A Flood Early Warning System

And

Flood Response Plan

For the City of Fort Worth

Final Report

Stormwater Management Division,

Transportation and Public Works Department

City of Fort Worth

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List of Acronyms

ALERT: Automated Local Evaluation in Real Time. The communication protocol in which measured data is transmitted from field locations by event without coordination between locations.

ALERT2: A telemetry protocol in which GPS clocks are used for communication coordination and elimination of data loss. The ALERT2 protocol is maintained by the National Hydrologic Warning Council (NHWC).

CAH: Central Arlington Heights. A neighborhood in the central southwest part of Fort Worth that experiences chronic flash flooding.

CASA: Collaborative Adaptive Sensing of the Atmosphere; a system of small footprint X-band and dual-polarization radars (8 radars) that work together collectively to track storms in the Dallas-Fort Worth metroplex.

CFW: City of Fort Worth.

COTS: Commercial off the shelf software.

EAP: Emergency Action Plan; a plan of action developed to address a range of emergencies that may be experienced at a vulnerable asset (dam) or emergencies by event (storms).

EPA: Environmental Protection Agency.

FCC: Federal Communication Commission

FEC: Forward Error Correction; a communication method in which the data payload in a message has additional redundancy built into the transmission such that the receiver can correct errors without having to receive additional re-transmissions of the same message.

FEMA: Federal Emergency Management Agency.

FEWS: Flood Early Warning System; a system that warns residents of impending floods that's currently based on measurement of rainfall intensities and water levels at the most flood prone low-water crossings.

FRP: Flood Response Plan; the plan developed for this grant summarizing City's efforts during flood events.

GPS: Global Position System; a constellation of satellites that transmit radio signals to receivers which keep accurate time and position.

HADS: Hydro-meteorological Automated Data System; The National Weather Service (NWS) operated system of weather data distribution for the NWS and partner agency weather stations.

ILA: Inter-Local Agreement; a legal agreement between the City of Fort Worth and a neighboring jurisdiction.

OS: Operating System; the instruction set within a micro-processor (computer) that specifies management of the micro-processor, memory, and peripherals.

ITB: Invitation to Bid; a document that advertises the City's request for services and equipment through the open bid process.

LHMP: Local Hazard Mitigation Plan; a regional county level (Tarrant County) plan identifying hazard threats and mitigation addressing those threats.

MADIS: Meteorological Assimilation Data Ingest System; a meterological observational database and data delivery system that is run by the NWS National Centers for Environmental Prediction (NCEP) Central Operations.

METAR: Meteorological Aerodrome Reports; the weather observations measured at airports.

NCTCOG: North Central Texas Council of Government

NIMS: National Incident Management System; a flexible and scalable incident management system that addresses all threats, hazards and events across prevention, protection, mitigation, response and recovery based on the principal of "Unity of Effort" to achieve common objectives across multiple organizational structures.

OEM: Office of Emergency Management at the City of Fort Worth.

PT: Pressure Transducer; a sensor that measures water level pressure from the stress levels placed on a piezoelectric crystal.

SOP: Standard Operating Procedure; a procedure developed by a division or department to address emergencies.

SDI-12: Serial Digital Interface 1200 baud rate; an addressable sensor that can be given commands to make and respond back with measurements to a data logger.

SWM: Storm Water Management Division in the Transportation and Public Works Department at the City of Fort Worth.

TDEM: Texas Division of Emergency Management.

TDMA: Time Division Multiple Access; a protocol that divides up a fixed time frame over which a transmitting station re-transmits (60 seconds for the ALERT2 implemented in CFW) into “slots.”

TRWD: Tarrant Regional Water District

TWDB: Texas Water Development Board

WMO: World Meteorological Organization

Executive Summary

The City of Fort Worth (CFW) was awarded a flood protection grant from the Texas Water Development Board (TWDB) to help improve the reliability, relevancy, and resiliency of CFW's flood early warning system (FEWS). The FEWS (prior to grant completion) consisted of 52 water level sensors at flood prone low-water crossings that triggered road-side flashers at road overtop, 39 rain gauges co-located with the water level sensors, 5 lake level monitors with rain gauges, and 2 dedicated weather stations. Reliability was proposed through additional instrumentation; resiliency through improved telemetry and advanced software; and, relevancy by making the data available for the public to view. The FEWS used the ALERT communication protocol on two radio frequencies (170.850 Mhz and 169.4625 Mhz) to report measurements from the field to the receive station at Burnett Plaza.

The following summarizes the outcomes by the 3 main tasks proposed in the grant.

Task 1: Water level and rain gauging for reliability and resilience.

The FEWS was evaluated for improvements from points of measurement to point of reception at Burnett Plaza. A major issue plaguing the system was the "open squelch" reception problem at the transceiver radio on the 169.4625 Mhz frequency. This was resolved by splitting the incoming signal power in half with a signal splitter. Evaluation of proposed bubbler sensor technology over current use of Pressure Transducers (PT) was judged to provide no significant improvement in sensing since both rely on the same resistance mechanism of piezoelectric crystals, and the additional water level measurements at same location could lead to confusion of which sensor to believe during flood emergencies. Improvements identified at the points of measurement included: lowering the PT to the flow line of the creek as much as practical, lowering the controller cabinet to eye-level for easier maintenance (currently some are at elevated levels requiring bucket trucks), and use of a 'data driven' process to monitor and identify problems before deployment in the field. A secondary receive station at Bridge Street was instrumented to provide resiliency in case the primary receive station at Burnett Plaza failed.

Since the low-water crossings were located at low-points in the terrain and were obstructed by trees and buildings, the crossings didn't meet commonly accepted placement criteria for rain and weather monitoring. Twenty new weather stations meeting these criteria were located to capture rain fall and weather to fill in gaps in the regional network to provide a good distribution of weather stations to monitor weather patterns.

Task 2: Advanced flood warning software.

Contrail from One Rain Inc. was acquired through open bid procurement, and then installed across the functionalities of the software ranging from real-time monitoring, storage of historical data, retrieval of real-time data, display to the public, to automated alarm distribution to first responders.

Task 3: Flood Response Planning

A Flood Response Plan (FRP) representing the City's preparedness, response, and recovery was developed. The draft FRP was distributed to relevant stakeholders, and made available to the public. A table top exercise was held to test the contents of the FRP. The FRP will be incorporated into the City's Local Hazard Mitigation Plan (LHMP) after FEMA accepts the LHMP.

Introduction

The City of Fort Worth (City) applied for, and received, a matching Flood Protection Grant from the Texas Water Development Board to make improvements to the City's FEWS. The total project budget amounted to $632,309 of which TWDB contributed $247,378 with the rest matched by the City. The project period was from January, 2017 to March, 2019.

The City's Flood Early Warning System (FEWS), prior to this grant, consisted of water level monitoring at 52 of the highest risk low water crossing sites. Thirty-nine sites were instrumented with tipping buckets for rainfall, five lake level monitoring sites with rain gauges at City owned dams, and two sites were dedicated as weather stations which measured temperature, rainfall, wind speed and direction, relative humidity, and air temperature. The water levels measured by PTs triggered road-side flashers to warn drivers of street flooding. The ALERT telemetry protocol was used for the communication between the remote sites, and from the remote sites to the receive station in the Burnett Plaza Building. Software sent email alarms based on rising water levels to City and external first responders. The Stormwater Management (SWM) field crews barricaded streets to prevent vehicles from getting into flooded areas of the street. Due to the flashy nature of flooding, field crews had very limited time in which to respond to flood emergencies. An overall objective of this grant was improving rain and weather monitoring to better capture rainfall intensities so that better "City-wide" lead response times could be developed for the field crews to deploy at flood prone locations.

At the monitored locations, the station with water level gauging is called a "Master" and the flashers that are turned on and off by the 'Master' are called "Remotes." Typically, there are 2-3 flashers associated with each 'Master.' When flood waters reach a pre-defined threshold, the Master sends two successive messages, each containing the target Remote identifier along with two data values that sum to 2047. The flashers, recognizing these messages and respond with two messages giving their status. If a flasher doesn't respond, the Master repeatedly tries five times. All transmissions between the Master and Remotes are also received by the decoder at Burnett Plaza (receive station) and forwarded, via IP connectivity, to flood warning software on a server. During storm events, there is a greater chance that reports from different Master/Remote sites can overlap, leading to "contention." The ALERT2 protocol overcomes contention problems by assigning time slots to each station. The Contrail software monitors the communication occurring between the master and remote (Flasher) stations. Lost communication is a good indicator that the remote may be having problems. If the flasher station does not respond, the non-response will be known by examination of the flasher performance on Contrail. The administrators of the FEWS monitor the system for these types of failures on Contrail. Improvements were proposed to the FEWS using ALERT2 telemetry, replacement of legacy flood warning software with more advanced software, and development of a Flood Response Plan (FRP).

Methodology

Project Management

Project management consisted of regular bi-weekly project meetings with participation by City Staff, consultants, vendors, and the TWDB staff. Project schedule, deliverables, and budget were tracked in scheduling software, and in Excel spreadsheets. Separate kick-off meetings were held for major phases of the project. Consultant and vendor services were procured following City bidding procedures. The consultant selected for professional services was Distinctive AFWS Designs Inc., Blue Water Design and Campbell Scientific Inc. for electronic equipment, and Bean Electric for infrastructure components and installation. Grant public meetings were advertised through multiple City outlets, and held on March 13, 2017, November 1, 2017, and December 12, 2018. A website was created to communicate project information to the public (www.fortworthtexas.gov/floodwarning).

Methodology by Tasks

Task 1: Water and Weather Gauging to improve reliability and resilience.

Sub-Task 1.1: Identify up to 10 critical flood prone low-water crossings at which to install additional water level gauges.

As part of Task 1, the entire FEWS was evaluated ranging from the points of measurement at the receive station to maintenance of the system.

The project team evaluated the benefit of installing additional water level measurement at the existing gauging sites, and concluded no benefit would result with additional level gauging at a location. When there are 2 sensors with similar/same measurement mechanisms at the same location giving contradictory water levels, it will be difficulty to determine which one to believe without additional information. In emergency situations, this could be potentially resolved by having a 3rd sensor. However, if the 3rd sensor is also providing contradictory data, then a fourth sensor will be required and so on. The approach taken here to resolve this problem was to use to 2 different type of sensors (one PT and the other an on/off float switch) and to confirm data provided by one against the other. The potential use of an on/off float switch to confirm flooding was determined to be of more benefit and tested at the new Bryce-Hulen sites (see Appendix A, station 43710). A concern with additional continuous level measurement was that conflict in levels between gauges during flooding could lead to questioning which gauge to believe.

Sub-Task 1.2: Identify up to 20 existing low-water crossings to install weather stations.

The following guidelines from the EPA and WMO (EPA, 2000; WMO, 2008) were used as aid in locating weather stations:

- Open space (non-concrete) surrounding the station out to 100-200 feet
- Level grade (no slope)
- Secure location
- Ease of access for maintenance
- Permission of landowner
- Clear transmission path to the receive station (nominally, 25 miles from Burnett Plaza)

The telemetry for the Burnett Plaza and proposed secondary receive station at Bridge Street Tower was evaluated for radio paths (Figures 1 and 2).

The inventory of low-water crossings, when examined for above criteria, proved unsuitable because they were located at low spots in the topography and were obstructed by riparian vegetation and buildings.

Sub-Task 1.3: Identify critical sites for installation of up to 20 weather stations.

New weather stations were situated to be adequately distributed in the City and capture "gaps" in the regional network. Inter Local Agreements (ILA) were executed with neighboring cities of Joshua, Godley, Mansfield, Annetta, Cresson, Alvarado, and with the Springtown Independent School District. An agreement was also reached to locate weather stations within the City of Fort Worth on Fire Station, Parks, and Water Department properties for a total of 21 stations.

Sub-Task 1.4: Install equipment, calibrate and validate gauging sites.

In ALERT2, each remote field station is given a "time slot" in which to report data to receive stations. A "Frame" is the time cycle over which a site is revisited. Accounting for the number of existing low-water crossing sites and the new weather stations, the 'Frame' was set at 1 minute (60,000 milliseconds), and the slot for each station was set at 500 milliseconds. These settings accommodate the current system and future growth of the system. Figure 3 is a depiction of the ALERT2 Time Division Multiple Access (TDMA) setting.

The equipment used for ALERT2 transmission was Blue Water Design's (BWD) A2M, which had Forward Error Correction (FEC), 250ms TDMA time slot, and low power usage. BWD's two-way A2X was used as the ALERT2 decoder at the receive station. The A2X has remote login capability for monitoring and update of firmware. Campbell Scientific's CR300 was used for data logging, rain gauging was made with YSI's H-3401 tipping bucket, and weather parameters were measured with Vaisala's WXT 536. The A2M ALERT2 relays the data from the CR300 to the receive station via a radio (Ritron brand) at a timed sequence using a GPS antenna to keep track of time. The equipment was procured through open bid solicitations (ITB 18-0155 and ITB 18-0116). The wind sensor on the WXT 536 measures wind speed and

direction based on an array of ultrasonic transducers that transmit and measure the transit time of sonic signals. Precipitation is measured based on the vibration due to impinging rain drops on a steel cover. Pressure, temperature, and humidity are measured by capacitance sensors. The Vaisala WXT536 is an SDI-12 device and was connected to the SDI-12 terminal in the CR300 datalogger (Vaisala, 2017). The WaterLOG H-3401 tipping bucket rain gauge has a magnetic reed switch for measuring tips. Three stainless steel screws located at the bottom the aluminum plate were used to level the tipping bucket gauge (YSI, 2018).

