MARICOPA COUNTY
FLOOD CONTROL DISTRICT

PROGRAM REVIEW

Fiscal Year 2020

Flood Warning Program (FWP)

Flood Control District of Maricopa County 2801 West Durango Street, Phoenix, AZ 85009 maricopa.gov/weather

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Executive Summary

The following report is for the purpose of providing a past, present and future narrative of the Flood Control District of Maricopa County's (FCD) Flood Warning Program (FWP). This report provides an overview of the entire program in one document, which will assist new and current staff in understanding its purpose, components and funding. This report is intended for internal audiences such as FCD staff, members of the Flood Control Advisory Board (FCAB) and members of the Board of Directors (BOD).

FWP customers include other government agencies and the private sector. They are emergency and water supply managers, insurance companies, researchers, engineers, planners, private citizens and others. We collect and make available operational (near real-time) and historic data including rainfall, streamflow, structure impoundment and weather.

The FWP supports the County's mission of providing regional leadership and necessary public services, the FCD's mission of reducing risk from flooding so that property damage and loss of life is minimized and the FCD Engineering Division's mission of providing support to other FCD divisions and protecting citizens from flooding impacts.

The FWP began in 1980 in response to earlier flooding on major rivers. As time and funding allowed, major rivers and FCD flood control structures were instrumented, as were flood-prone roadway crossings and flood control structures owned by cities within FCD jurisdiction. Planning studies, emergency action plans, new projects, flood events and wildfires also justified the need for expansion of the gaging system.

Today the FWP generally is composed of these elements: Planning, Detection, Communication, Action, Maintenance and Exercises. Planning varies from the decision of what sensors to locate at an ALERT Station to a Flood Response Plan covering an entire city or watershed. Detection includes the ALERT gaging system plus information from other tools and agencies. The ALERT System has 409 transmitting stations which house 356 rain gages, 218 water-level sensors and 40 weather stations. Communication and Action covers the ***who, what and how*** of transmitting warnings to recipients who need and use them. Maintenance can refer to plans, ALERT stations, computers and software. Finally, exercises allow decision makers and responders to practice their roles during a simulated flood event.

FWP staff include a Manager, Senior Hydrologist, Meteorologist, Program Specialist, Water Instrument Technician Supervisor and four Water Instrument Technicians. The ALERT storage and communication hardware consists of three base station computers, one web server computer, several data receivers and antennas at FCD and Maricopa County Emergency Management Department (MCDEM) for redundancy. ALERT software consists of one commercial application developed for ALERT plus several freely-available Linux programs. Since 2006, the FWP has had an annual budget averaging $1.2 million, which for FY2020 represented 4.7% of the FCD operating budget. The lifecycle cost for an ALERT station that measures only rainfall is estimated to be $60,000 over a 50-year period; adding a water-level sensor increases this cost to approximately $77,000.

A comparison of the FWP with recent survey responses from similar flood warning programs in the western US suggests that:

- FWP ALERT gage density is considerably lower than comparable locales
- FWP maintenance staff cover more area and gages with similar numbers of maintenance personnel
- Equipment and ALERT station installation costs are competitive
- Flood response and emergency action plans are more frequently used by FWP

Special studies of the FWP include a Flood Warning Services Market Study in 1992, a Network Loading and Evaluation in 2008 and an internal audit in 2011. All three were supportive of the program and provided valuable advice and recommendations that contributed to improvements of the system.

The ALERT system sensors (rain, water-level and weather), as a whole, have maintained 99% system availability and have accurately provided data since these records were first compiled in 1997. Since January 2015, the rain sensors have operated at 99.52% availability, the water-level sensors at 99.29% availability and the weather sensors at 98.77% availability. This excellent operational efficiency is due to diligent management and maintenance efforts of the ALERT system staff.

Technology advancements are expected to allow ALERT components to become smaller, faster and less expensive. Gaging methods are also advancing and becoming more efficient. Most significantly, improvements are being made regarding estimates of rainfall intensity from weather RADAR, which could reduce the number of rain gages needed to provide appropriate flood warning.

Likely advancements will also include cloud data storage, artificial intelligence decision support and improved storm development and flood-area forecasting. ALERT has existed as a tool for Maricopa County decision makers for approximately 40 years – 40 years from now it is likely that there will be facets of the FWP that cannot be imagined today.

Introduction

This report provides a brief program history, a chronology of the changes to the program as the FWP progressed, a short overview of the participation and overall impact of outside agencies and a prognosis for the future of the program. Data were gathered from various FCD Branches, existing documents, other flood warning programs and customer/client feedback.

Program Mission and Relation to Governing Missions

Portions of each mission that are supported by the FWP are underlined in this section.

The mission of **Maricopa County** is to provide regional leadership and fiscally responsible, necessary public services so that residents can enjoy living in a healthy and safe community.

FCD's mission is to reduce risk from flooding so that property damage and loss of life are minimized, economic development is supported in a safe and responsible manner and stormwater is recognized as a resource for the long-term benefit of the community and environment.

The mission of the **FCD Engineering Division** is to provide support to District Divisions, develop water resources technology and projects and protect citizens from flooding impacts.

The **FWP** mission: We provide real-time and historic flood-related information to agencies and the public to protect lives, property and flood control structures. The FWP objectives are to:

1. Provide information and technical support to flood response agencies prior to and during flood emergencies.
2. Support local flood warning and environmental programs within our jurisdiction.
3. Maintain an accurate and accessible historical database.
4. Support public relations through education and programs.
5. Support research related to flooding and flood damage.
6. Develop accessible, value-added products from the databases we maintain.
7. Promote continuous education and training for staff and clients in support of our mission.

Customer Base and Needs

FWP customers include any person or agency that can benefit from the data collected and made available. The data itself can be classified as operational or historic. Operational data is available in near-real time and is generally used by emergency responders at the local, county, state and federal levels, as well as the general public. Operational data is used to determine the distribution and intensity of rainfall, the height and discharge of flow along watercourses, the height and volume of water stored by flood control structures and weather conditions at numerous points in and near the County. Historic data may be used by the same groups as operational data, but can also include users such as water supply managers, design engineers, forensic engineers, insurance companies, attorneys, researchers, climatologists and planners.

Program History

Flooding, along with its adverse effects, has been a part of Maricopa County's history. Following devastating storms in the early 20th century, coupled with rapid urbanization and a consistent risk of flooding, Arizona lawmakers addressed the need for regional flood control. Legislation was passed requiring the creation of flood control districts for each county. Established in 1959, Maricopa County's FCD spent its early years developing programs and providing staff to meet the needs of designing and constructing regional flood control structures that were identified in the initial 1963 Comprehensive Report (a countywide survey of flooding problems). However when storms struck the County, there was little to no information about how these structures were performing, hence the beginnings of an ALERT flood detection system. ALERT is an acronym for Automated Local Evaluation in Real Time and refers to a standard for hardware and software that measures and communicates rainfall, streamflow and weather data through a radio network to a base computer. An ALERT station is a unique transmitting structure that has one or more sensors connected and sending data.

Early Information Needs

Following are quotes from an article in the Phoenix Gazette dated March 21, 1978 entitled County Flood Chief Wants More Data:

> *The recent floods could spur creation of a major network of monitoring and warning devices, an issue county officials will discuss Wednesday. "Current rainfall, stream and reservoir data are inadequate," said Herb Donald, managing director of the Maricopa County Flood Control District. He wants to budget for 15 rain gauges for 1978-79, but said eventually the county may have as many as 150, placed every 100 square miles. "Later we will consider radio-controlled stream gauges that could give warnings of impending high waters", he said. "There are virtually no records of the rainfall since the first of this year affecting many of our structures and no records of the amount of runoff converted or retarded by these structures," County Hydrologist Les Bond said. Bond added "the county must consider the potential for liability for damages and the present inadequate rainfall data upon which we base our hydrology for flood control structures."*

