fence post with zip ties
        i. Ensure unit is southern facing for northern hemisphere installations
    c. Mount head unit to mounting bracket

2. **Data Communication Cable:**
    a. Measure conduit length from in-stream pin to head unit
        i. Cut conduit to required length
    b. Feed fish line through conduit
        i. Attach in-stream sensor to fish line with electrical tape
    c. Feed in-stream sensor data communication cable through conduit
    d. Run conduit and data communication cable from head unit to in-stream sensor location
    e. Secure conduit with rip-rap, zip-ties, landscaping stakes and other materials

3. **In-stream Sensor**:
    a. Drive pin into creek bed
    b. Secure in-stream sensor to mounting bracket
    c. Submerge in-stream sensor into creek and secure to 24' steel stake

4. **Final Install Steps:**
    a. Power unit on per vendor specific instructions
    b. Secure signage to unit
    c. Secure extra cables and conduit
    d. Position camera to desired monitoring location
    e. Ensure data is being received

APPENDIX C: Low Cost Flood Sensor Operation and Maintenance Plan

REFER TO LCS VENDOR SPECIFIC INSTRUCTIONS AND MODIFY O&M CHECKLIST AS NEEDED

General O&M Plan for CMSWS Personnel:

1. **Daily**:
    a. Check data communication server for alerts or alarms
        i. Ensure all units are geographically present on the server
        ii. Ensure battery levels are adequate to maintain unit's reporting frequency
        iii. Ensure stage is reporting at sites where applicable*

    *Dry installation sites will show a stage of 0" outside of storm events

        iv. If any of the aforementioned criteria present issues, investigate further with site visits

2. **Monthly:**
    a. Conduct monthly site visits
        i. Refer to "Physical O&M Plan Inspection Checklist" below
        ii. Conduct validation measurement at lower sensor, documenting site, date, time and measurement
            1. Ex.
               Site: FMB1
               Date: 1/1/20
               Time: 12:00 PM
               Validation Measurement: 0.05"
    b. Insert validation measurement into a data management system (if applicable)
        i. This data is used as a means of conducting Quality Assurance/Quality Control (QAQC) for the flood sensors

Physical O&M Plan Inspection Checklist:

1. Head unit:
    a. Structure to which Head unit is Mounted:
        i. Ensure that the structure is secure
    b. Mounting Bracket
        i. Ensure mounting bracket is securely attached and is southern facing
    c. Head Unit
        i. Ensure that head unit is securely attached to mounting bracket
        ii. Inspect for signs of vandalism
        iii. Damage to solar panels
        iv. Missing or broken antennas
        v. All cables are properly inserted into their designated ports
        vi. Inspect for signs of pest in or around the head unit
            1. Address accordingly

2. **Data Communication Cable:**
    a. Cable
        i. Ensure that data communicate cable is plugged into unit
        ii. Ensure majority of data communication cable is protect inside conduit
            1. Storm events can cause cable to become exposed
        iii. Check for damaged/exposed wires
    b. Conduit
        i. Ensure conduit is securely attached to head unit mounting structure
        ii. Check for damage to conduit

3. **In-stream Sensor**:
    a. Pin
        i. Ensure pin is securely driven into creek bed or deployed location
    b. In-stream Sensor
        i. Ensure in-stream sensor mounting bracket is securely attached to in stream pin
        ii. Ensure in-stream sensor is securely attached to mounting bracket
        iii. Check in-stream sensor for signs of physical damage
        iv. Ensure conduit is securely attached to in-stream mounting bracket
        v. Check in-stream sensor data communication cable is protected inside of conduit

4. **Additional Inspections:**
    a. Cameras
        i. Ensure camera is properly secure
        ii. Ensure camera cables are plugged in and undamaged
    b. Signage
        i. Ensure signage is properly secured and visible
    c. Vegetation
        i. Ensure all vegetation around the head unit is removed
        ii. Ensure all vegetation posing a health hazard (i.e. Poison Ivy) is removed from the site