Installation had two components: installation of infrastructure, and installation of sensors, data loggers, and telemetry. Infrastructure installation consisted of a concrete pad foundation with earth grounding to a depth of 6', base mount (Pelco brand) and aluminum pole, a water tight Adelco brand cabinet box to house the controller electronics, and the 2 mast-booms hosting the multi-parameter Vaisala WXT 536 and the WaterLog H-3401 tipping bucket rain gauges.

The steps for installation were: 1) Assembling the boom mounts for the sensors; 2) Mounting the radio antenna onto the mast; 3) Threading the sensor and antenna cables through the pole opening into the cabinet using a guide string; 4) Connecting the grounding wire to the cabinet and ground of the terminal block (the terminal block connectivity gives convenient access to the CR300 data logger data ports); 5) Inserting sensor leads into the terminal block ports; 6) Connecting the GPS antenna cable to the A2M; 7) Connecting the antenna cable to the radio transmitter; 8) Connecting the A2M to the Ritron radio; 9) Connecting the Campbell Scientific CR300 data logger to the A2M device; and 10) Connecting the battery to the terminal block power port. Figure 4 depicts the devices and connectivity in the controller cabinet.

Figures 5 and 6 depict installed ALERT and ALERT2 equipment at Burnett Plaza and secondary receive station at Bridge Street. The A2X unit decoder is connected to a Ritron transceiver radio on the receive port, and tied to the Ethernet WAN on the output side. The serial to IP connectivity is integrated within the A2X. The GPS clock information is accessed by the A2X from the internet via servers that track GPS time.

A PT and float switch were installed at the Bryce-Hulen detention pond (see Appendix A, Station 43710) to test measurement of flooding via two different sensors.

Task 2: Advanced Flood Warning Software.

Sub-Task 2.1: Develop Software requirements, and advertise for flood warning software.

Software specifications were developed for "base" qualification, functionality, and usability. The base qualification consisted of the software's ability to ingest ALERT and ALERT2 protocols, delivery of data through APIs, text and email alarming, two-way communication, spatial mapping, and robust customer support. The functionality and usability specifications were: Commercial-Off-the-Shelf (COTS) software with minimal use of third-party software, minimal base code reconfiguration to fit the City's requirements, cloud hosting, security certification,

integrity with common database platforms, documentation, training, and mobile and desktop browser compatibility.

Sub-Task 2.2: Procure software satisfying City requirements.

The software bid was released on February 8, 2017 (RFP 17-0188).

Sub-Task 2.3: Install software, and train staff on software usage.

City's IT and One Rain Inc. followed vendor's pre-installation and installation procedures subject to the City's firewall and security requirements.

Figure 7 shows the replication connectivity between the One Rain cloud server and the City's server, both running the MySQL based Contrail server software on the Linux Operating System (OS) platform. The IP feeds from the ALERT/1 and ALERT/2 decoders at Burnett Plaza and Bridge Street Tower are supplied to the servers via independent IP connections from the receive sites. The Contrail server software receiving data via IP connectivity from Burnett Plaza and Bridge Street automatically and continuously communicate and replicate their MySQL databases.

Task 3: Flood Response Planning.

Sub-Task 3.1: Develop the conceptual level FRP for City needs.

City staff involved in flood emergency preparedness, response, and recovery participated in the development of the draft FRP document which was refined through feedback. Meetings were held with external partner agencies to get their input.

Sub-Task 3.2: Coordinate with relevant stakeholders, evaluate and refine FRP.

The draft FRP document was sent out to regional partner agencies such as the Tarrant Regional Water District (TRWD), USACE, and Tarrant County, and the FRP was presented at the TWDB grant public meeting and made available to the public for review.

Sub-Task 3.3: Incorporate the FRP in the Local Hazard Mitigation Plan (LHMP), and submit the FRP to the TDEM and the TWDB.

The LHMP, which incorporates the FRP, is under review by TDEM and FEMA. As requested in the TWDB contract Article III, B, the Flood Response Plan was incorporated in the City's Hazard Mitigation Plan which was developed for Tarrant County by the North Central Texas Council of Governments (NCTCOG). The NCTCOG submitted the plan to the Texas Division of Emergency Management which reviews the plan before it goes to the FEMA. The APA is sent to the NCTCOG and the county (Tarrant County); the City of Fort Worth will not receive a separate APA letter. The current expectation is that the APA letter will be received next year at which time a copy will be sent to the TWDB.

Results

Task 1: Water and Weather Gauging to improve reliability and resilience.

Sub-Task 1.1: Identify up to 10 critical flood prone low-water crossings at which to install additional upstream and downstream water level gauges.

The intent of this sub-task was to evaluate opportunities for supplementary gauging at 10 locations from among the highest risk prone low-water crossings that were instrumented with water level sensors. It was soon realized that an overall "audit" of the FEWS was the best first step, since measurement required context. Project consultant DDI conducted interviews with key personnel, visited multiple remote sites, performed data analysis of measurements, evaluated maintenance procedures, modeled the radio path, and reviewed Federal Communications Commission (FCC) licensing (DDI, 2017). The main outcomes were: to install the new Contrail software as soon as possible, reformulate maintenance to be more "data-driven", to fix problems on first visit (instead of repeat trips) after diagnosis, anticipation by evaluating historical data, and to enhance in-house technical capabilities. During the system evaluation, it was noticed that the "open-squelch" problem on the 169.4625MHz channel was a persistent, "dirty" data problem that had plagued the FEWS for some time. This was resolved by reducing the radio signal strength going into the transceiver radio by splitting the incoming signal from the antennas.

Additional gauging was proposed in the grant application to supplement gauging with bubbler based water level sensors. While the main advantage to installing bubbler sensors over other sensors is keeping the data logging equipment safe from flooding, the disadvantage to data-logging equipment being washed off can be overcome by ensuring safety of equipment by elevating it above the high flood stages (>100-year floods). In bubbler sensors, the pressure exerted against an air bubble in a tube is in fact measured by a pressure transducer (PT). In terms of mechanism, both the direct PT measurement and the bubbler rely on the transducer mechanism in which a piezo-electric crystal changes its resistance to differential pressure. Adding another depth gauge for real-time measurement could also lead to confusion of which gauge to believe during conflicting measurements.

During this grant, continuous water level measurement with a PT and float switch was tested at the Bryce-Hulen detention basin in the Central Arlington Heights (CAH) neighborhood to test flood measurement by two different sensors. The float switch provides a simple on/off trigger signal when the water level reaches a determined depth. The additional gauging with float switch was tested at the Bryce-Hulen detention basin only. Once tested, the combination (PT and float switch) gauging will be implemented by the City as separate effort. The CAH neighborhood faces chronic flooding problems due to undersized storm drains installed during the 1910-20 period. In 2016, a dry detention basin and underground culvert storage of flood waters below streets was constructed to provide relief from flooding. Graph comparison of

flooding events in the detention basin in September and October of 2018 showed favorable results (Figure 8).

Sub-Task 1.2: Identify up to 20 existing low-water crossing sites to install weather gauges.

From the inventory of low-water crossings, sites were investigated, both on desktop and by field inspection, for placement of new ALERT2 stations. Because these low-water crossings are located at low points in the topography and were surrounded by vegetation or building obstructions, the sites did not meet the criteria given earlier in methodology.

Sub-Task 1.3: Identify critical sites for installation of dedicated weather gauges at up to 20 new sites.

Figure 9 shows the ultimate locations for the new ALERT2 weather stations. These were distributed about 7 miles apart on average. Details for each weather station are given in Appendix A.

Sub-Task 1.4: Install equipment, calibrate, and validate gauging sites.

Since installation of the ALERT2 stations in August, 2018, several storm events have enabled comparison between the tipping bucket and WXT536 disdrometer (acoustic sensing of steel cover) measurements at a variety of locations. A sample comparison for the Chisholm Trail Park station at 15-minute intervals is shown in Figure 10 for the September 21-22, 2018 storm. Comparisons at other sites also showed similar results. In general, we found that the installed WXT536s will need to be individually calibrated to the co-located tipping bucket, and at this time, we are unable to develop a single generalizable relationship between the disdrometer and tipping bucket measurements. With more measurements in the coming years, we will be able to evaluate the rainfall measurements against each other and with other longer-term stations in the regional network.

Task2: Advanced Flood Warning Software.

Sub-Task 2.1: Develop software requirements, and advertise for flood warning software.

The bids for software were released on February 8, 2017 (ITB 17-0188).

Sub-Task 2.2: Procure software satisfying City requirements.

From the three submittals received, One Rain Inc. was selected based on the published criteria. The contract was for an initial term of 2 years, with option to renew annually for another 3 years.

Sub-Task 2.3: Install software, and train staff on software usage.

Contrail website ingests data from the City of Grand Prairie, US Geological Survey stream and lake gauging sites for the area (https://waterdata.usgs.gov/nwis), Hydro-meteorological Automated Data System (HADS) (https://hads.ncep.noaa.gov/), distributed by the National Weather Service, and Aviation Weather Center METAR stations (https://aviationweather.gov/metar), distributed by the National Oceanic and Atmospheric Administration (NOAA). Data were also exchanged with the City of Grand Prairie's flood warning system, the Tarrant Regional Water District (TRWD), and the North Texas Council of Governments (NCTCOG), and the NWS' Meteorological Assimilation Data Ingest System (MADIS) system.

Software training for staff was provided by the vendor with on-site training and on a continual basis and as needed. Additionally, training was available via vendor webinars.

A public-facing flood warning website www.fortworthtexas.gov/floodwarning was made available after the final public meeting for the grant on December 12, 2018. Information on the website was publicized with stories in Star-Telegram on 2/15/2019, Mayor's Community Engagement Workshop held on 2/16/2019, posting of specially made video on the City's webpage, City News broadcasts, and the Stormwater newsletter insert in water bill sent to all residents. A screen shot of the public-facing website is shown in Figure 11.

Alarms from real-time measurements are sent via emails to first responders from the City and external partner agencies. The City's Office of Emergency Management (OEM) issues public warnings and internal emails. A sample warning using data from the new stations is shown in Figure 12.

Task 3: Flood Response Planning.

Sub-Task 3.1. Develop the conceptual-level Flood Response Plan (FRP) for City needs.

Available emergency action plans (EAPs) and Standard Operating Procedures (SOPs) were reviewed and the FRP was categorized into four areas: flash flooding in City creeks and storm drains, riverine (Trinity River) flooding, City dams, and regional dams. For each of these flood risk categories, flood preparedness and response were addressed. Since the City has an All Hazards National Incident Management System (NIMS) plan, recovery is found in the Annexes of the NIMS plan. The FRP development from this grant is given in Appendix B.

Sub-Task 3.2. Coordinate with relevant stakeholders, evaluate and refine FRP.

The FRP was desktop exercised on July 24, 2018 for overall content and breach of Luther dam was simulated. The exercise scenario consisted of describing the dam and surrounding area, storm event, reports of breach observation, flood extent, and threat of downstream assets. As the scenario was developed, participants described their responses to the flooding scenario, including

potential need to evacuate as threat intensified. The main outcomes from the table top exercise were participants learned of potential failure modes of dams, points of contact, and downstream impacts. The FRP also reflects a table top exercise for Lake Benbrook conducted by the USACE on February 20th, 2019.

Sub-Task 3.3. Incorporate FRP in the Local Hazard Mitigation Plan (LHMP), and submit FRP to the Texas Department of Emergency (TDEM) and the TWDB.

The FRP was submitted to the TDEM and the TWDB for review on January 27th, 2019. The FRP is incorporated in the LHMP and the LHMP is currently undergoing review by FEMA.

Conclusions

Efforts through this flood protection grant enabled the City to progress towards a more resilient, reliable, and relevant Flood Early Warning System. System improvements were made by updating the telemetry, acquisition of new software (Contrail), and development of a flood response plan. Twenty new weather stations were installed to capture rainfall and weather data at locations appropriate for weather monitoring. Collected data is being distributed to partnering agencies, such as the National Weather Service. Overtopping of roads at monitored locations is displayed from a publically accessible link on the City's website (www.fortworthtexas.gov/floodwarning). The City's FEWS will be undergoing continual improvements, among which are: update of the flasher sites to ALERT2 telemetry, water level gauging with addition of float switches, improvements to maintenance of the system with help of data ("data driven" maintenance), development of flood emergency response tools, and enhancements to the public website.

References

1). Distinctive AFWS Designs, Inc. (DDI), Early flood warning performance review, October, 2017.

2). EPA, 2000, Meteorological Monitoring Guidance for Regulatory Modeling Applications, EPA-454/R-99-005, p. 28-41.