Historic Growth Patterns

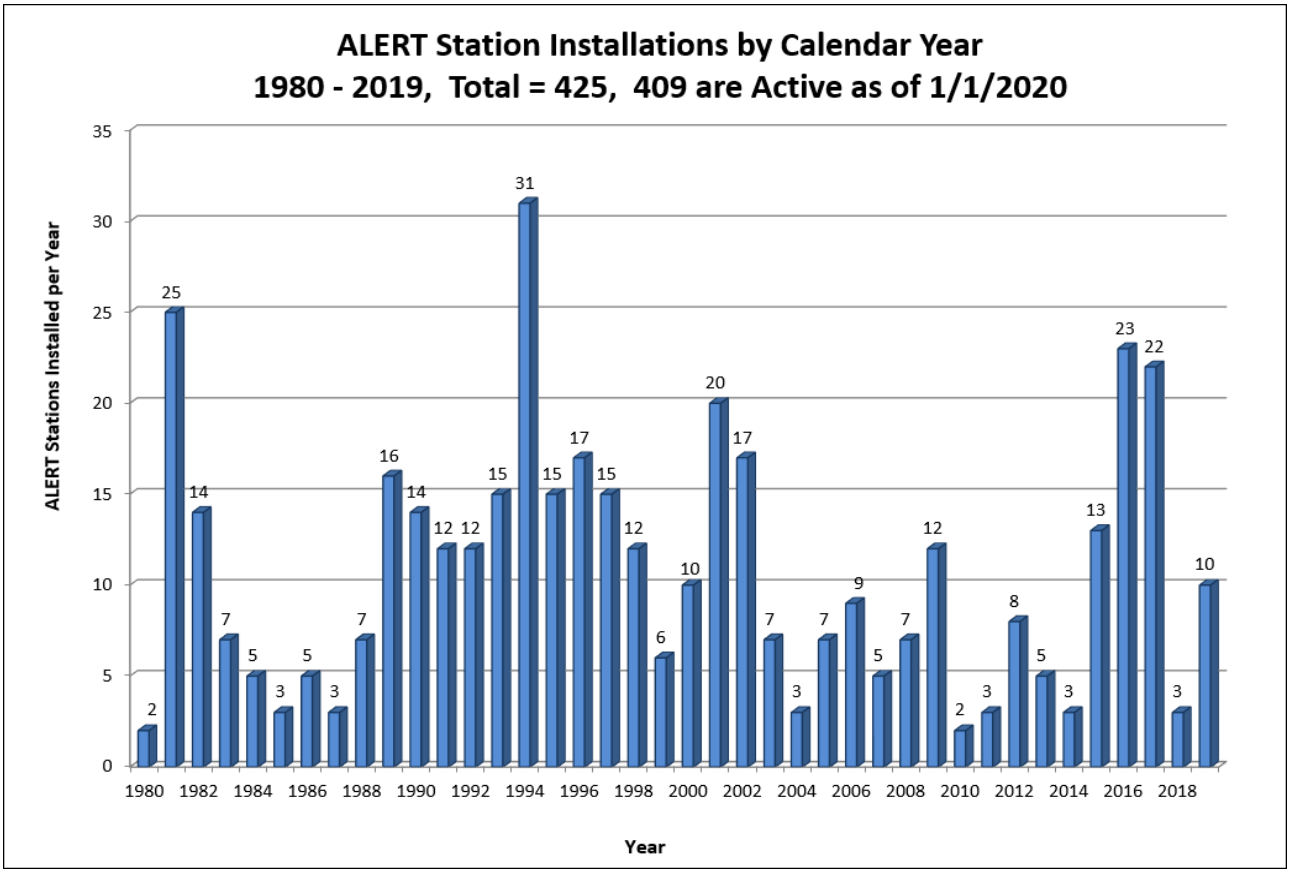

Figure 1 - ALERT Station Installations by Calendar Year

Major Rivers

In 1978 and again in the winter of 1980, Arizona experienced significant flooding on nearly every major river north of the Gila River, including the Salt, Verde, Agua Fria, Hassayampa Rivers as well as Centennial Wash. Gaging of the Verde and Salt Rivers was reasonably covered by existing telemetered stations owned by the US Geological Survey (USGS) and Salt River Project, so FCD began installing ALERT rain and stream stations on the watersheds of the Agua Fria River, Hassayampa River, Trilby Wash and Centennial Wash in September 1980. **Figure 1** shows this initial growth from 1980-1984, and **Figure 2** demonstrates that most of the ALERT stations north of Maricopa County have long records. Some of these stations were cost-shared with, and cooperated by, the USGS but were later assimilated by FCD. The District also established an Intergovernmental Agreement (IGA) with the National Weather Service (NWS) to operate the ALERT System. All information from the ALERT system has been shared with NWS to be used as input to public forecasts and warnings.

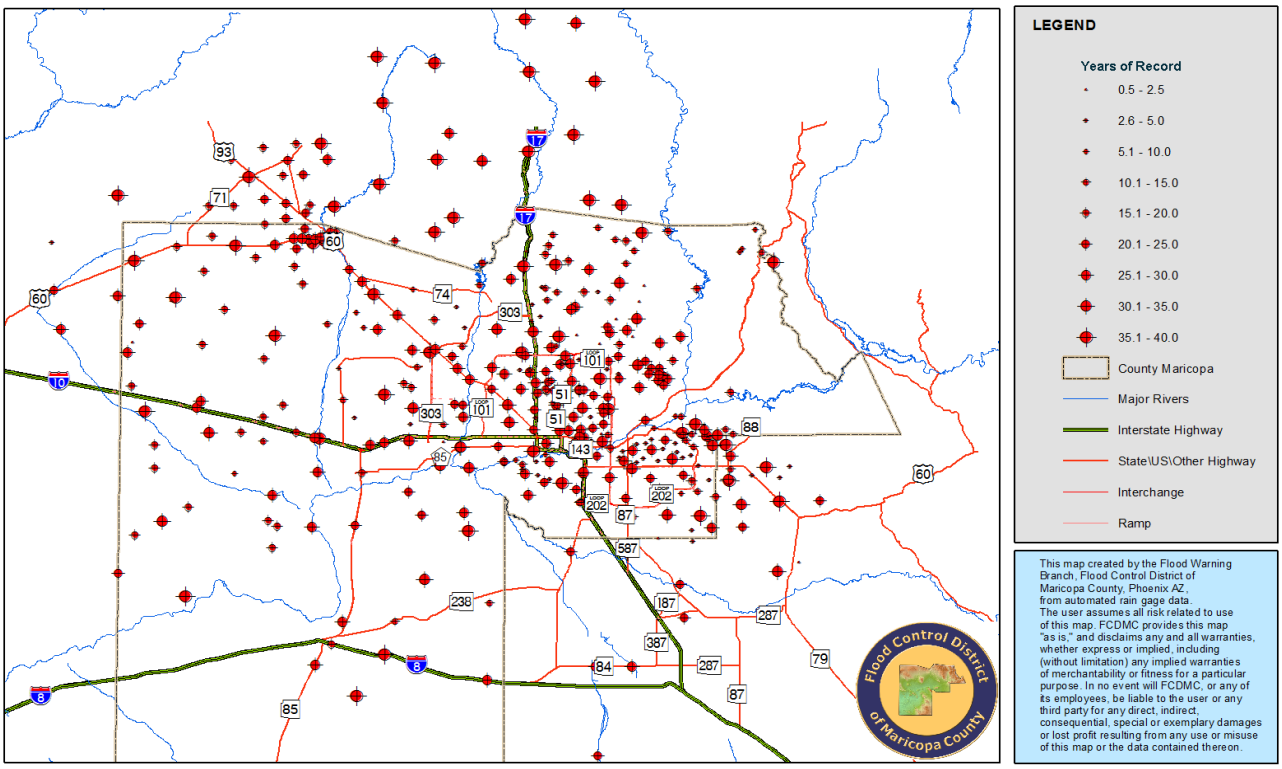

Figure 2 - Years of Record for ALERT Stations as of 12/1/2019

Flood Control District and Other Structures

Title 12, Chapter 15 of the Arizona Administrative Code (June 2000) mandates that owners of jurisdictional dams in Arizona must monitor them either in person, or by means of instrumentation, for safety reasons during times of impoundment and develop for each an Emergency Action Plan (EAP) that can be used by local officials in the event of a dam release or failure. The District owns and operates 22 earthen dams in and near the County, and each of these has an ALERT monitoring station that automatically transmits the water level data to the FCD office. The first FCD dam to be instrumented was Apache Junction FRS on December 16, 1981, and the last was Casandro Wash Dam on August 15, 1996. The ALERT stations are vital to the safe operation of the dams, and the EAPs are driven by information from the stations. FCD ALERT also monitors the impoundment levels behind dams owned by Phoenix, Scottsdale, Fountain Hills, the Arizona Department of Transportation, Magma Flood Control District, Central Arizona Project and the US Army Corps of Engineers. Intergovernmental agreements exist between these agencies and FCD to maintain the monitoring equipment and in some cases provide warnings according to established criteria.

MCDOT Flooded Roadway Response Program

In 1997, FCD began to participate with the Maricopa County Department of Transportation (MCDOT) in the Flooded Roadway Response Program. More than 50 cost-shared ALERT stations have been deployed throughout the County to warn of hazardous conditions at unbridged County-owned road crossings. Warnings are issued by the ALERT system operators to MCDOT barricade

crews who make necessary closures during times of flooding. The ALERT stations allow for specific route planning, saving valuable time and resources and add a measure of safety to the traveling public.