3). Vaisala, 2017, User Guide, Vaisala Weather Transmitter, WXT530 Series (www.vaisala.com).

4). WMO, 2008, Guide to Meteorological Instruments and Methods of Observation, WMO-NO.8, 7th Ed., p. 567-591.

5). YSI-WaterLOG, Rain Gauge specification for H-3401.

Figures

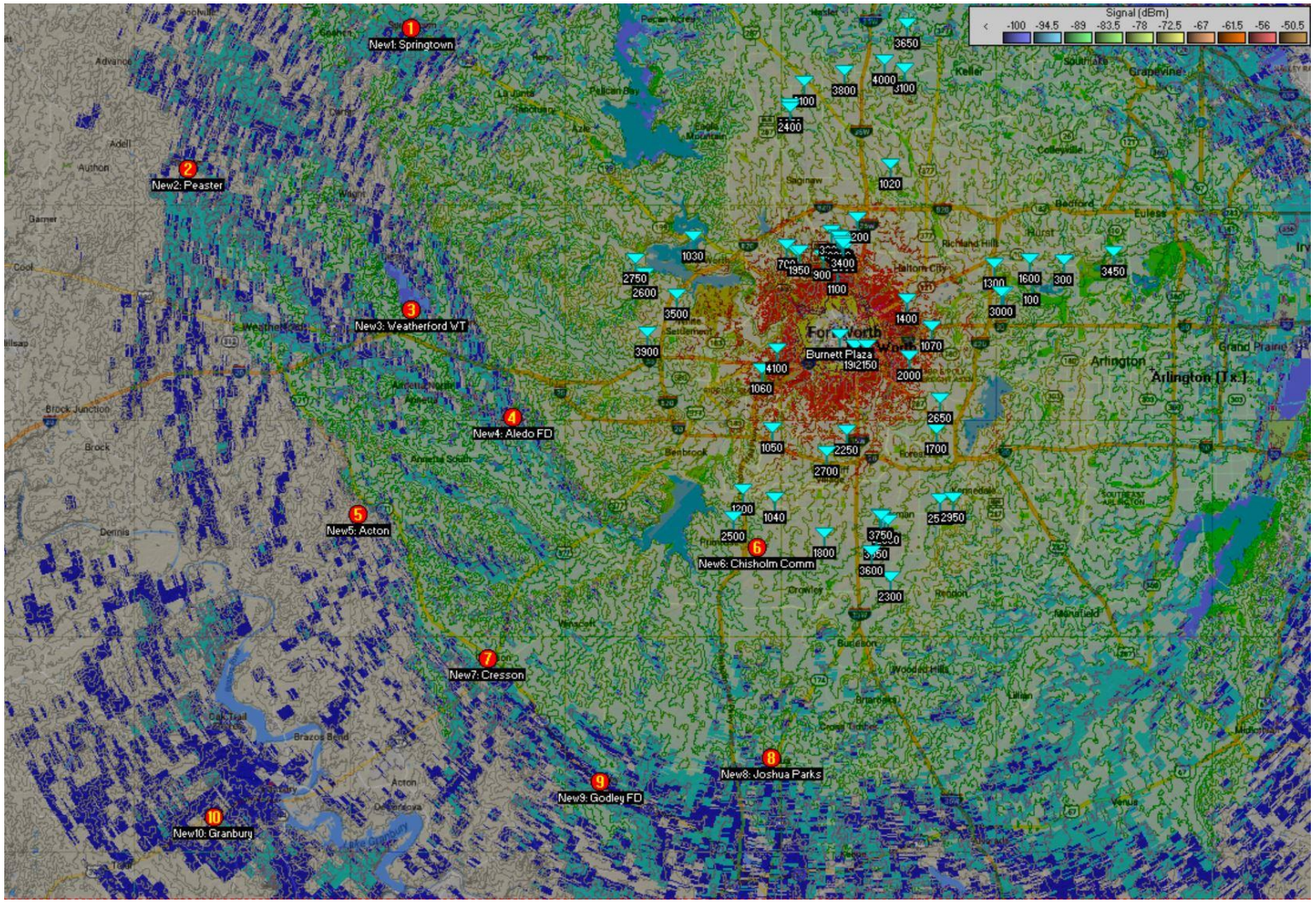


Figure 1. Radio path analysis for the Burnett Plaza receive site. The colored areas represent areas with good reception. The existing monitoring sites (inverted triangles) on ALERT telemetry, and proposed sites (circles) on ALERT2 telemetry are shown as overlay.

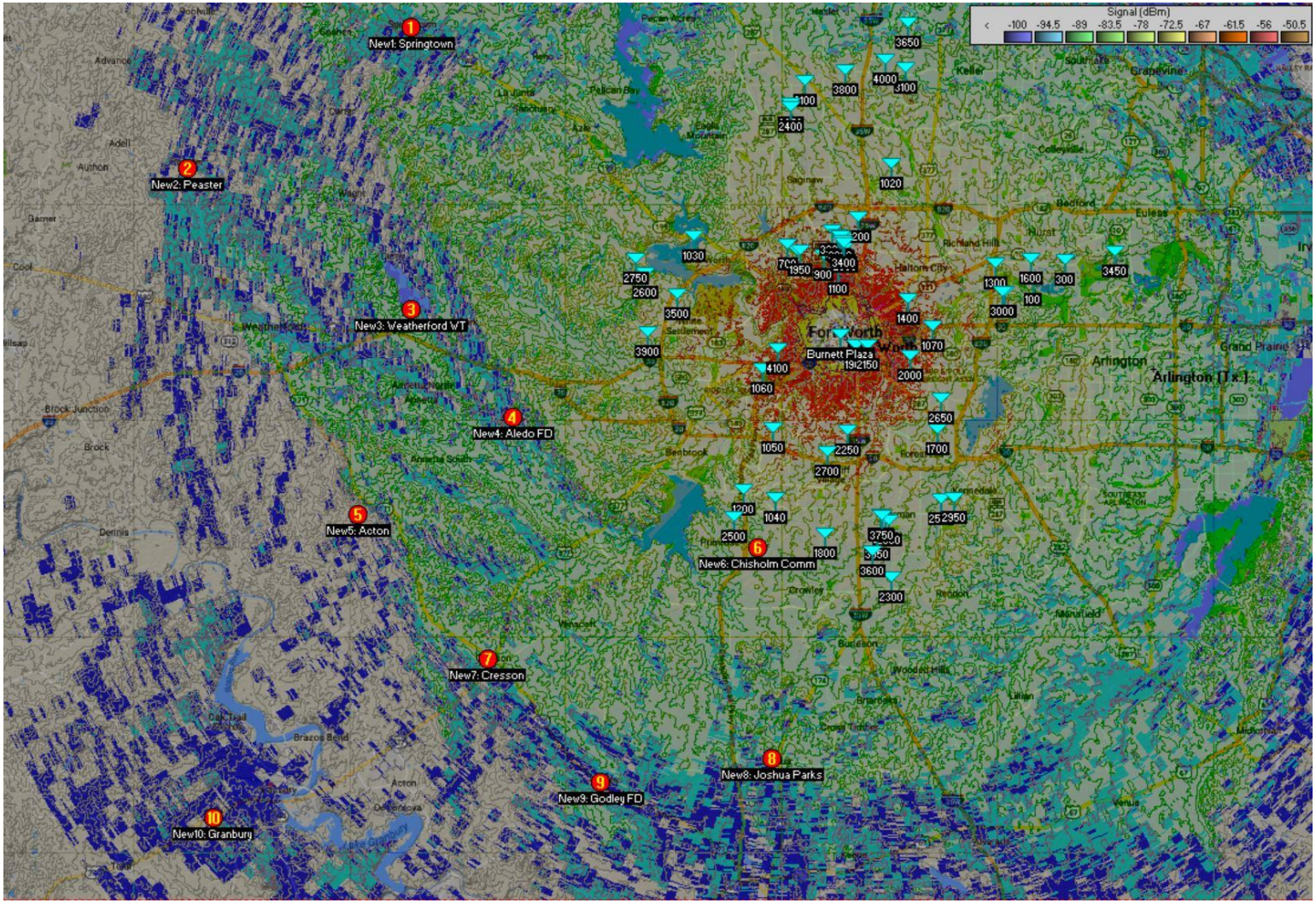


Figure 2. Radio path analysis for the receive station at Bridge Street. The colored areas represent areas with good reception. The existing monitoring sites are shown overlaid with inverted triangles, and the proposed sites are shown as circles.

Figure 3. Time Division Multiple Access (TDMA) structure for the City's ALERT2 network.

Figure 4.Panel layout in the controller cabinet.

Figure 5. Burnett Plaza Receive equipment.

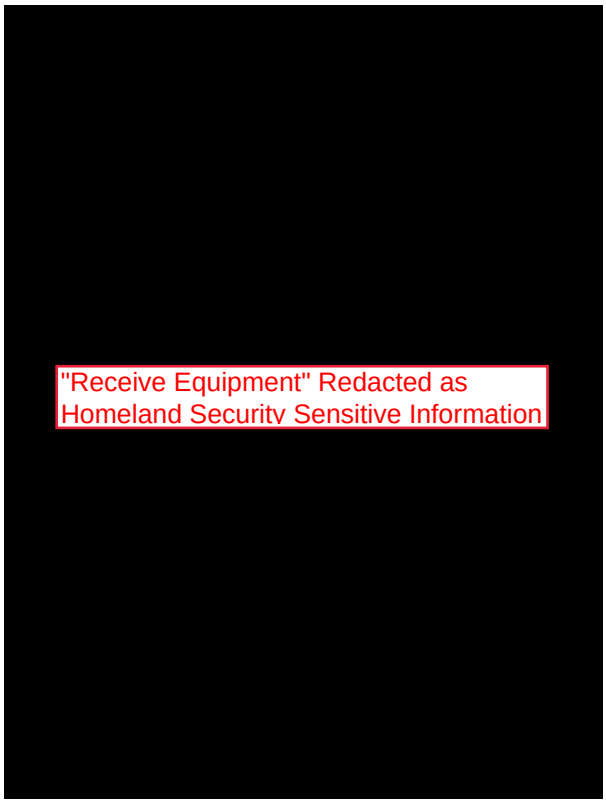


Figure 6. Bridge Street receive equipment.

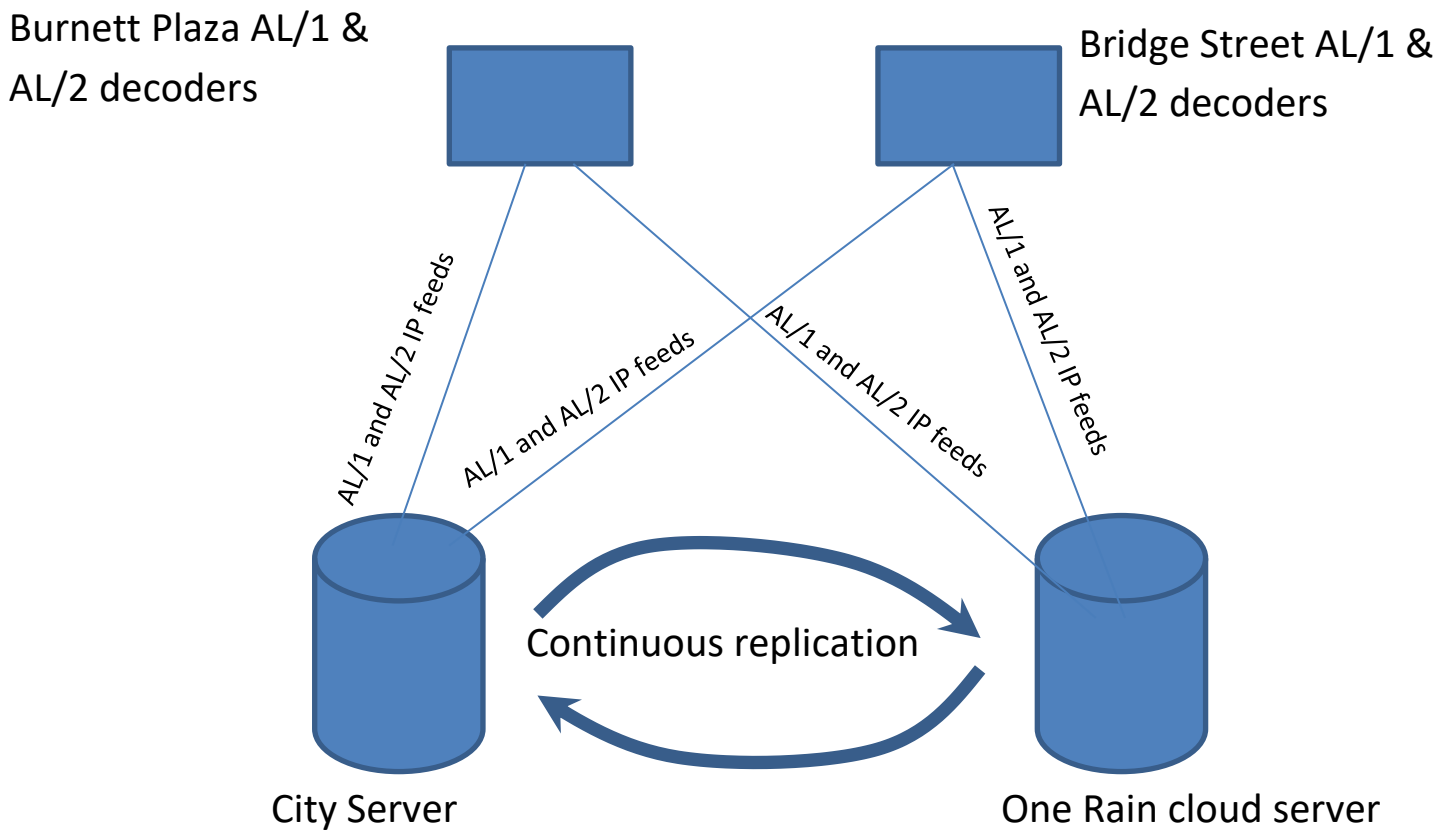


Figure 7. Replication connectivity between the City and hosting servers.

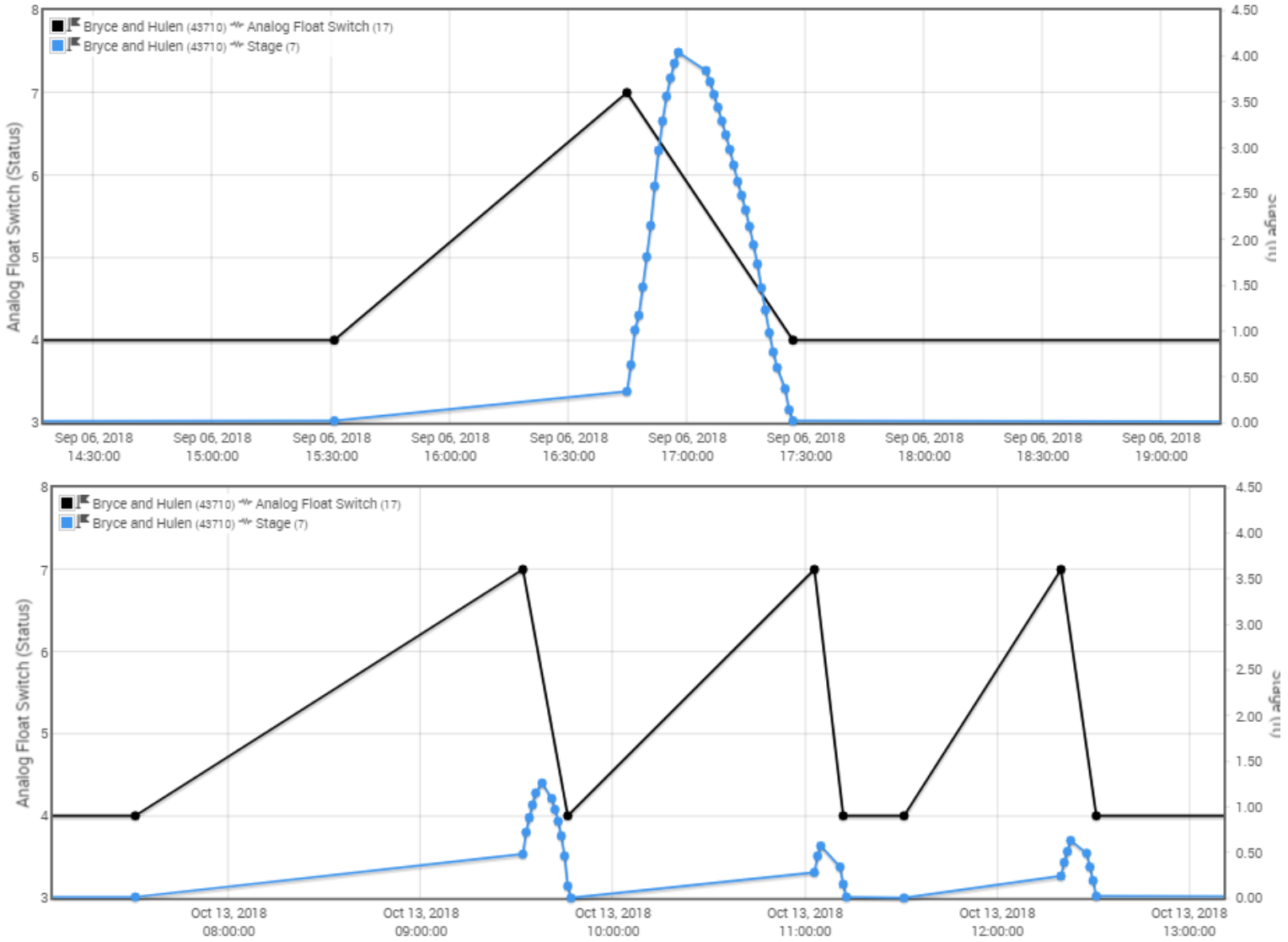


Figure 8. Comparison of float switch response against water level measurement at the Bryce-Hulen detention basin for two events in 2018 (installation was completed in August, 2018). These graphs were generated in the Contrail software. The dots mark timing of reports to the receive station.

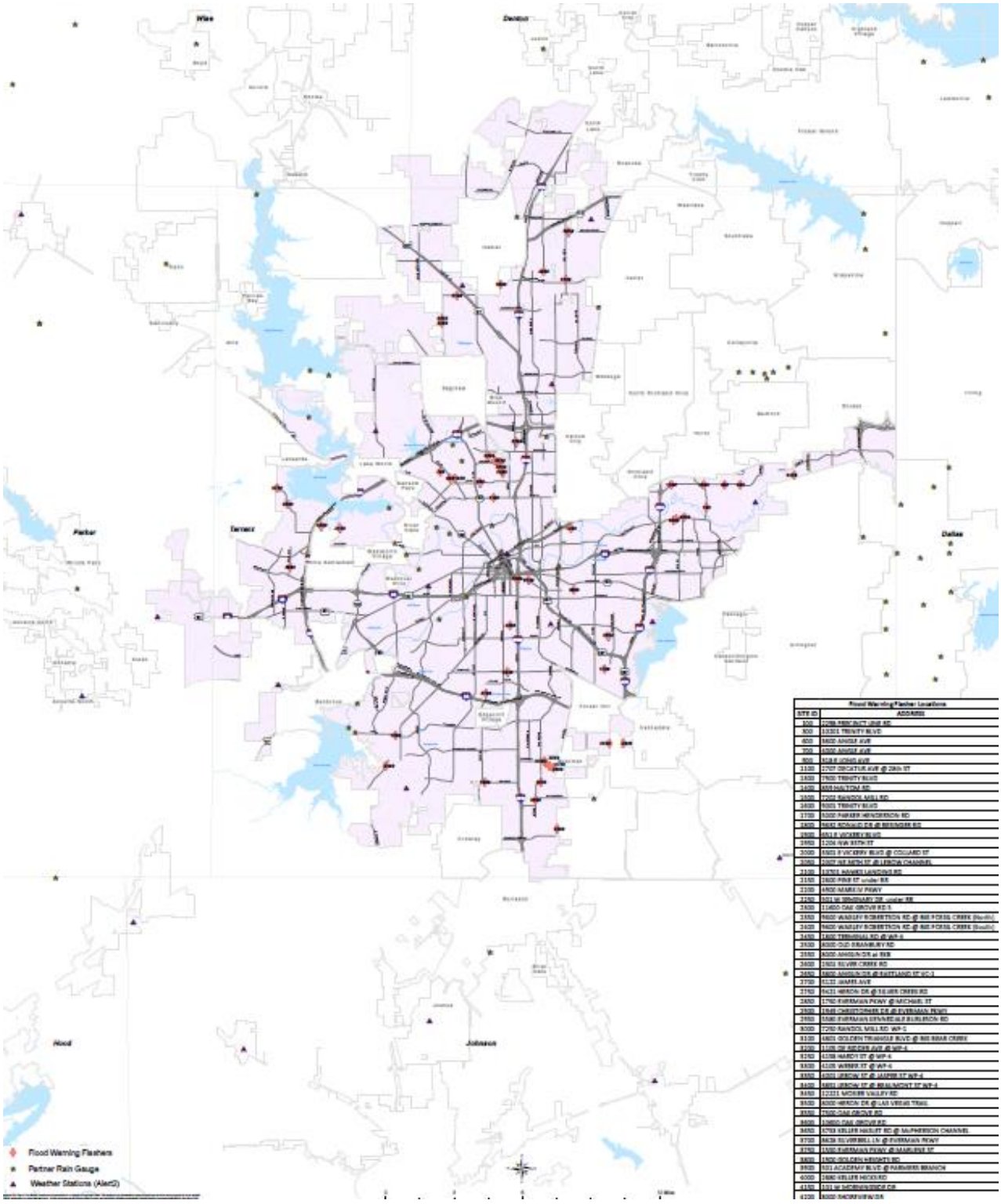


Figure 9. Distribution of existing and new ALERT2 weather stations in and surrounding the City. The new ALERT2 stations are shown as triangles, and the partner gauges are shown as stars.

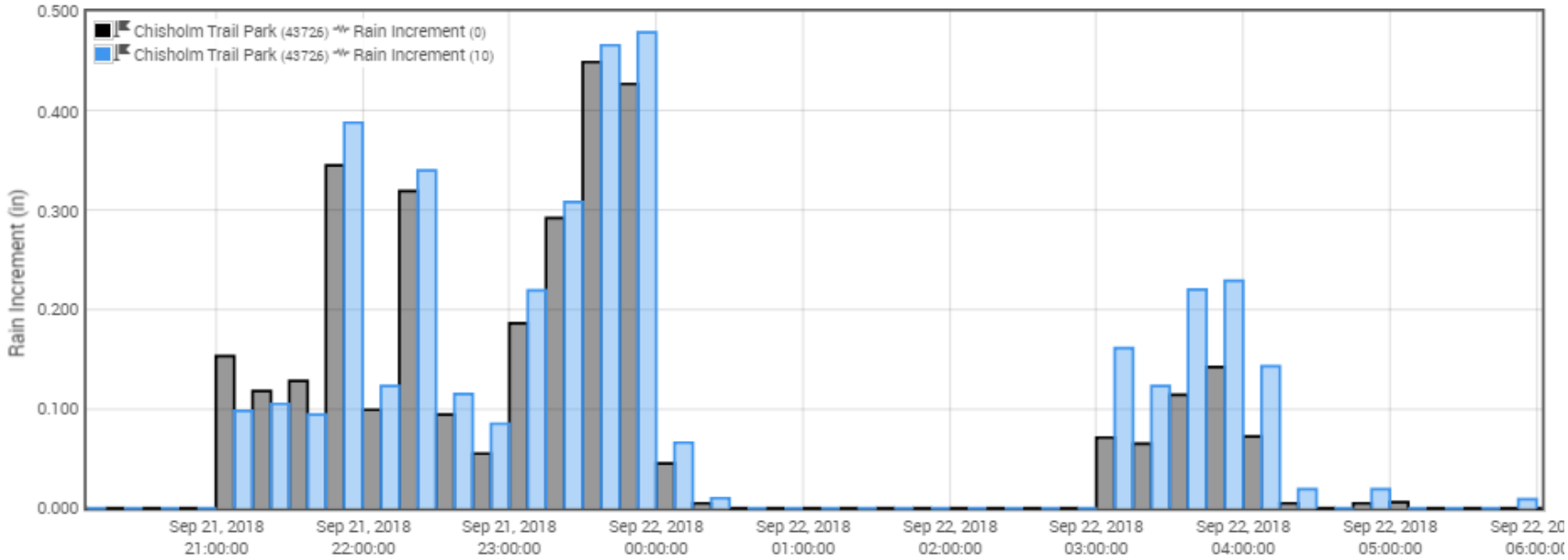


Figure 10. Comparison at 15-minute intervals between the Vaisala WXT536 and YSI H3401 tipping bucket measurements during the September 21-22, 2018 storm at Chisholm Trail Park weather station. The WXT 536 measurements are shown by the grey columns.