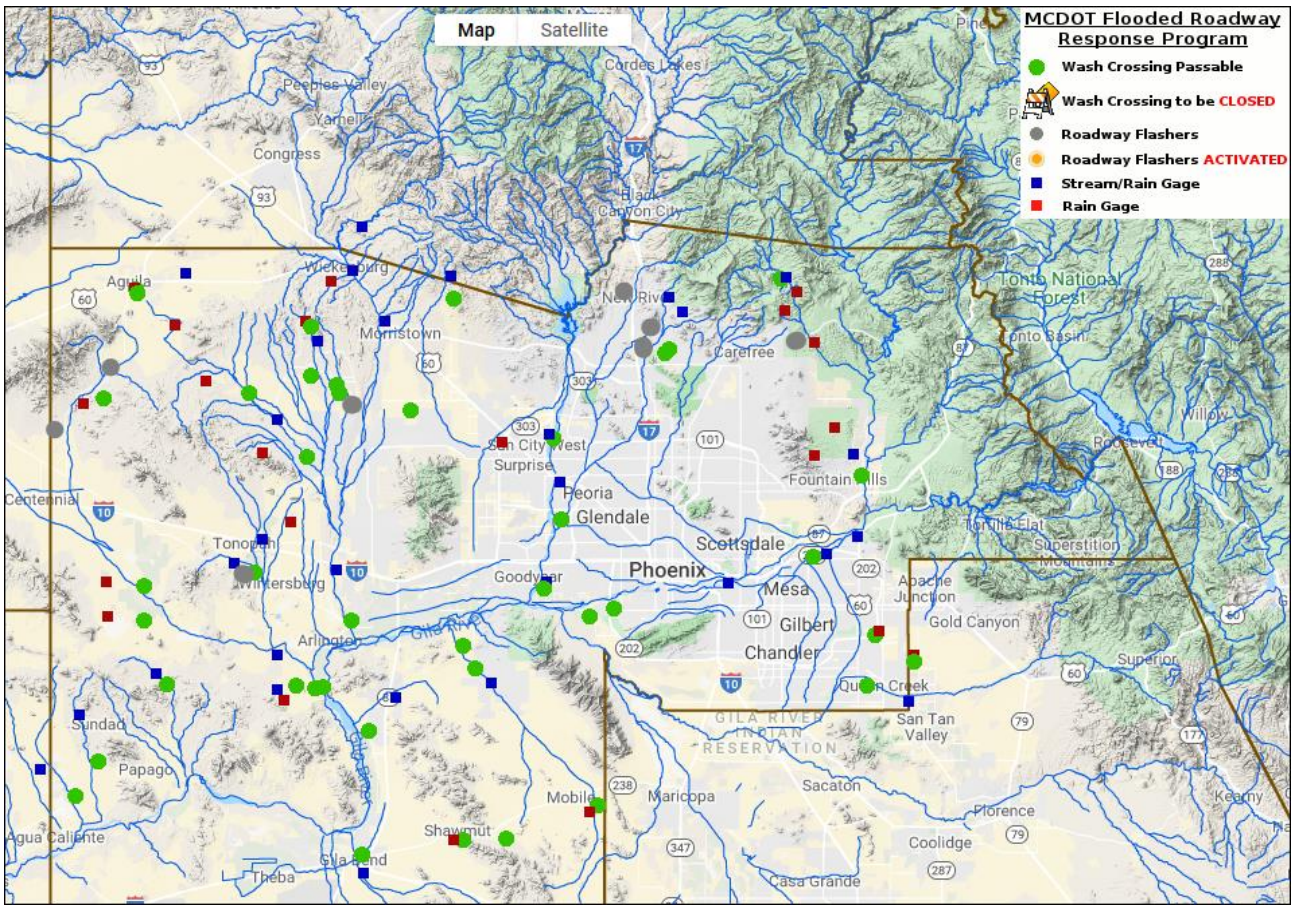

Figure 3 - MFRRP Data Display Map

In 2005, FCD and MCDOT partnered on an expansion of this program that featured flashing lights above and *Do Not Cross When Flooded* signs and flashing lights below. These warning devices alert motorists to hazardous floodwaters well before the crossing can be closed by a MCDOT barricade crew, and sometimes even before water reaches the crossing. These lights can be activated directly by a water sensor upstream of the crossing or by an ALERT system operator at the base station computer. To date, seven pairs of flashing warning signs are operational; however, expansion plans for growth of the program are on hold at this time.

Figure 4 - Flashing Warning Signs, Skunk Creek at Honda Bow Road

Flood Forecast Partnership with National Weather Service

The NSW's Colorado Basin River Forecast Center (CBRFC), located in Salt Lake City, provides streamflow forecasts for waterways throughout the Colorado Basin (including the Gila River and its tributaries). Prior to 2004, there were approximately 12 forecast points in Maricopa County. FCD provided modeling parameters for dozens of locations on streams and above dams in 2004. These points then could be added to CBRFC continuous prediction computer models. No new ALERT stations were added as a part of this effort, but today there are more than 50 forecast points where forecasts of peak discharge and time-of-peak are available to emergency planners, including those at FCD operations.

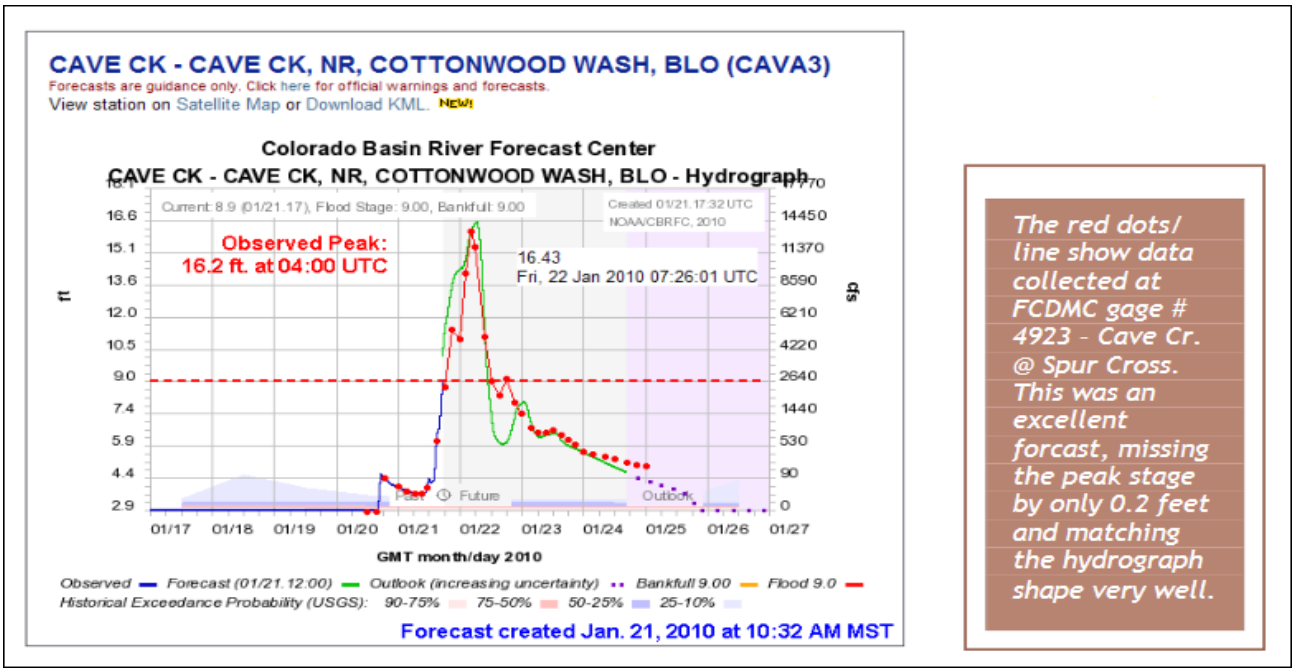

Figure 5 - Cave Creek forecast created 1/21/2010 by CBRFC vs. Actual Post-Event Data

Growth Driven by Planning and Projects

The need to study a particular watershed or monitor the performance of a new flood control structure has driven the installation of many ALERT stations. Cost-shared basins such as Crossroads Park Basin in Gilbert, University/62nd Street Basin in Mesa and Tatum Basin in Phoenix were instrumented shortly after their completion. Large regional projects such as the Arizona Canal Diversion Channel and the East Maricopa Floodway included installation of ALERT stations as part of construction. Stations such as Rawhide Wash and Reata Pass Wash were installed not only to provide warning for downstream floodplains and unbridged crossings but also to establish records for future projects.

Growth Driven by Flood Events

Large storms and floods often garner more attention from decision makers and the public than dry periods. These storms reveal problem areas requiring mitigation and corresponding funding. The

original storms and floods that spurred the creation of the ALERT system occurred in the years 1978-80. By the end of 1984, 53 stations had been installed (**Figure 1**). A series of winter storms in 1993 caused major flooding on waterways in central Arizona and in 1994 FCD installed 31 stations. The four major storms in the summer of 2014 prompted the County to install 58 additional stations over the next three years. Most of these were implemented with IGAs with Phoenix and Mesa as well as via a cost-share grant from the Arizona Department of Emergency and Military Affairs' Division of Emergency Management.

Growth Driven by Wildfires

Wildfires present a special challenge to flood forecasting in the Sonoran Desert. Fires superheat the soils, creating a hydrophobic condition which dramatically increases the amount of runoff generated by a burned watershed. This effect can last up to five years. In 2005, northern Maricopa County experienced the Cave Creek Complex fire that burned portions of the Cave Creek, New River and Camp Creek watersheds. FCD responded with the installation of five new ALERT stations to monitor the increased runoff. The Sunflower fire of 2012 burned much of the Sycamore Creek watershed north of State Route 87, prompting the installation of three monitoring stations. The Woodbury Fire of 2019 burned much of the Superstition Mountains south of State Route 88, and FCD responded with three additional stations.

It is interesting to note that as the ALERT system has grown, the percentage of stations installed at the request of, and supported by, outside agencies has risen steadily (**Figure 6**). This indicates trust and reliance in the ALERT system and the work of the FWP.