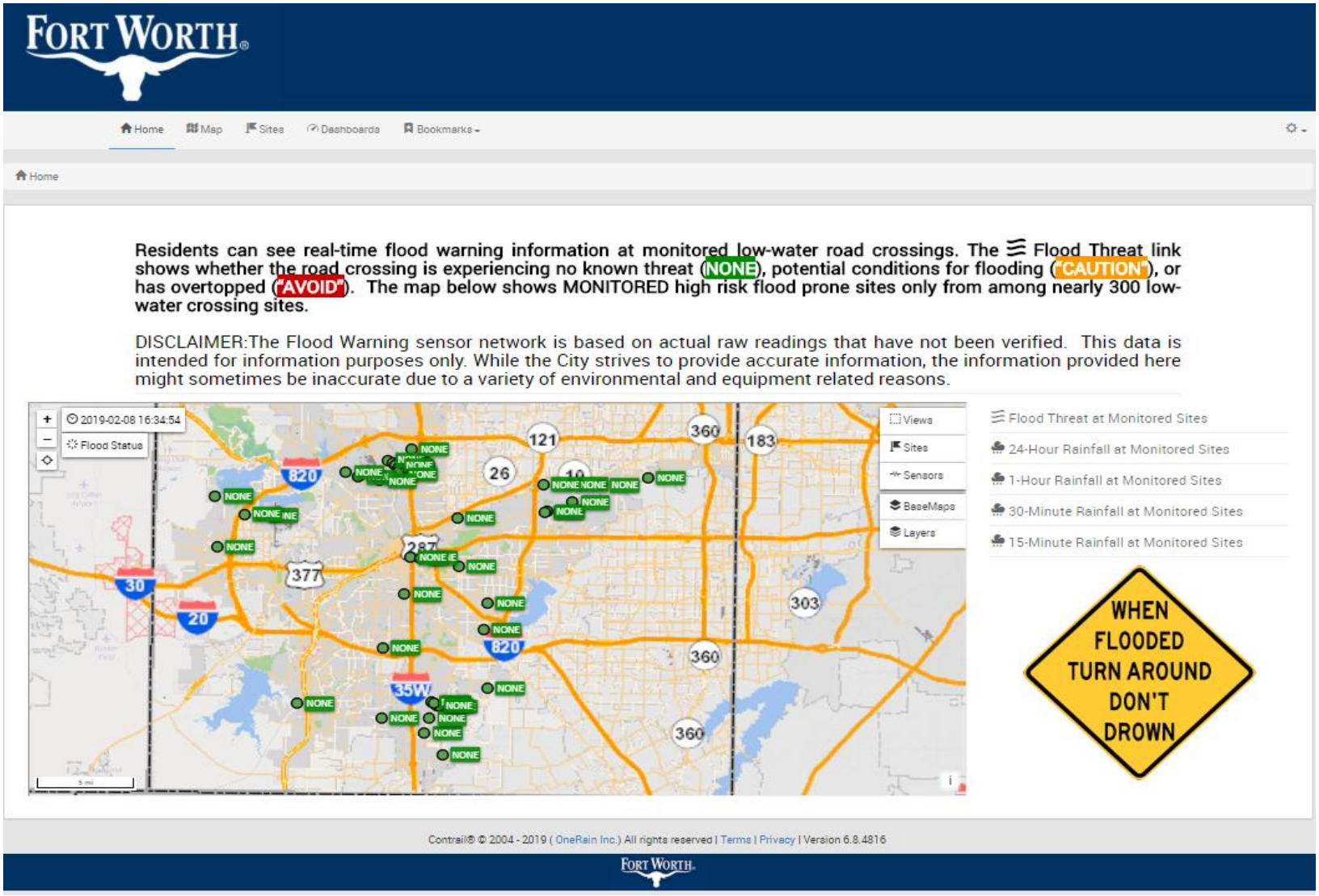


Figure 11. Screenshot of public-facing flood warning web site.

OEM is currently monitoring the situation and has activated the JEOC with representatives from Fire, PD, MedStar, T/PW, and Tarrant County OEM.

- A Winter Weather Advisory for Tarrant/Johnson remains in effect until noon today. A light glaze may develop on bridges, overpasses, and fly-overs.
- A Winter Weather Advisory for Denton/Parker/Wise remains in effect until 6AM Friday. Freezing rain and then snow are possible in these areas as colder temperatures are expected.
- Temperatures are currently in the 30-32 degree range across Fort Worth with some 29-30 in far west Fort Worth and far north Fort Worth.
- Precipitation will increase throughout the day with the greatest icing potential for a few hours this morning and then into the overnight hours.
- Incidents are increasing on elevated roadways and are mainly in the north part of the City.
- TXDOT and NTTA have been notified to sand additional trouble spots.
- WebEOC Incident: Ice 01 02 2019.

OEM will determine any needs for an overnight activation after morning conference calls and additional weather models.

Graphics:

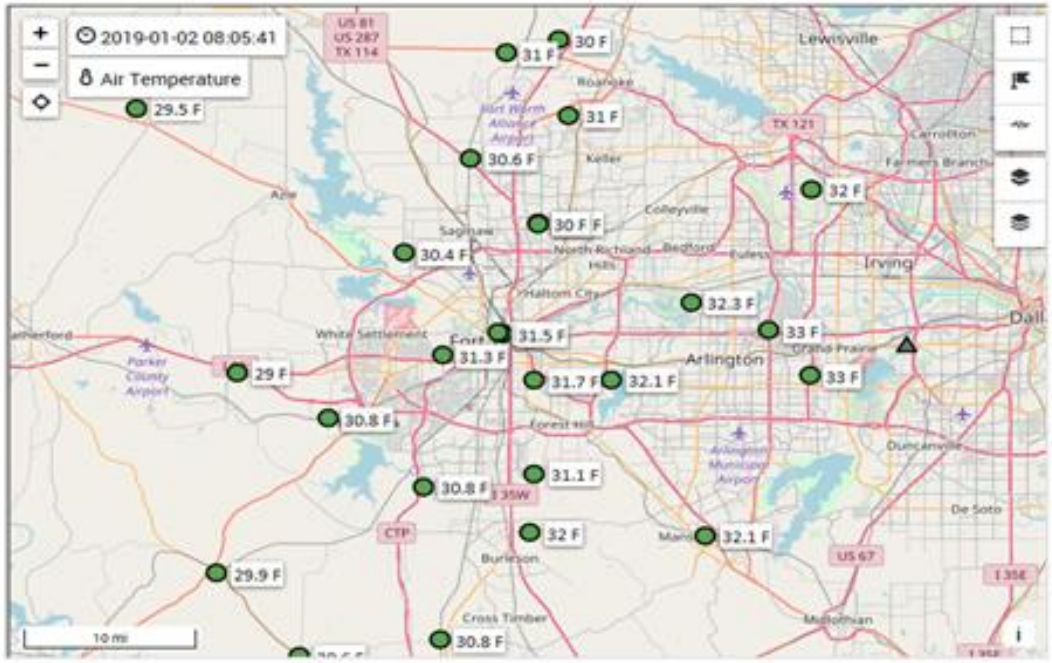


Figure 12. Sample lead-up weather warnings issued by the City's OEM showing use of Contrail and ALERT2 weather stations.

Appendix A

ALERT2 Weather Stations

Station: Bryce and Hulen (Central Arlington Heights), City of Fort Worth; **Station ID:** 43710.
Description: This weather station is located in the Central Arlington Heights detention basin at the intersection of Bryce and Hulen Streets. A pressure transducer and float switch (inset picture) located at the outfall of the culvert measure the water level in the detention basin.
Latitude: 32.739373 dd; **Longitude:** -97.38734 dd
Sensors: Vaisala WXT 536 multi-parameters, Keller PT.
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz; Ritron radio

Station: CASA site (Boat Club Road), City of Fort Worth; **Station ID:** 43711
Description: Station is located on Water Dept property off Boat Club Road. The CASA radar is located is located in the background.
Latitude: 32.838737dd; **Longitude:** -97.425971dd
Sensors: Vaisala WXT 536 multi-parameters.
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz; Ritron radio

Station: Cresson station, City of Cresson; **Station ID:** 43712.
Description: Station is located within the groundwater pump station perimeter fence and near intersection of US Hwy 377 with Tx 171.
Latitude: 32.52756 dd; **Longitude:** -97.61184 dd
Sensors: Vaisala WXT 536 multi-parameters; YSI tipping bucket H-3401-00-01.
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz; Ritron radio

Figure Station: Everman Parkway, City of Fort Worth; **Station ID:** 43713
Description: The station is located on the Everman Parkway median between Christopher and Michael Drive.
Latitude: 32.624164dd; **Longitude:** -97.296482dd
Sensors: Vaisala WXT 536 multi-parameters
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz, Ritron radio

Station: Fire Station 1, Near Downtown Fort Worth; **Station ID:** 43714
Description: Station is located as Weatherford and Belknap Street converge in downtown
Latitude: 32.759735 dd; **Longitude:** -97.328435 dd
Sensors: Vaisala WXT 536 multi-parameters; YSI tipping bucket H-3401-00-01.
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz; Ritron radio

Station: Fire Station 11, City of Fort Worth; **Station ID:** 43715.
Description: Station is located off TX114 in Fire Station 11 property on Texan Drive, near Northwest High School.
Latitude: 33.032031dd; **Longitude:** -97.324364dd
Sensors: Vaisala WXT 536 multi-parameters.
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz; Ritron radio

Station: Fire Station 31, City of Fort Worth; **Station ID:** 43716.
Description: Station is located within the fenced property of Fire Station #31 off Longstraw Dr.
Latitude: 32.867025dd; **Longitude:** -97.292836dd
Sensors: Vaisala WXT 536 multi-parameters.
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz; Ritron radio

Station: Fire Station 38, City of Fort Worth; **Station ID:** 43717.
Description: Station is located within the fenced property of Fire Station #38 off Park Vista Blvd.
Latitude: 32.971437dd; **Longitude:** -97.261935dd
Sensors: Vaisala WXT 536 multi-parameters; YSI tipping bucket H-3401-00-01.
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz; Ritron radio

Station: Godley, City of Godley; **Station ID:** 43718.
Description: This station is located on the Fire Department property adjacent to the groundwater pump fence line.
Latitude: 32.462898 dd; **Longitude:** -97.390025 dd
Sensors: Vaisala WXT 536 multi-parameters
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz; Ritron radio

Station: Joshua, City of Joshua; **Station ID:** 43719.
Description: This station is located close to City of Joshua Park Department property near the rail road line.
Latitude: 32.462898 dd; **Longitude:** -97.390025 dd
Sensors: Vaisala WXT 536 multi-parameters
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz; Ritron radio

Station: Mansfield City Hall, City of Mansfield; **Station ID:** 43720.
Description: Station is located behind Mansfield City Hall and the R.R. line.
Latitude: 32.564157dd; **Longitude:** -97.125795dd
Sensors: Vaisala WXT 536 multi-parameters.
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz; Ritron radio

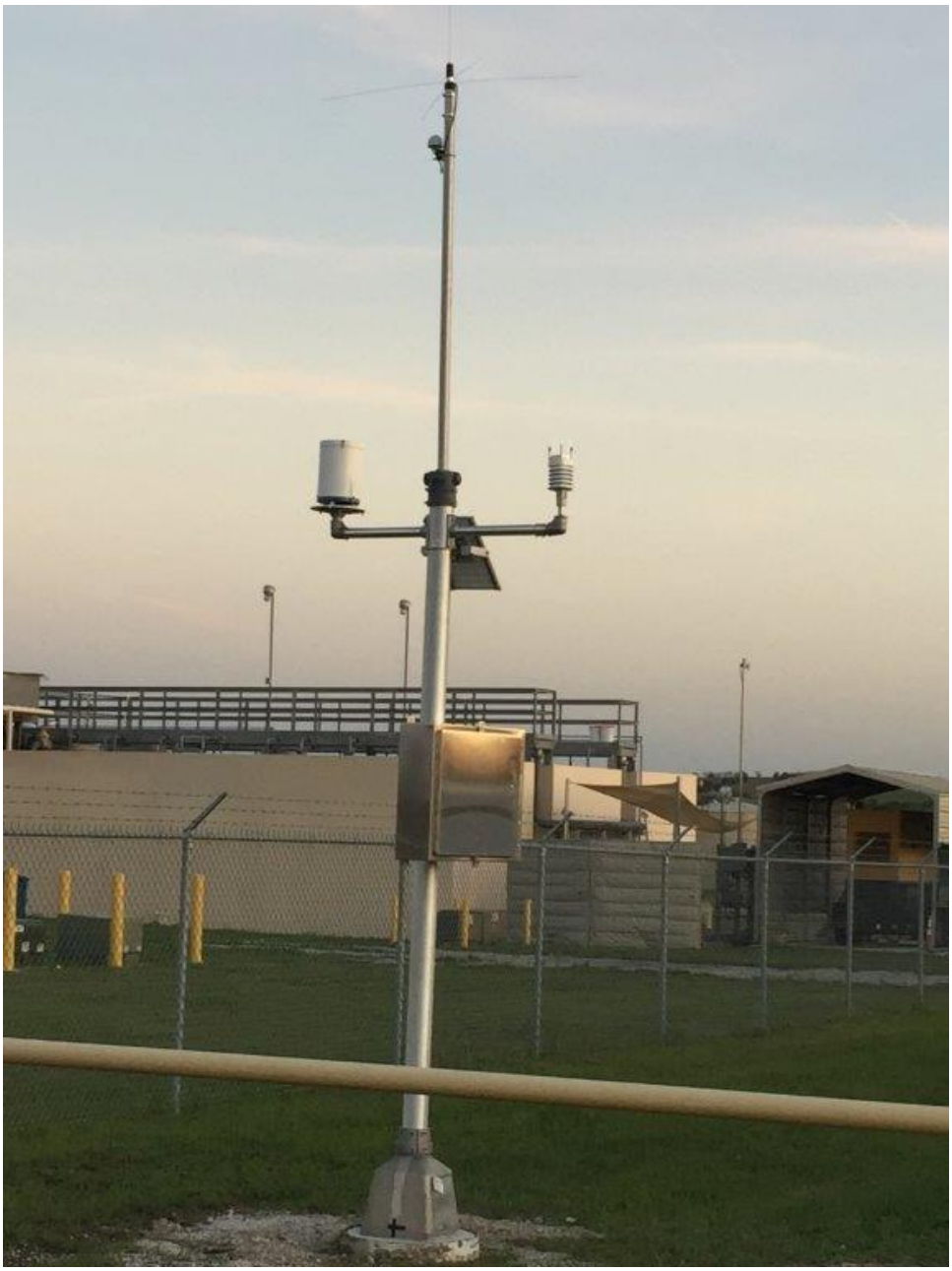
Station: North Service Center (NSC), City of Fort Worth; **Station ID:** 43721
Description: Station is located on the southeastern edge of the lay down area.
Latitude: 32.930408dd; **Longitude:** -97.359342dd
Sensors: Vaisala WXT 536 multi-parameters.
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz; Ritron radio

Station: Ventana Pump Station, City of Fort Worth; **Station ID:** 43722
Description: This weather station is located within the Ventana pump station near R.R crossing and FM2871 intersection.
Latitude: 32.677957 dd; **Longitude:** -97.501309 dd
Sensors: Vaisala WXT 536 multi-parameters
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz; Ritron radio

Station: Village Creek Dewatering (off Greenbelt Road), City of Fort Worth; **Station ID:** 43723
Description: Station located near the dewatering main office.
Latitude: 32.79084dd; **Longitude:** -97.140571dd
Sensors: Vaisala WXT 536 multi-parameters, YSI H-3401-00-01 tipping bucket
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz; Ritron radio

Station: Walsh Range Pump Station, City of Fort Worth; **Station ID:** 43724
Description: This weather station is located within the Walsh Ranch pump station near Aledo off I-20.
Latitude: 32.722212 dd; **Longitude:** -97.59141 dd
Sensors: Vaisala WXT 536 multi-parameters, YSI H-3401-00-01 tipping bucket
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz; Ritron radio.

Station: Annetta Station, City of Annetta; **Station ID:** 43725
Description: This weather station is located on the NW corner of the park adjacent to a retention pond.
Latitude: 32.672255 dd; **Longitude:** -97.648791 dd
Sensors: Vaisala WXT 536 multi-parameters, YSI H-3401-00-1 Tipping bucket
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz, Ritron radio



Station: Chisholm Trail Park, City of Fort Worth; **Station ID:** 43726
Description: This weather station is located on the NW corner of the park adjacent to a retention pond.
Latitude: 32.611551 dd; **Longitude:** -97.405753 dd
Sensors: Vaisala WXT 536 multi-parameters, YSI H-3401-00-1 Tipping bucket
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz, Ritron radio

Station: Eugene McCray Park (Quail & Elizabeth Rd.), City of Fort Worth; **Station ID:** 43727
Description: This weather station is located in the Eugene McCray Park on the west shore of Lake Arlington near the intersection of Quail and Elizabeth Roads.
Latitude: 32.715233 dd; **Longitude:** -97.219426 dd
Sensors: Vaisala WXT 536 multi-parameters
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz, Ritron radio

Station: Cobb Park, City of Fort Worth; **Station ID:** 43728
Description: This weather station is located in Cobb Park across from the play scape area off of E. Berry Street that runs through park.
Latitude: 32.714692 dd; **Longitude:** -97.295981 dd
Sensors: Vaisala WXT 536 multi-parameters
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz; Ritron radio

Station: Alvarado, City of Alvarado; **Station ID:** 43729.
Description: This weather station is located next to the bottom of the access ramp off Shirley Drive (in Stonegate Neighborhood) adjacent to the City park/NRCS pond.
Latitude: 32.739373 dd; **Longitude:** -97.38734 dd
Sensors: Vaisala WXT 536 multi-parameters, YSI Tipping Bucket H 3401-00-01
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz; Ritron radio

Station: Springtown High School, “Pojo” station, City of Springtown; **Station ID:** 43730.
Description: This weather station is located adjacent to the parking lot outside the baseball field of the Springtown High School, and off Pojo Road.
Latitude: 32.978787 dd; **Longitude:** -97.691604 dd
Sensors: Vaisala WXT 536 multi-parameters, YSI H-3401-00-01 tipping bucket
Data logger: Campbell Scientific CR-300
Telemetry: Blue Water Design A2M-IND ALERT2 at 170.325 Mhz; Ritron radio

Appendix B

Flood Response Plan

Flood Response Plan

City of Fort Worth, Texas

Version 1.0

1/30/2019

Approval & Implementation

1/30/2019

The Flood Response Plan for the City of Fort Worth is hereby approved for implementation. This plan shall be reviewed and updated annually by the Transportation & Public Works Department/Stormwater Management Division and the Fort Worth Office of Emergency Management in coordination with other affected City departments/divisions and external partners as necessary.

This plan uses resources currently available to the City and does not obligate political jurisdictions outside the City limits.

_____

Greg Simmons
Assistant Director
Stormwater Division
Department of Transportation & Public Works

_____

Maribel Martinez-Mejia
Emergency Management Coordinator
Office of Emergency Management
Fire Department

RECORD OF CHANGES

CHANGE #	DATE ENTERED	ENTERED BY
1	2/27/2019	Ranjan S. Muttiah, TPW/ Stormwater. Update for Lake Benbrook.

TABLE OF CONTENTS

ATTACHMENTS

I. Authority

This Flood Response Plan (FRP) was developed pursuant to requirements of the Flood Protection Grant received by the City of Fort Worth from the Texas Water Development Board (TWDB) through TWDB Grant No. 1600012041. The City has authority through Federal, State, and Local laws to perform flood emergency planning activities. These include:

A. Federal

1. Robert T. Stafford Disaster Relief and Emergency Assistance Act
2. Emergency Planning and Community Right-To-Know Act
3. National Incident Management System
4. National Response Plan

B. State

1. Government Code, Chapter 418, Emergency Management
2. Government Code, Chapter 433, State of Emergency
3. Government Code, Chapter 791, Inter-Local Cooperation Contracts
4. Health and Safety Code, Chapter 778, Emergency Management Assistance Compact
5. Administrative Code, Title 37, Part 1, Chapter 7, Division of Emergency Management

C. Local

1. City Ordinance 11592, dated June 6, 1994, Emergency Management Ordinance
2. City Ordinance 16781-1-2006, dated January 19, 2016, Establishment of Stormwater Utility
3. Mutual-aid and inter-local agreements shown as Attachment 6 in the Basic Plan of the City's Emergency Management Plan
4. City Ordinance 10056, Floodplain Ordinance

II. Explanation of Terms

A. Definitions

Emergency Operations Center (EOC): The physical location at which the coordination of information and resources to support incident management (on-scene operations) activities normally takes place. An EOC may be a temporary facility or may be located in a more central or permanently established facility, perhaps at a higher level of organization within a jurisdiction. EOCs may be organized by major functional disciplines (e.g., fire, law enforcement, medical services), by jurisdiction (e.g., Federal, State, regional, tribal, city, county), or by some combination thereof. The EOC is managed through protocols for communicating with the incident site, obtaining resources, and applying appropriate resources to address the incident.

Flash Flood: A damaging and life-threatening, rapid rise of water into a normally dry area beginning within minutes to multiple hours of the causative event (e.g., intense rainfall, dam failure, ice jam). Ongoing flooding can have rapid intensification of severity of impacts in cases where excessive rainfall results in a rapid surge of rising flood waters. Flash flooding, such as dangerous small stream or urban flooding and dam or levee failures, requires immediate action to protect life and property. (Source: National Weather Service)

High Water Warning System (HWWS): A system of road side flashers that responds to road overtopping determined by water level sensors, and rain gauges maintained and operated by the City of Fort Worth's Stormwater Management Division, Transportation and Public Works.

National Incident Management System (NIMS): A flexible Incident Command approach applicable for any emergency across multiple jurisdictional levels and disciplines. The NIMS has a consistent national framework for preparing for, preventing, responding, and recovering to incidents. The main components of NIMS are: use of common terminology, "typing" of all resources by their capabilities, span of organizational control to no more than 7 levels, common understanding of the emergency situation, integrated communications, and accountability.

Preparedness: A continuous cycle of planning, organizing, training, equipping, exercising, evaluating, and taking corrective action in an effort to ensure effective coordination during incident response. Within the National Incident Management System, preparedness focuses on the following elements: planning; procedures and protocols; training and exercises; personnel qualification and certification; and equipment certification. Preparedness activities take place prior to storm events. Preparedness can also include outreach activities to informing the public about flood risks and prevention measures.

Response: The capabilities necessary to save lives, protect property and the environment, and meet basic human needs during and immediately after storm events. Since some storm events and associated flood threats can extend over multiple days, response may not be limited to a single day or duration of a single storm.

Recovery: The capabilities necessary to assist communities affected by an incident to return to pre-disaster conditions or as close to pre-disaster conditions as feasible.

B. Acronyms

CFW	City of Fort Worth
CIP	Capital Improvement Program
EAP	Emergency Action Plan
FEMA	Federal Emergency Management Agency
FMP	Floodplain Management Plan of the City of Fort Worth
FRP	Flood Response Plan
EOC	Emergency Operations Center
HWWS	High Water Warning System
NIMS	National Incident Management System
NWS	National Weather Service
OEM	Fort Worth Office of Emergency Management
TRWD	Tarrant Regional Water District
TWDB	Texas Water Development Board
TPW	Fort Worth Transportation and Public Works Department
USACE	U.S. Army Corps of Engineers

III. Purpose and Plan Organization

A. Purpose

The purpose of the City of Fort Worth (CFW) Flood Response Plan (FRP) is to identify flood threats to the City, describe flood preparedness efforts, and outline response to flood incidents. This plan compliments specific response procedures used by responding agencies. The Stormwater Division, Department of Transportation and Public Works (TPW) and the Fire Department Office of Emergency Management (OEM) have joint responsibility for this plan. This plan will be attached to the Local Mitigation Action Plan as required by the Texas Water Development Board in the Flood Protection Grant received by City of Fort Worth.

B. Plan Organization

This FRP plan is organized by flood hazard types which are: flash flooding, riverine and levee breach flooding, and flooding from dam breaches.

IV. Situation and Assumptions

A. Situation

1. Fort Worth is subject to flooding that may result in casualties and/or damage to property. The most frequent flood hazard in Fort Worth is flash flooding. Riverine flooding and dam/levee failure are possible but considered unlikely due to good maintenance practices. The City has experienced 17 fatalities since 1986 due to vehicles entering high water at low-water roadway crossings.

2. One-Hundred year Federal Emergency Management Agency (FEMA) designated floodplains cover almost 50 square miles or 14% of the City's 353 square mile land area. There are 5,693 buildings located in the 100-year floodplain. Repetitive Loss Analysis from the 2016 Floodplain Management Plan (FMP) shows that of the 44 repetitive flood loss properties in the City, 11 are located within the 100-year floodplain. Drainage complaints from 2009-2015 show that 18% of flood related complaints are located within the floodplain while the rest are located in areas outside the floodplain. This is indicative of the role played by undersized storm drains within the City.

B. Assumptions

1. City resources will be sufficient to respond to most flood incidents. When additional resources are required the City will follow processes outlined in departmental procedures and/or the Fort Worth Emergency Management Plan. No new budgetary allocations are required by the City as result of this FRP.

2. The City of Fort Worth will continue to have approval and funding through the Mayor and City Council to conduct periodic planning, training, exercises, and purchase equipment to improve readiness and deal with flood emergencies.

3. This plan is based upon the concept that flood emergency functions performed by the TPW department parallel some of the normal day-to-day functions. To the extent possible, the same personnel and material resources used for day-to-day activities are employed during flood emergencies. Some routine functions that do not contribute directly to emergency response may be suspended for the duration of an emergency. The personnel, equipment, and supplies that would normally be required for those functions will be re-directed to accomplish the emergency tasks. When City resources are overwhelmed during a major disaster, outside assistance will be available in accordance with local, state and federal emergency procedures. Outside assistance may also be provided by voluntary groups and private organizations.

4. The City of Fort Worth Emergency Management Plan outlines emergency response organization and responsibilities based on an "all-hazards" approach.

5. There will be adequate lead time for the City Emergency Operations Center (EOC) to be activated for severe distress experienced by regional dams (Lake Benbrook, and Eagle Mountain-Lake Worth).

V. Mitigation and Recovery

A. Mitigation

The City has a proactive mitigation program that includes developing linear parks along flood-prone creeks, a capital improvement program (CIP) for storm water management, HWWS of road side flashers to warn drivers and emergency responders, development reviews to reduce downstream flooding, proactive flood plain management including enforcement of flood plain permitting, and creation of the Stormwater Management Utility. The Fort Worth section of the Tarrant County Multi-Jurisdictional Hazard Mitigation Action Plan has additional information.

B. Recovery

Recovery procedures can be found in Annex J of the Fort Worth Emergency Management Plan.