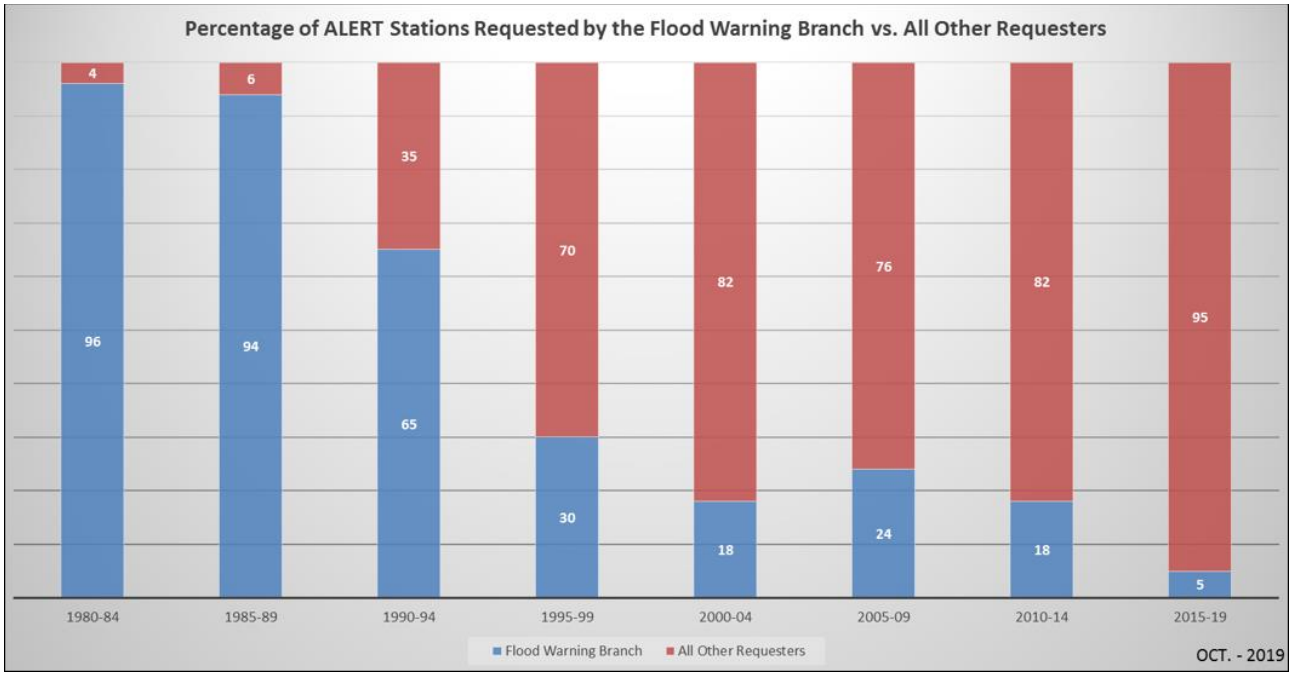

Figure 6 - Percentage of ALERT Stations Requested

Planning

Planning covers many aspects of the flood warning program, including Flood Response Planning and Emergency Action Plans. Planning could also describe varied tasks like the process of choosing the types of sensors to locate at a particular ALERT station, the locations of ALERT stations within a watershed, the quantity and design of information available to customers and the public via the Internet, the scenario and participants for a flood exercise or the maintenance procedures for a particular type of sensor.

Flood Response Planning

A Flood Response Plan (FRP) is a comprehensive plan that strives to identify all the flood hazards within the boundaries of the plan (such as a political jurisdiction or a watershed), then document the detection and communication of, and response to, those hazards. A typical FRP may be delivered in the form of a bound document, atlas, wall map, electronic display map or any combination of these.

The FCD Planning Branch completed an Area Drainage Master Study for the Wickenburg area in the early 1990s. This plan included a number of structural solutions to flooding problems and an alternative that had not been suggested to this point – a flood warning system which included a flood response plan. A severe hit from tropical storm Nora in September 1997 convinced many that the non-structural alternative could have merit. Sixteen additional ALERT stations were installed in the Wickenburg area in 1994-95, followed by the completed FRP in 1999.

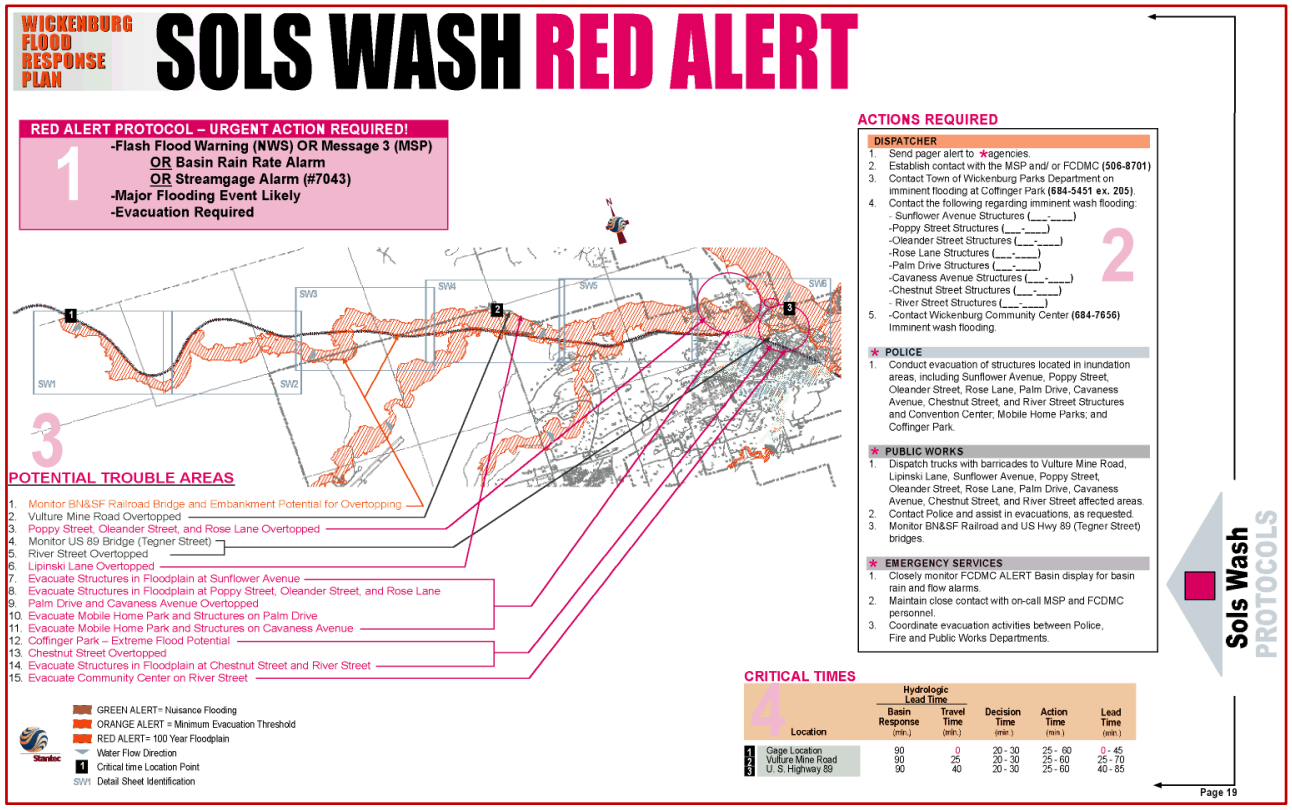

Figure 7 - A Red Alert page from the original Wickenburg FRP

Figure 7 is a page from the 1999 plan, demonstrating the four pieces of information necessary for response to a flood event on a watercourse:

1) What message triggers the response?
2) Who takes action based on those triggers and what are those actions?
3) Where are the potential trouble areas?
4) How much time is available for communication and action?

For this particular Plan, there are also *Green Alert* pages that mostly relate to flooded roadways, and *Orange Alert* pages that represent the level at which the first occupied structure is affected. The *Red Alert* level represents a severe event on the order of 1% annual probability (often referred to as the 100-year flood).

Appendix B is a listing of completed Flood Response Plans to date. Early FRPs were produced by outside consultants, but they have been completed in-house since 2008. The decision to develop or update an FRP can come from FWP staff or an outside agency and may be in response to a particularly damaging storm. All FRPs rely heavily on information from the ALERT system, as well as weather and flood forecasts from FCD and NWS in order to function.

Emergency Action Plans

Emergency Action Plans (EAP) differ from FRPs in that they are focused on one or a series of related flood control structures. For FCD these structures are either dams or levees. EAPs are not produced under the FWP, but their execution depends on information from the ALERT system as input for specific actions. For example, a dam may require notifications when filled to 25, 50, 90 and 100% of storage capacity. These levels can be programmed as alarms in the ALERT system software, and as each is reached, actions specified in the EAP are taken by the affected agencies.

Detection

Detection describes the observation of weather, rainfall and runoff parameters in space and time to discern what might cause damaging floods. It can be as simple as an observer with a cell phone, or as complex as dual-pole doppler weather RADAR. This section will focus on three methods of detection used in the FWP: the Meteorological Services Program, USGS Cooperative Gages and the ALERT system.

Meteorological Services Program (MSP)

Around the same time as the first FRP was being conceptualized, a solution to the problem of providing forecasts for rapidly-responding watersheds was being sought. Watersheds with response times of one hour or less exist not only in and around Wickenburg but throughout the FCD jurisdiction. With high-intensity storms, these watersheds can generate hazardous runoff so quickly that stream and rain gages give little lead time. The only way to initiate a proactive response in these conditions was to develop a way to act on the *potential* for heavy rainfall, thus making a meteorological component to forecasting necessary. It became evident that a program needed to be

developed that could forecast the timing and quantity of rainfall on a much smaller and more frequent scale than the National Weather Service could provide at the time.

A pilot program was started in 1995, modeled after an existing program being operated for the Urban Drainage and Flood Control District in Denver. The same firm providing meteorological products for the Denver district was contracted for a one-year pilot. The program's success led to a two-year contract awarded to the firm. Products delivered to FCD and the client base included a daily weather outlook with anticipated heavy rain potential for each forecast zone (**Figure 8**) and message products that designated a flood watch, warning and all clear by zone. In 1998, the contract was rebid and unfortunately awarded to a provider that was cancelled after one year of substandard operation. It was decided to continue the MSP by hiring an in-house meteorologist and not rely on outside help.

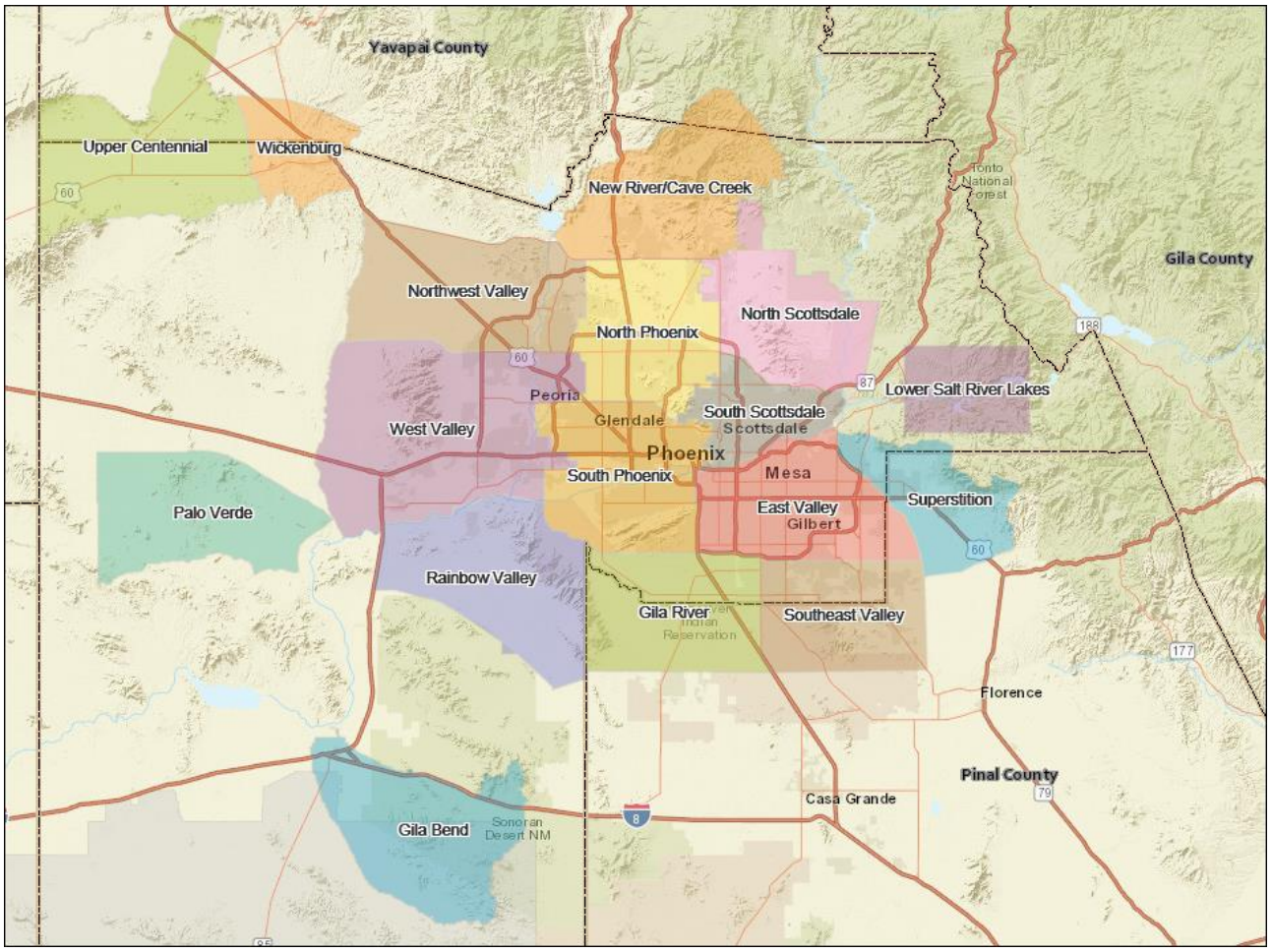

Figure 8 - MSP Forecast Zones Map

The FWP has since operated a year-round MSP to provide detailed meteorological forecasts and support to county, city and other local emergency responders. The MSP covers approximately 9,500 square miles encompassing Maricopa County and surrounding watersheds and is currently divided into 17 operational forecast zones covering roughly 5,400 square miles (**Figure 8**). These zones are

the primary warning areas identified by emergency management officials (Note that several of the watersheds have origins in higher terrain located outside of Maricopa County). Daily weather outlooks are provided to more than 1,500 clients. Weather statements are delivered to 350 subscribers, and lake alerts (warnings of severe weather at recreational lakes) are provided to nearly 1,000 people.

USGS Cooperative Gages

The USGS is tasked with monitoring the surface water supply for the nation, accomplished in part though gaging of surface waterways. Their program funding has generally dropped through the past 40 years to the point of needing local sponsors to assist in the costs of maintenance, collection and publication of data for stream-gaging stations. Since the early 1990s, FCD, through the FWP, has continued a joint funding agreement with USGS to support both continuous and peak-flow monitoring stations. In the 2019 agreement, FCD is supporting nine continuous gaging stations and 22 peak-flow stations at an annual cost of approximately $137,000. The FCD also supports special USGS studies using both USGS and FCD data to better understand some aspect of the hydrologic cycle that leads to flooding, such as rates of water lost to soil and channel infiltration, resistance to flow in channels, detailed statistical data reports for stations/watersheds in the County and the relationship of depth to discharge along a waterway.

Figure 9 - USGS Continuous Stream Gage on the Hassayampa River near Morristown

ALERT System

The ALERT system (system) forms the backbone of the FWP detection component. ALERT was devised by NWS scientists in the mid-1970s in response to flooding on the Sacramento and American Rivers in central California. These scientists developed a binary radio message that was composed

of two parts, one representing the ID number of the sensor sending the message and one the data value. It was simple and a one-way only communication. At a base-station computer this message was given the timestamp of the computer as it was filed in a rudimentary database using the sensor ID. The receiving computer software applied calibration parameters to display the integer data value in understandable units. For example, a temperature report of 110º Fahrenheit might have a base-value of -40, and when added would represent a temperature of 70º Fahrenheit. This format was adequate until systems grew to a point where two things happened: 1) ID numbers became scarce between systems that could hear (communicate with) each other and 2) the radio messages began to collide and become corrupted or lost during severe storms. The FCD system suffered from both of these problems; however, ALERT2 was fortunately ready for distribution starting in 2017. ALERT2 offers more ID numbers, more information in the message, accurate on-site GPS timekeeping, and the ability to program the timing of transmissions so that they do not collide. The system is completely converted to ALERT2 as of early 2019.

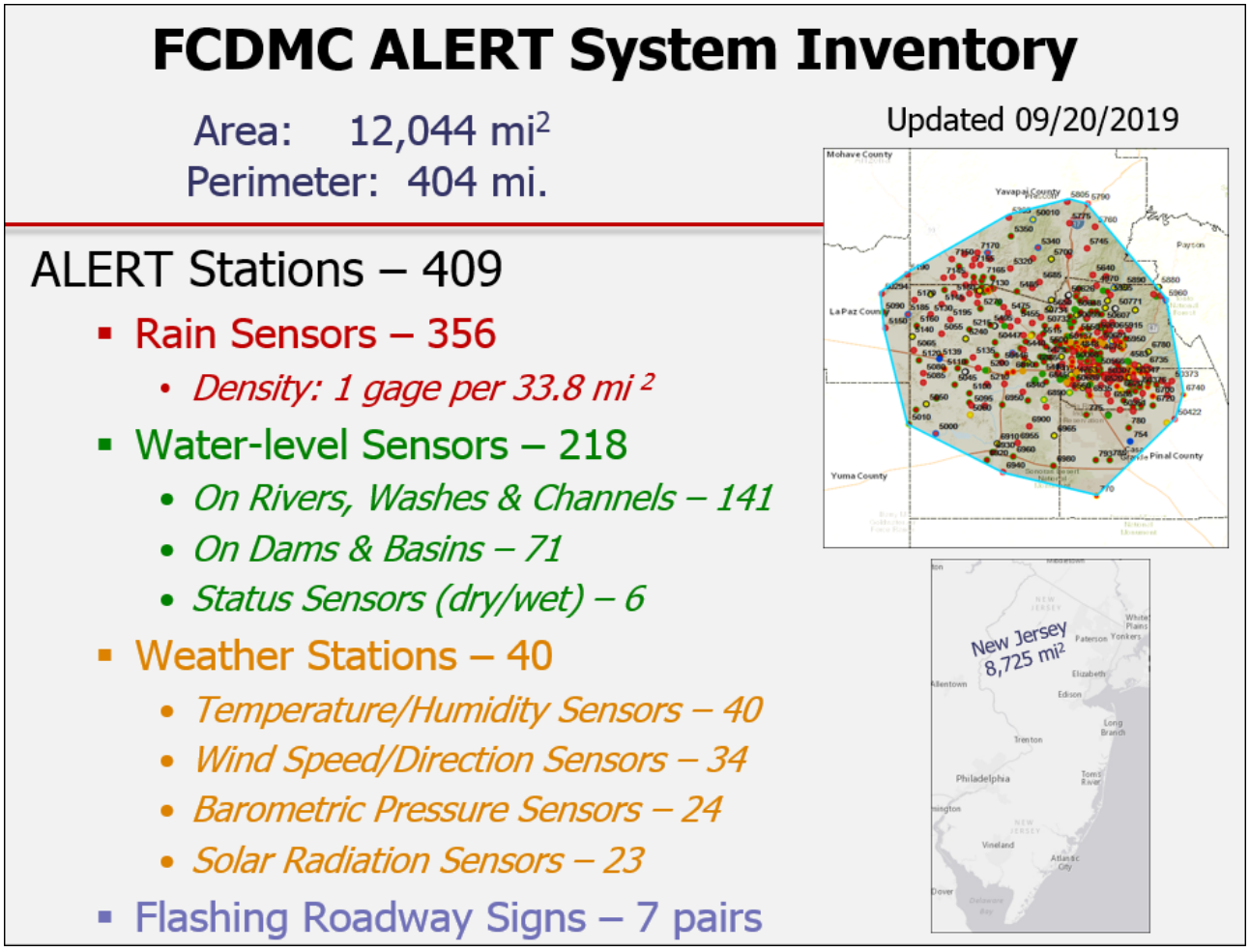

Figure 10 - ALERT System Inventory

Sensors: **Figure 10** shows that the system consists of 409 stations. An ALERT station is a unique transmitting structure that has one or more sensors connected and sending data. 356 of the stations measure rainfall using a sensor called a tipping bucket. As rain falls, this bucket fills with water until it reaches the equivalent depth of 1 millimeter (0.03937 inches). At that depth, the bucket tips on an axle and lets a twin bucket on the other side full up. This continues through the storm, and as each tip occurs a message is transmitted with the accumulated count and the time.