VI. Flood Hazards, Preparedness, and Response

A. Flash Flooding

Overview

1. Flash flooding can occur almost anywhere in the City.

2. Creeks that are prone to flooding in Fort Worth include Bear Creek, Little Bear Creek, Big Fossil Creek, Marine Creek, Mary's Creek, Calloway Branch, Farmers Branch, Lebow Channel/Schwartz Creek, and Sycamore Creek.

3. Flood hazards for specific creeks vary considerably. The FEMA Flood Insurance Study (FIS) and the Open Channel studies conducted by the City may be consulted for specific information. A listing of City studies can be found in the FMP.

Flash Flood Preparedness

1. TPW/Stormwater has developed an Emergency Action Plan (EAP) entitled "Emergency Response Plan, Streets and Stormwater Operations" for response to flash flood incidents.

2. OEM, Fire, Police, and on-call TPW/Stormwater Field Operations staff monitor weather conditions.

3. TPW/Stormwater Field Operations and OEM monitor alarms received via text and email from the HWWS.

4. TPW/Stormwater Field Operations places barricades at overtopping HWWS crossings sites, as well as other known low-water crossings when flooding is likely.

5. Calls from citizens regarding storm water system maintenance follow-up are routed to the TPW Call Center and tracked via Accela service work orders.

6. TPW/Stormwater Field Operations personnel ensure availability of equipment for flood emergencies such as vacuum trucks ("vactor" trucks) and barricades.

7. Prior to flood incidents, TPW/Stormwater Field Operations inspects and removes debris from storm drains in drainage areas prone to flooding.

8. Stormwater Field Operations crews stabilize known erosive areas, replace missing manhole covers, and repair potholes as much as practicable prior to flood incidents.

9. To keep residents aware of flooding and threats from severe storms, educational material is sent to residents every 3 months as inserts in the water bills.

Flash Flood Response

1. Flood response during emergencies may follow a recognizable build-up period during which local readiness actions increase with increasing flood threat. The readiness level is based upon the severity of flooding and the number of teams deployed. Level 4 is the least severe, and Level 1 is highest level during which the EOC is activated. Typically, field crews run pre-determined routes that have known flooding problems before and during flood incidents to determine severity of flooding.

2. OEM, Fire, and Police Departments will follow their departmental procedures for emergency response.

3. The Streets and Stormwater Field Operations section of TPW is responsible for TPW's initial monitoring and response to flooding emergencies. Crews in the section are activated on a rotating 24/7 schedule.

4. The Field Operations Superintendent escalates departmental resource requests for the most severe flooding in coordination with the TPW/Business Head and the TPW/Stormwater Assistant Director.

5. The OEM is kept updated with field conditions and may activate the EOC depending on flood severity.

6. The TPW Operations Command Center is activated during the most severe storm events (at Level 1). The TPW Business Support Head is responsible for directing this Center.

7. The TPW/Stormwater Assistant Director or designee reports to the EOC when activated.

8. Warning can be provided to the public by EOC via the media and/or emergency alert radios, City Outdoor Warning System sirens, and route alerting.

9. Additional information can be provided by use of NIXLE messaging and the media.

B. Riverine Flooding/Levee Breach

Overview

1. The Fort Worth levee system (floodway) is a Federal flood control project designed and constructed by the US Army Corp of Engineers (USACE) with Tarrant Regional Water District (TRWD) serving as the local sponsor responsible for on-going maintenance and operation. The floodway system is regularly inspected by USACE to ensure the project meets the original design level of protection.

2. Levees in the City are: Clear Fork Levee Loop, Water Works Levee, Overton Levee, North Main Levee, West Fork Levee Loop, Crestwood Levee, White Settlement Levee, Carswell Levee, Sump 6 Levee, and Brookside Levee.

Riverine Flood\Levee Breach Preparedness

1. The TRWD Emergency Action Plan (EAP) is called "Emergency Action Plan, Fort Worth Floodway System, Tarrant County, Texas."

2. TRWD provides training, coordination, and technical support to the City in preparation to flooding.

3. Updates to the TRWD EAPs are shared with the City.

4. The City participates in table top exercises hosted by the TRWD.

Riverine Flood\Levee Breach Response

1. There are 3 levels of emergencies for the levees. These are: Level 1 when water is forecast to touch the levees, Level 2 when forecast at the Clear Fork gauge is at 22 feet depth and the Upper White Settlement Bridge gauge is at 49 feet depth, and Level 3 when boils are observed or levee overtopping is forecast.

2. The TRWD Floodway Superintendent or designee is responsible for initiating the Riverine/levee emergencies. TRWD takes on responsibility thereafter to coordinate with relevant agencies and to inform the City.

3. The OEM will be notified by the TWRD Director of Operations if any emergency level is reached.

4. The TRWD liaison will locate in the City's EOC for Level 2 and 3 emergencies, or upon request.

5. Warning can be provided to the public by EAS via the media and/or emergency alert radios, City Outdoor Warning System sirens, and route alerting.

6. Additional information can be provided by use of NIXLE messaging and the media.

C. City Owned Dams

Overview

1. The City of Fort Worth owns the dams at the following lakes: Lake Como, Luther Lake, Lake Worth, Fosdic Lake, Willow Lake, Northside Drive Number 3, French Lake, Echo Lake, and Greenbriar Lake.

2. Ownership for Echo Lake dam (TX04558) has been transferred from Tarrant County to the City. The EAP was developed by Tarrant County.

3. There are a number of privately-owned dams in the City including White Lake Dam, Bal Lake Dam, Seventeen Lakes with multiple dams, and Ridglea Country Club Estates Dam. Copies of EAPs submitted to the City are stored by Stormwater Management and OEM.

City Dam Preparedness

1. Emergency Action Plans (EAPs) for City Dams are included in a document entitled "Emergency Action Plans: Lake Como Dam (TX00777), Fosdic Lake Dam (TX04416), French Lake Dam (TX07106), Lake Greenbriar Dam (TX09625), Luther Lake Dam (TX00778), White Lake Dam (TX00783), Willow Creek Lake Dam (TX04796)." Please note that White Lake Dam is now privately owned.

2. While there has never been a recorded dam failure in Fort Worth, the TPW conducts dam safety assessments as required by relevant regulations.

3. The City inspects dams for issues such as seepage failure, embankment of foundation sliding, structural failure, or overtopping failure. The City Dams EAP should be consulted for more details for recognition of these failure modes.

4. Dam responsibilities for Lake Como, Luther Lake, and Willow Lake belong to the TPW Department.

5. Dam responsibilities for Greenbriar Lake Dam, Fosdic Lake Dam, and French Lake Dam belong to the Park and Recreation Department.

City Dam Response

1. The Emergency Management Coordinator has authority to implement and carry out all procedures in the City Dam EAPs.

2. OEM, Police Department, and Fire Department are responsible for performing notification and evacuation of residents.

3. The notification chart in each EAP should be used to notify the proper personnel and residents in the affected areas.

4. Warning can be provided to the public by EAS via the media and/or emergency alert radios, City Outdoor Warning System sirens, and route alerting.

5. Additional information can be provided by use of NIXLE messaging and the media.

D. Regional Dams (Lake Benbrook, Eagle Mountain-Lake Worth, Marine and Cement Creek)

Overview

1. Regional dams of concern for Fort Worth are Eagle Mountain Reservoir and Lake Worth on the West Fork of the Trinity River, and Lake Benbrook located on the Clear Fork of the Trinity River. Lake Worth is a pass-through reservoir and considered as one unit with Eagle Mountain (Eagle Mountain-Lake Worth).
2. Lake Worth is City owned. The lake is formed by a rolled earth-fill dam 3,200 ft. long, with a 700-foot long ungated ogee-shaped concrete spillway near the center of the dam.
3. Eagle Mountain Reservoir is owned and operated by the TRWD.

4. Eagle Mountain Lake is a water supply reservoir on the West Fork Trinity River. The Eagle Mountain Dam is formed by two sections of rolled earth-fill separated by natural high ground, and total length of the dam is 4,800 feet. The original service spillway is located on the east end of the west dam section and consists of four 25-foot bays with a crest elevation of 649.1 feet MSL (three of which are equipped with vertical lift gates). The side-delivery spillway is located approximately 400 feet northeast of the original spillway and includes six 11.25-foot by 22-foot tall gates with a crest elevation of 636.65 feet MSL that discharge to a 25-foot box conduit. The emergency spillway is located in the natural ground between the two earth fill dam sections and consists of a 1,300-foot fuse plug that activates at elevation 676 feet MSL with a crest elevation of 670 feet MSL.
5. Lake Benbrook is owned and operated by the US Army Corp of Engineers (USACE).
6. Lake Benbrook is located in southwest Fort Worth, 15 river miles upstream from the confluence of the Clear Fork and the West Fork of the Trinity River. The drainage area of the Lake is 325 mi^2. The lake was impounded in 1952.
7. The population at risk is 265,000 and property at risk is valued at $17.2 Billion.
8. The Lake Benbrook Dam consists of 3 main features: a compacted 3:1 side sloped homogeneous earth embankment 9,130 feet long, a 500-foot uncontrolled ogee shaped concrete gravity spillway with top width of 100 feet and crest elevation of 710.0 feet, and outlet works consisting of approach channel, reinforced concrete intake and control structure (6.5 x 13 foot Broome type gates), a service bridge, conduit, low-flow outlets, stilling basin, and outlet channel.
9. The top of the Lake Benbrook Dam is at elevation 747 feet, and the Probable Maximum Flood is also located near this elevation.
10. The Dam Safety Action Classification for Lake Benbrook is 2.
11. During flood events, debris may inhibit water flow through the Lake Benbrook emergency spillway resulting in road closures due to the danger of sudden debris release.
12. Marine Creek Lake is owned and maintained by TRWD. The dam is a 3,400 ft. earth-fill structure located in northwest Fort Worth on Marine Creek near Interstate Highway 820. The service spillway is morning glory style drop inlet structure with a diameter of 11 feet and crest elevation of 687 feet MSL. The emergency spillway is an 800-foot earth cut with an effective crest elevation of 715.2 feet MSL located approximately 500 feet from the east end of the dam.
13. Cement Creek Lake is owned and maintained by TRWD. The dam is a 2,250 ft. earth-fill structure located in northwest Fort Worth on Cement Creek south of Interstate Highway 820. The service spillway is morning glory style drop inlet structure with a diameter of 9.5 feet and crest elevation of 655 feet MSL. The emergency spillway is a 350-foot earth cut with an effective crest elevation of 695.5 feet MSL located at the western abutment of the dam.

Regional Dams Flood Preparedness

1. Regional lake EAPs are provided to the City's OEM by TRWD and USACE.

2. Lake Benbrook EAP is developed and maintained by the USACE and is called "Benbrook Lake (TX00003, CWIS 001350), Clear Fork of Trinity River, Texas, Embankment, and Outlet Work and Spillway, Emergency Action Plan."

3. The Eagle Mountain EAP is developed and maintained by TRWD and is called the "Eagle Mountain Lake Dam (TX00779) Emergency Action Plan."

4. The Lake Worth EAP is maintained by the City's Water Department. The EAP is titled, "Emergency Action Plan, Lake Worth Dam (TX00785)." Breach analysis in the Lake Worth EAP covers sunny day breach and flooding from a Probable Maximum Flood (PMF).

5. The Marine Creek Lake EAP is developed and maintained by TRWD and is called the "Marine Creek Dam (TX00784) Emergency Action Plan."

6. The Cement Creek Lake EAP is developed and maintained by TRWD and is called the "Cement Creek Dam (TX04794) Emergency Action Plan."

7. Lake Worth has a flood surcharge capacity of 24,000 acre-feet; flood easement at 606 feet, and top of the spillway is at 594 feet MSL. The conservation storage is 33,495 acre-feet.

8. The City participates in Lake Benbrook and Eagle Mountain-Lake Worth regional dam exercises.

Lake Benbrook Flood Response

1. The Lake Benbrook EAP lists roles and responsibilities for USACE ranging from the Commander to the Operations Project Manager. The responsibility for initiating notifications around the Lake property area belongs to the Lake Manager.

2. The USACE activation stages increase from "WATCH", "ALERT," "WARNING," "SPILLWAY WARNING" through to "EMERGENCY." These are defined as follows:

   WATCH: Flood pool level is between 694.0 and 699.0 feet
   ALERT: Flood pool level is between 699.0 and 705.0 feet
   WARNING: Flood pool level is between 705.0 and 710.0 feet
   SPILLWAY WARNING: Flood pool is greater than 710.0 feet
   EMERGENCY: Flood pool level is above spillway and exceeds 724 feet.

3. Distress messages from the USACE are issued to downstream emergency management offices and the public using the National Weather Service (NWS) Emergency Alert System (EAS) and the media as the situation warrants.

4. The USACE District Commander or Chief of Emergency Management Operations can activate the USACE EOC.

5. The USACE uses a "Battle Rhythm" to include: coordination and control of deployment, data collection, and mobilization of crisis teams, daily briefings, and stakeholder briefings.

6. Downstream notification for City of Fort Worth is made to OEM and Stormwater Management.

7. Warning can be provided to the public by EAS via the media and/or emergency alert radios, City Outdoor Warning System sirens, and route alerting.