Water-level sensors in use are status, pressure transducer or RADAR. A status sensor is a float that makes a contact when levitated by water, giving notice of wet or dry at a particular stream depth. A PT is a device that measures the pressure exerted by a fluid and converts that to a voltage. The voltage is read by the ALERT station computer and converted to a number that is then transmitted to the base station as a depth of water. A RADAR sensor is mounted to a fixed structure like a bridge and aimed straight down at the water surface. The transmitted RADAR signal bounces off the surface below and returns to the sensor. As the water level rises the time the signal takes to make the trip becomes shorter, and the depth of water can be inferred knowing the time/distance relationship.

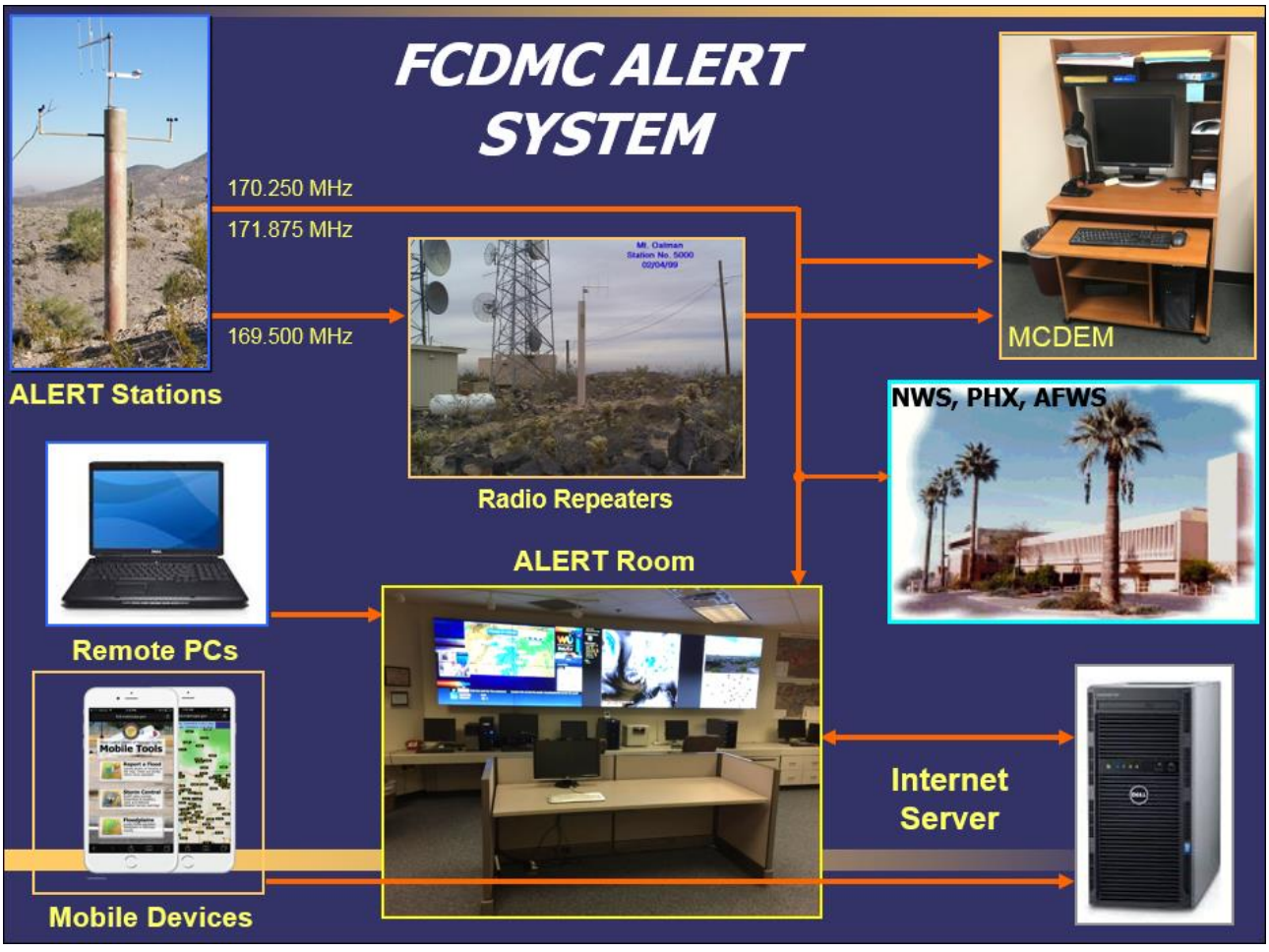

Figure 11 - ALERT System Schematic

For an ALERT station to be considered a Weather Station (**Figure 11** upper left), it must minimally include a temperature/humidity sensor. Dew point temperature data can be calculated at the base station computer from temperature and humidity data. Weather Stations may also have wind speed

and direction sensors, solar radiation sensors and barometric pressure sensors. The system has Weather Stations from 750 to 7,500 feet above sea level, providing a unique analysis tool for measuring the water vapor content of the lower atmosphere. Wind sensors transmit wind speed and direction near thunderstorms, useful in FCD Lake Alert warnings and for detecting microbursts.

System Architecture: **Figure 11** is a schematic showing how data flows through the ALERT system. Starting with the stations in the field (upper left), data messages are transmitted on one of three FM frequencies. One frequency is used for the radio repeaters, two others for direct transmissions. The messages are decoded and stored in three places simultaneously: by a base station at the NWS office in Phoenix, by the FCD backup base station at MCDEM and by decoders in the FCD Operations Building. From the third location decoded messages are transferred via T1 lines to servers in the ALERT Room. These servers can be accessed by computers on the County network for direct display and control. ALERT data and products can be requested by phones, tablets and PCs via the FCD web server – all available in near-real time as soon as they are stored in the servers.

Permits: Each ALERT station requires a semi-permanent anchoring to the ground on a property owned; therefore, it is necessary to acquire permits to allow long-term access for installation, repair and maintenance. **Figure 12** shows how station locations are distributed amongst different entities. Permits can take anywhere from a week to several years to acquire. IGAs can serve as a permit, as is the case with all stations located on City of Phoenix property. While most permits are free, occasionally a review fee or rental fees are charged.

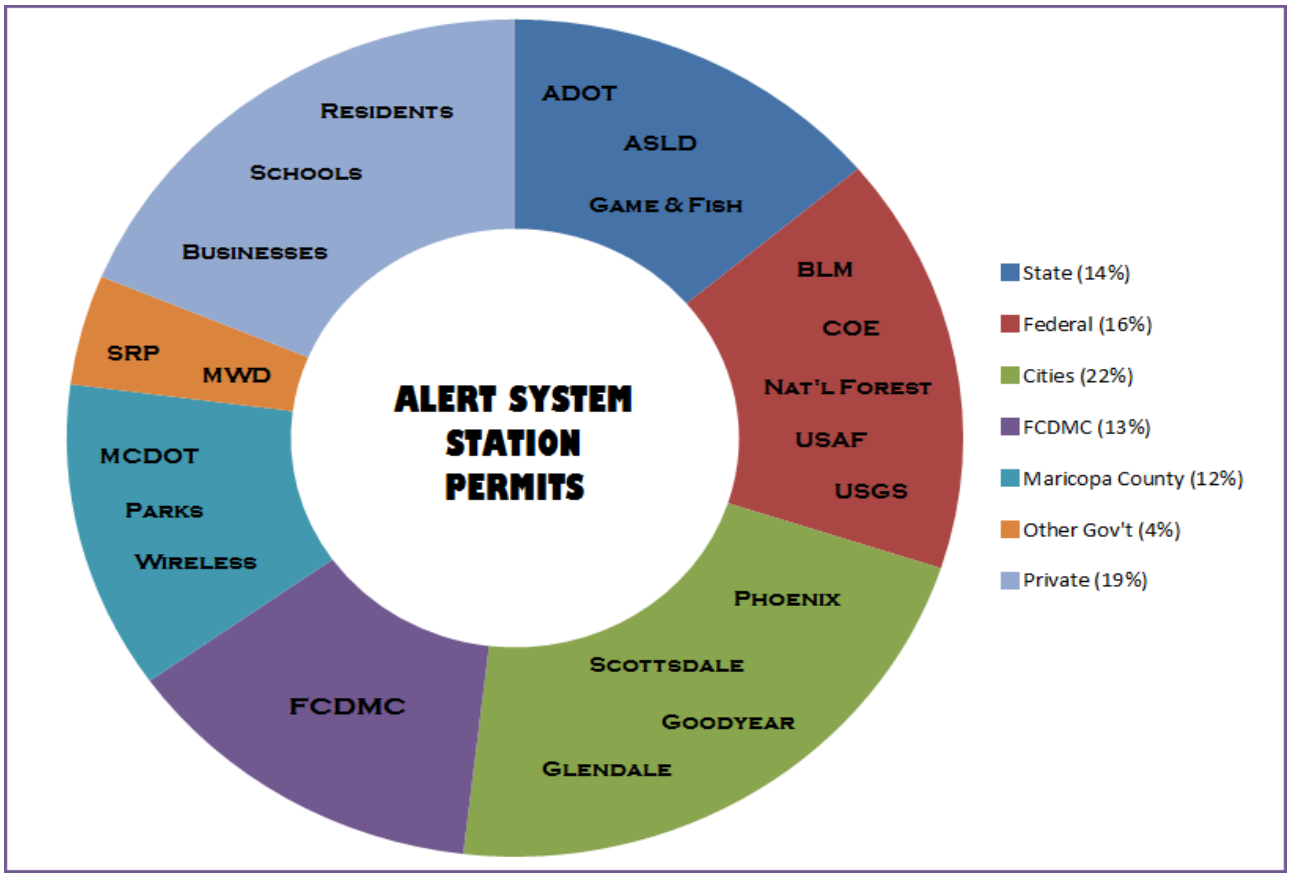

Figure 12 - ALERT Station Permit Grantors

Licenses: Each ALERT station uses an FM transmit radio rated from four to 20 watts; therefore, the FCC requires a radio license (technically a Radio Station Authorization). Up to six ALERT stations can be covered by one license, which has a unique call sign (e.g. WQLG517). The Authorization must be renewed every 10 years, and there is no charge for public safety use.

Criteria for Adding an ALERT Station: Many factors must be evaluated when considering the installation of a new ALERT station.

1. Data usefulness. Examples considered include:
    a. Is it measuring rain on part of a watershed that contributes to a downstream hazard?
    b. Is it measuring streamflow at or above a potential hazard?
    c. Does it transmit weather information for an area that was previously blind?
2. Funding availability. Funding can include capital monies, cost-sharing with a local municipality, grant funds, etc.
3. Long-term agreement. An agreement with the property owner needs to be secured for operation and maintenance access.
4. Site suitability for proposed sensors. Rain gages require open space and protection from high wind. Stream gages require relatively straight reaches and stable banks, and weather stations need open space and homogeneous surrounding terrain.
5. Available radio path. A radio signal needs to be received by a repeater or directly by the base station.
6. Other factors. Considerations include aesthetics, ease of access, proximity to other gages and the potential for vandalism.

Communication

Communication represents the portion of the FWP where information from the detection system is verified and passed on to those accountable for a response (i.e. actions). This information is generally passed from the ALERT Duty Officer (ADO) to agency response staff. The communications can be referred to by a number of different names: information, messages, watches, warnings, etc. It is rare for FCD to directly provide messages, watches or warnings to the public because federal law gives this responsibility to the National Weather Service.

Warning Responsibilities Manual

The Warning Responsibilities Manual is an ever-evolving document developed and maintained by FWP staff. It summarizes all of the program's warning responsibilities and is updated as needed. A linked table of contents makes accessing the FRPs, EAPs, Levee EAPs, Areas of Special Concern, Cities, Construction Projects, Waterways and Structures sections easier. These sections contain warning threshold and contact information necessary for successful communication of a hazard. There are also informational sections covering the Sand Bag Map, social media accounts, MCDEM's WebEOC (incident management) software and access to live-image cameras at FCD dams.

Information via the Internet – 1998 to Present

Prior to an Internet presence in 1998, ALERT data was requested by email, phone or in person. A standard form was completed and data was delivered by email, printed copy or fax machine. A few select agencies had access to the data in real-time via phone modems and login accounts. This changed in 1998 when the first series of webpages went live. Although the initial products were simple, now everyone, agency users and the public now had access to ALERT data in real time. The Internet was not considered reliable enough at the time to be used for operational purposes, so phones and modems remained in service for several years. As time passed and the Internet stabilized, the webpages became the go-to method of supplying data and products for both historic and operational data. In 2011, the FWP launched the AIDD (ALERT Interactive Data Display Map). This platform uses Google® Maps, familiar to most Internet users, as a base for data overlay. Multiple combinations of data types can be overlaid, in real-time or historic, and many GIS layers can be added to the map including current weather radar and radar-estimated rainfall depth. Today the FCD web portal contains pages featuring rainfall, water-level and weather data, a statistical report generator, maps for locating ALERT stations, metadata for stations, custom products/maps/plans (which includes electronic interfaces to FRPs), publications, links to similar sites as well as a disclaimer. These webpages are visited by less than 1,000 users on a typical day, but usage picks up dramatically on storm days. September 8, 2014, registered 1.1 million hits.

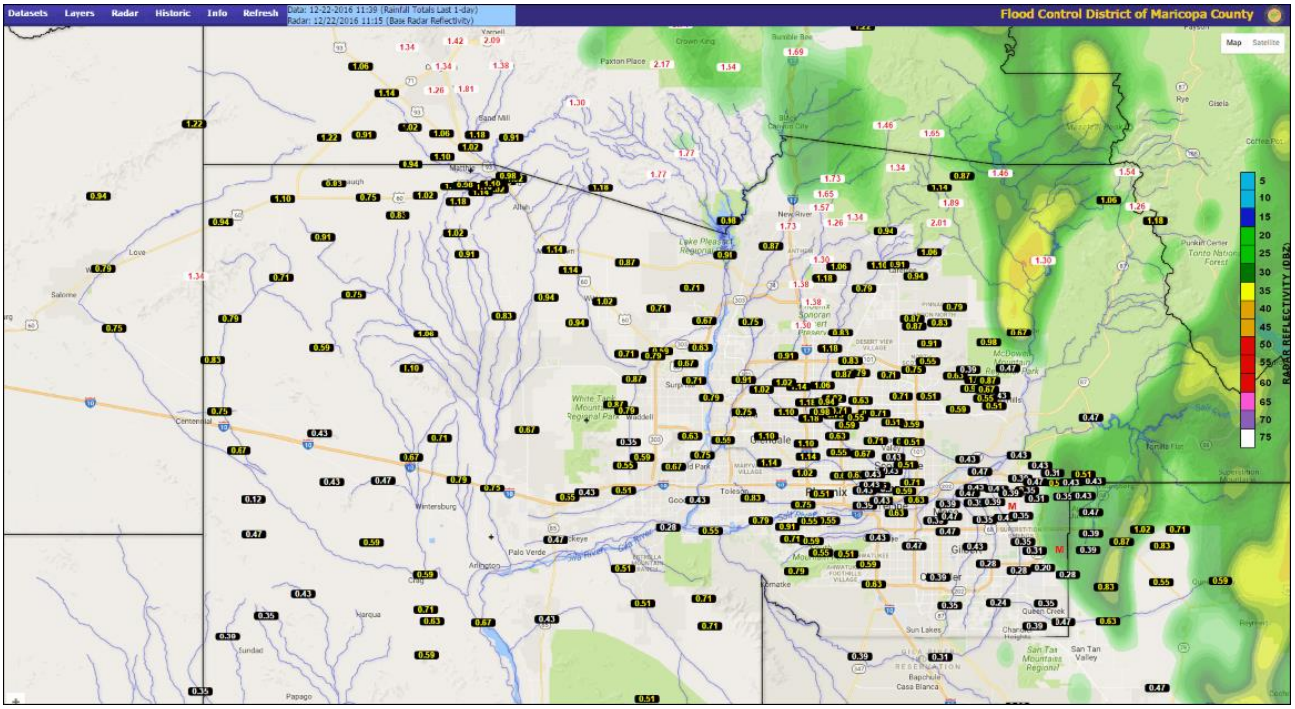

Figure 13 - AIDD Map from 12/22/2016 showing 1-day rainfall and current RADAR

Interaction with FCD and County Communications

The FWP has a long-standing relationship with FCD Communications (Public Information Office or PIO). Prior to, and during storm events, it is not uncommon for the media to request interviews with

FWP staff. PIO staff will arrange the interview, greet the media representatives, oversee the interview and generally supervise the whole process. This allows FWP staff to continue their duties with as little interruption as possible. FWP staff are often asked to present at conferences, seminars, trainings and public meetings, often accompanied by PIO staff.

After the storms of summer 2014, the County's Office of Communications and FCD created a Storm Alert program. The process begins with a determination by the ALERT Duty Officer that a Storm Alert should be issued. This designation is based on potential rainfall forecast criteria that changes seasonally. When this occurs a warning banner is launched at the top of all County webpages with a *more information* link that brings up a page with directions on how to prepare for flooding, information on flood-proofing, where to find sand bags (using a map application) and other helpful resources.

Direct Notifications

The ALERT system has the capability to send a text message to any email address. Staff have been experimenting with direct client notifications. The downside to this is that the messages are not verified by the ADO prior to delivery, but recipients are made aware that false alarms can and will occur. Current test users include the City of Mesa (stream warning), the City of Goodyear (water sampling), a private construction company and USGS contractor conducting research in the upper portion of Sycamore Creek.

Actions

Actions are tasks to be completed based on communications. In other words, a message or warning is received and a response must be initiated. Most flood-response actions take place outside of FCD; however, there are in-house actions taken by FWP and FCD staff.

Flood Emergency Response Manual (FERM)

The FERM is another ever-evolving document maintained by FWP staff. It serves as a guiding document for all of FCD staff and operations during times of flood response. The document describes the logistics of setting up and staffing the ALERT Operations Center (AOC), detailed tasks to be completed by each FCD Division, observation and safety procedures, emergency procedures and the makeup and destinations of flood-response teams. Informational appendices are included such as travel times on major rivers, staff gage to ALERT gage elevation conversions, gated outlet operations and standard terminology definitions.

MCDEM Support Via the ALERT Operations Center

The AOC is an area within the ALERT Room that is staffed or opened for response to a flood event that is more than can be managed by FWP staff. A light activation takes place in circumstances where the ADO may need extra assistance responding to a flood event but a full activation of the AOC is unnecessary. During a light activation, the AOC will be staffed by the ADO, AOC Chief, a

representative from the O&M Division, an Event Historian, GIS/Technical Support or MCDEM Emergency Operations Center liaison groups. AOC staff will help monitor and log information in WebEOC, monitor specific flooding locations and/or structures, and be available to answer phones, questions and any requests coming into the AOC. During a full activation, the AOC is staffed by the ADO, AOC Chief and representatives from Dam Safety, O&M, Public Information Office, GIS/Technical Support and the Shift Leader. A Levee Safety Engineer will be available to the AOC if an event affects an FCD Levee. A two-person team of FCD staff members are sent to the MCDEM EOC to act as a liaison between FCD and other involved agencies. In either a light or full activation, a primary duty of the AOC staff is to clearly communicate weather and flood information to decision makers at MCDEM. This is accomplished by direct phone conversations, messages via WebEOC and periodic conference call briefings.