8. Additional information can be provided by use of NIXLE messaging and the media.

Eagle Mountain-Lake Worth Flood Response

1. The Reservoir Manager at Eagle Mountain Lake is responsible initiating and coordinating flood emergencies related to this lake.

2. OEM also monitors lake conditions in coordination with the Water Department and TRWD.

3. Eagle Mountain Lake release notification to the City is issued by the TRWD system monitor on duty or another representative of the TRWD Flood Team.

4. Emergency action procedures are initiated for Eagle Mountain Lake when a "watch" or more serious condition is reached. City will receive notification of this condition.

5. TRWD Engineering is mobilized for any of the emergency conditions.

6. The City's Concept of Operation at Lake Worth is to inform residents living in the flood easement (there are 7 residences that are located in the flood easement) during releases from Eagle Mountain. This activity is coordinated between the TRWD, Water Department, and OEM.

7. Warning can be provided to the public by EAS via the media and/or emergency alert radios, City Outdoor Warning System sirens, and route alerting.

8. Additional information can be provided by use of NIXLE messaging and the media.

VII. Administration and Support

This section of the plan covers general administrative requirements and support needs for flood emergencies by the City.

A. Agreements and Contracts

1. TPW maintains a viable stockpile of equipment and materials and assigns duties to responsible staff, as described in the TPW Streets & Stormwater Operations Emergency Response Plan. Senior management within the TPW and Fire/OEM departments agree to jointly coordinate and monitor resource expenditures and anticipated needs.

2. When a flood emergency requires external resources the EOC will coordinate resource requests using established procedures.

B. Reports

The OEM Duty Officer and the TPW Command Center closely monitor National Weather Service forecasts, Police and Fire response and TPW Call Center calls. With this information OEM will prepare and distribute timely briefing reports on actions underway to prepare for and respond to potential flood events and incidents.

C. Records

1. To return normal departmental operations to the pre-incident level, City departments are required to establish administrative controls and maintain records for flood emergency operations in accordance with fiscal and standard cost accounting procedures. Such records may include activity logs, expenditures of supplies and equipment, and staff hours.

2. City departments are required to protect vital records.

D. Post-incident and Exercise Review

OEM is responsible for organizing and conducting a critique after a flood emergency or exercise.

VIII. Plan Development and Maintenance

This section establishes the policies and procedures for the review and update of the FRP.

1. The Director of the TPW department or designee and the Fire/OEM Emergency Management Coordinator or designee are responsible for reviewing and updating the plan annually.

2. Plan updates will address deficiencies identified from flood emergencies.

Attachment 1: Agency Contacts by Flood Threat

NOTE: EAPs should be consulted for a full list of contacts.

Flood Threat/Purpose	Department	Office Phone	24/7/365 Contact
Any flood emergency	CFW Police CFW Police Non-Emergency		9-1-1 817-392-4222
Emergency Management	CFW Office of Emergency Management	817-392-6170	817-392-8866
Lake Worth Dam	CFW Water Department	817-392-6818	817-269-7256
Flash flooding	CFW, TPW/Stormwater, Asst. Director	817-392-7862	817-319-1259
Flash flooding	CFW, TPW/Stormwater, Field Ops, Superintendent	817-392-5196	817-944-3649
Lake Benbrook Dam	USACE Deputy Chief of Emergency Management	817-886-1444	817-886-1501
Eagle Mountain Lake, Cement and Marine Lake dams, and levees	TRWD Flood Center		817-720-4296

Attachment 2: List of References

1. City of Fort Worth Emergency Management Plan. City of Fort Worth, Office Emergency Management.

2. Local Mitigation Action Plan, Tarrant County, Texas, June 2015. Available from the OEM website: fortworthtexas.gov/emo.

3. City of Fort Worth Floodplain Management Plan, September 2015. Available from the Stormwater Management Website: fortworthtexas.gov/stormwater.

4. Emergency Response Plan, Streets & Stormwater Operations, Transportation & Public Works, Fort Worth, April 2017, Field Operations Sections, Stormwater Management Division, City of Fort Worth.

5. Emergency Action Plan, Fort Worth Floodway System, Tarrant County, Texas, November 17, 2015, TRWD.

6. Emergency Action Plan: Lake Como Dam (TX00777), Fosdic Lake (TX04416), French Lake Dam (TX07106), Lake Greenbriar Dam (TX09625), Luther Lake Dam (TX00778), White Lake Dam (TX00783), Willow Creek Lake Dam (TX04796). January, 2012, Stormwater Management Division, TPW.

7. Eagle Mountain Lake Dam (TX00779), Emergency Action Plan, March, 2012. Engineering Division/Dam Safety Section, Tarrant Regional Water District (TRWD).

8. Emergency Action Plan, Lake Worth Dam (TX00785), July, 2016, City of Fort Worth Water Department.

9. Benbrook Lake (TX00003, CWIS 001350), Clear Fork of the Trinity River, Texas, Emergency Action Plan, August, 2017. Available from the USACE, Fort Worth District, Southwestern Division.

10. Marine Creek Dam (TX00784), Emergency Action Plan, March, 2012. Engineering Division/Dam Safety Section, Tarrant Regional Water District (TRWD).

11. Cement Creek Lake Dam (TX04794), Emergency Action Plan, March, 2012. Engineering Division/Dam Safety Section, Tarrant Regional Water District (TRWD).

Attachment 3: Planning Meeting Documentation

Planning Meetings	Date	Description
1st TWDB grant public meeting	March 23, 2017	TWDB staff, City of Fort Worth staff, partner agencies, residents
City of Fort Worth Internal Stakeholder Meeting	May 31, 2017	TPW and OEM staff
2nd TWDB grant public meeting	Nov 1, 2017	TWDB staff, partner agencies, City of Fort Worth staff, residents
Meeting with TRWD	Nov 20, 2017	Meeting to discuss TRWD EAP for Eagle Mountain
Edits to Conceptual FRP	2/9/2018	Internal CFW meeting between SWM and OEM
Lake Benbrook EAP Exercise	2/21/2018	Flooding scenarios exercised for Lake Benbrook.
OEM severe weather outlook for May-June	3/21/2018	Severe weather seminar hosted by OEM

Attachment 4: Table Top Exercises

Exercise Date	Participating Entities	Description
7/24/2018	CFW-OEM,CFW-Stormwater/TPW, CFW-Parks Dept, CFW-Public Information Office, CFW-TPW, CFW-Marshall, CFW-Police Dept, TRWD	Flood response plan review and exercise
2/20/2019	USACE, impacted communities, regional water agencies	Lake Benbrook and Joe Pool Lake USACE table top exercise

APPENDIX C

City Response to TWDB Review Comments

ATTACHMENT 1

City of Fort Worth Flood Early Warning System
City of Fort Worth
Contract #1600012041
Texas Water Development Board Comments to Draft Report

REQUIRED CHANGES

General Draft Report Comments:

In general, the study follows standard methodologies and practice. Mitigation alternatives identified may be eligible for funding under the Texas Water Development Board's financial assistance programs. Application requirements and eligibility criteria are identified by Texas Water Development Board rules specified in Section 363 of the Texas Administrative Code (TAC). The report would be appropriate for use in support of an application to the Board for financing the proposed improvements. All additional information required by Board rules, 31 TAC 363.401-404, as well as necessary information to make legal findings as required by Texas Water Code chapter 17.771-776, would be required at the time of loan application.

Please conduct a final edit of the document for grammar, spelling, typographical errors, and inconsistent usage of acronyms, and abbreviations. Please spell out all acronyms, with the acronym in parentheses, the first time they are used. Please include a list of acronyms used in the report after the Table of Contents.

Specific Draft Report Comments:

1. **Page 1** – Please remove **"TWDB Flood Protection Grant No. 1600012041"**.
2. **Page 5, paragraph three** – You state that *"if a flasher doesn't respond, the Master repeatedly tries five times"*. After the fifth try, what happens if the flasher does not activate? Is a notification sent to City personnel that the flasher is malfunctioning?
3. **Page 9, Sub-Task 3.3** – How long to you anticipate the review of your Flood Response Plan by FEMA will take? Please also include in this sub-task a statement that the City will provide the TWDB with copies of the "APA" (Approved Pending Adoption) letter from Texas Division of Emergency Management, as well as provide the TWDB with a copy of the community's adoption of the Flood Response Plan.
4. **Page 10, Sub-Task 1.1** – What criteria were used in selecting the 10 crossings?
5. **Page 10, Sub-Task 1.1, paragraph two** – Your sentence *"While the main advantage to installing bubbler sensors is keeping the data logging equipment safe from flooding, this can be overcome by ensuring safety of equipment by elevating above the high flood stages (>100-year floods)."* This sentence seems contradictory. You discuss the main advantage to installing a bubbler-sensor, then

you discuss how that "can be overcome by ensuring the safety of equipment...". Is there a missing disadvantage that you meant to put into this sentence?

6. **Page 10, paragraph three** – Could you provide the date that the inadequate, undersized storm drains were installed?
7. **Page 10, Sub-Task 1.2** – Were any low water crossing sites installed? If not, please provide a statement indicating why none were installed.
8. **Appendix A** – Please provide the City that Station: #43710, #43711, #43712, #43713, #43715, #43716, #43717, #43718, #43720, #43721, #43722, #43723, #43726#43727, #43728, and #43730 is in.

Exhibits and Tables Comments:

None.

General Comment:

"Please conduct a final edit of the document for grammar, spelling, typographical errors, and inconsistent usage of acronyms, and abbreviations. Please spell out all acronyms, with the acronym in parentheses, the first they are used. Please include a list of acronyms used in the report after the Table of Contents"

City response: List of acronyms has been created, acronyms have been spelt out, and grammar and other errors have been checked.

Specific Draft Report Comments:

1. Page 1 – Please remove "TWDB Flood Protection Grant No. 1600012041."

   City response: This has been removed.

2. Page 5, paragraph three – You state that "if a flasher doesn't respond, the Master repeatedly tries five times." After the fifth try, what happens if the flasher doesn't activate? Is a notification sent to City personnel that the flasher is malfunctioning?

   City response: The information between the masters and remotes is also received via antenna by the decoder at the receive station at Burnett Plaza. The data from the decoder is sent to a server running the Contrail data collection software. We use the Contrail software interface to monitor if the flashers turned on/off during a storm. If communication was lost from the master to the flasher in the field, then the contrail software will show that the flasher never turned on.

3. Page 8, Sub-Task 3.3 – How long do you anticipate the review of your Flood Response Plan by the FEMA will take? Please also include in this sub-task a statement that the City will provide the TWDB with copies of the "APA" (Approved Pending Adoption) letter from the Texas Division of Emergency Management, as well as provide the TWDB with a copy of the community's adoption of the Flood Response Plan.

   City response (text added): As requested in the TWDB contract Article III, B, the Flood Response Plan was incorporated in the City's Hazard Mitigation Plan which was developed for Tarrant County by the North Central Texas Council of Governments (NCTCOG). The NCTCOG submitted the plan to the Texas Division of Emergency Management which reviews the plan before it goes to the FEMA. The APA is sent to the NCTCOG and the county (Tarrant County); the City of Fort Worth will not receive a separate APA letter. The current expectation is that the APA letter will be received next year at which time a copy will be sent to the TWDB.

4. Page 10, Sub-Task 1.1. What criteria were used in selecting the 10 crossings?

   City response (text added): The intent of this sub-task was to evaluate opportunities for supplementary gauging at 10 locations from among the highest risk prone low-water crossings that were instrumented with water level sensors.

5. Page 10, Sub-Task 1.1, paragraph two – Your sentence "While the main advantage to installing bubbler sensors is keeping the data logging equipment safe from flooding, this can be overcome by ensuring safety of equipment by elevating above the high flood stages (> 100-year floods)." This sentence seems contradictory. You discuss the main advantage to installing a bubbler-sensor, then you discuss how that "can be overcome by ensuring the safety of equipment …" Is there a missing disadvantage that you meant to put into this sentence?

City response (text added): The sentence has been reworded as follows,

Additional gauging was proposed in the grant application to supplement gauging with bubbler based water level sensors. While the main advantage to installing bubbler sensors over other sensors is keeping the data logging equipment safe from flooding, the disadvantage to data-logging equipment being washed off can be overcome by ensuring safety of equipment by elevating it above the high flood stages (>100-year floods).

6. Page 10, paragraph three – Could you provide the date that the inadequate, undersized storm drains were installed?

   City response (text added): During the 1910-20s.

7. Page 10, Sub-Task 1.2 – Were any low water crossing sites installed? If not, please provide a statement indicating why none were installed.

   City response (text added): During this grant, continuous water level measurement with a PT and float switch was tested at the Bryce-Hulen detention basin in the Central Arlington Heights (CAH) neighborhood to test flood measurement by two different sensors. The float switch provides a simple on/off trigger signal when the water level reaches a determined depth. The additional gauging with float switch was tested at the Bryce-Hulen detention basin only. Once tested, the combination (PT and float switch) gauging will be implemented by the City as separate effort.

8. Appendix A – Please provide the City that the stations (list of stations in Appendix) are located.

City response: Cities have been provided in the Appendix. Please note that the Annetta station was added subsequent to submission of the draft report and is now part of the ALERT2 network.