Figure 14 - Flood Exercise in the AOC, 5/9/14

Exercises

Purpose of Flood Exercises

A flood exercise (i.e. flood drill) is a gathering of materials and personnel for the purpose of practicing their response to a simulated flood. It can involve just a few people around a table (tabletop), a more involved response to a written script (small-scale) or a realistic response with dispatched field crews, actors and simulated phone calls (full-scale). FCD aims to conduct at least one full-scale exercise to

satisfy FEMA CRS requirements. This involves staffing the AOC, sending liaisons to MCDEM, sending O&M crews and dam safety personnel to structures and observation points and reacting to simulated data and problem statements. After the exercise a report is produced chronicling inadequate responses and recommending methods to increase either the speed or accuracy of the response.

Exercise Support From the ALERT System

The ALERT system plays a pivotal role in full-scale flood exercises. Rainfall amounts and water levels are programmed and made available to players prior to, and during, an exercise in an effort to simulate an actual storm in the area and structures included in the simulation. Players make many of their decisions based on the data presented by the ALERT System. This not only makes for a realistic scenario, but it also tasks players with searching for and interpreting the information just as they would do during a real event.

Staffing, Maintenance and Costs

Personnel

Personnel assigned to the FWP are as follows:

Flood Warning Branch Manager: Provides overall direction for the FWP; supervises three FTEs and one intern; responsible for budget and purchasing; maintains ALERT hardware and software and web server; serves as Duty Officer; responsible for ALERT station permits and FCC licenses; participates in flood monitoring and exercises; serves as backup meteorologist; negotiates IGAs and maintains data from precipitation sensors.

Senior Hydrologist: Oversees the stream-gaging program (all water-level sensors); selects locations based on established standards and past experience; surveys sensor elevations in relation to structure elevations or stream cross-sections to develop/modify rating tables; conducts visits to each water-level sensor annually to verify function and surroundings; works with Water Instrument Technicians to resolve problems; maintains data from water-level sensors; participates in flood monitoring and exercises; maintains webpages for water-level gages and administers the annual joint use agreement with USGS.

Flood Warning Program Specialist: Oversees the flood response planning effort (including creating/updating plans); maintains the FERM and Warning Responsibilities Manual; writes computer code for display of ALERT data and products using GIS; oversees social media effort and participates in flood monitoring and exercises.

Meteorologist: Oversees the meteorological services program; disseminates weather forecasts, watches and warnings; writes computer code for display of ALERT data and products; serves as Duty Officer; conducts annual visits to each weather station to verify function and surroundings; works with Water Instrument Technicians to resolve problems; maintains data from weather sensors and participates in flood monitoring and exercises.

Water Instrument Technician Supervisor [O&M]: Supervises four Water Instrument Technicians; distributes work assignments for installation, repair and maintenance of ALERT stations; budgets for and procures parts and equipment for station repair and maintenance; maintains equipment and service database; trains and assists staff and writes standard operations procedures for station installations, repairs and maintenance.

Water Instrument Technician (4) [O&M]: Installs, repairs and maintains ALERT stations; calibrates sensors and receives work assignments from, and submits reports to, supervisor. The current staffing level of four technicians has remained constant since 2002. This stability is attributed to more efficient operation and increased equipment reliability.

Hardware: ALERT Stations, Transmission Network and Base Station

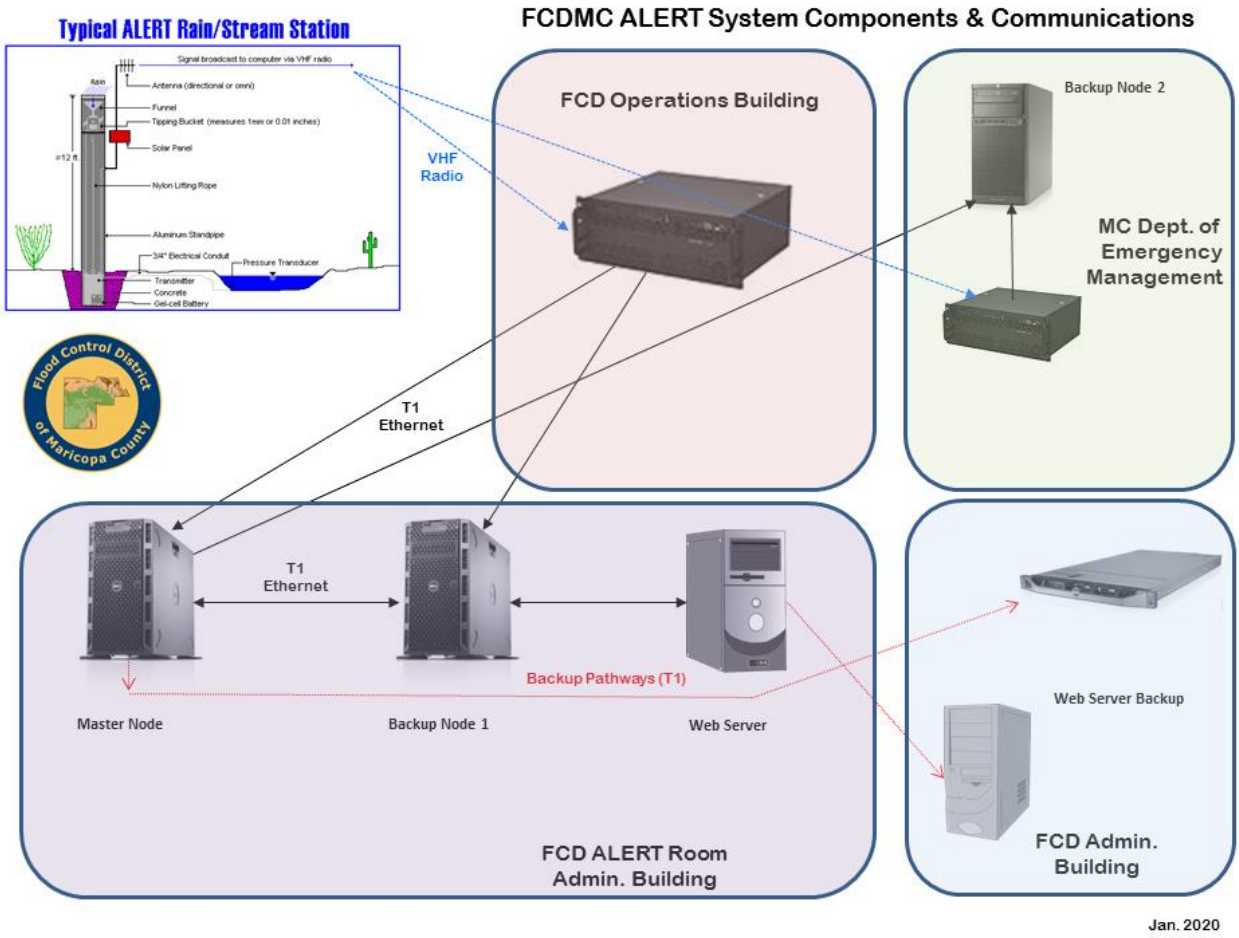

Figure 15 - ALERT Communication Hardware

As previously noted, an ALERT station is a unique transmitting structure that has one or more sensors connected and sending data. For most of the stations this structure is a one-foot diameter aluminum tube, placed 10-12 feet above ground and three feet below (**Figure 15**). The transmitter and 12-volt battery are placed inside this aluminum tube below ground level. The transmitter consists of a radio, computer board and ports for plugging in sensors. The battery is typically trickle-charged by a small

solar panel attached to the antenna mast. The antenna is generally three to six feet higher than the tube, and it is pointed to either a repeater or the ALERT base station at the FCD offices. In a few places, such as on mountain tops and on larger dams, FCD staff takes advantage of existing buildings that were constructed specifically to house instruments. In those cases the transmitter can be located inside, and if available, commercial power is used with a battery backup.

Figure 15 shows the route ALERT data takes after leaving a station. Data is ingested and translated by one of two receiver/decoders then transferred via T1 lines to two base computers. In normal operation, data is processed and stored on the main machine and synchronized with the other databases. If the main database goes down, other databases can take over its duties and maintain this synchronization. If both go down, ALERT operations are moved to MCDEM and a backup will receive and store its own data. Aside from the three base computers, the ALERT database is stored nightly on a County server and on an Amazon cloud computer by FCD's software vendor.

Software: NovaStar, PostgreSQL, ESRI Products, Google Maps and Apache Web Server

Although there are many programs and packages available, this section highlights the more important ones used by the FWP. The operating system of choice for the FWP is Debian Linux, which is available for free download. The relational database used to store the ALERT data is called PostgreSQL, also a freely available program. The interface program (not a free service) between the data and the database is called NovaStar©. As one of three commercially available packages for ALERT data, NovaStar© allows for the creation of stations and sensors with ID numbers – virtual destinations for storing and querying the data. Alarms can be programmed within NovaStar© that will trigger some task if a data threshold is reached, such as a rainfall rate or height of water. That task is most often to send an email to the Duty Officer, which contains not only the threshold reached but instructions on the action to take. Other commercial software, such as ESRI ArcMap® and Google Maps® are used to display the ALERT data in formats that are familiar to a great many users. The ALERT web server also runs on the Debian Linux operating system and uses the free and popular Apache Web Server software as the engine for distributing data and products to web users.

Budget History and Lifecycle Costs

Figure 16 chronicles the FWP budget from 2006 – 2020. Funding has trended upward slightly to take into account staff raises and the price of services and equipment. The result is little has changed in the 15 years shown. The latest annual budget of $1.4 million represents approximately 4.7% of FCD's $30 million operating budget. The lifecycle cost for an ALERT station that measures only rainfall is estimated to be $60,000 during a 50-year period; adding a water-level sensor bumps this cost to around $77,000. A detailed breakdown of these costs is presented as Appendix D.

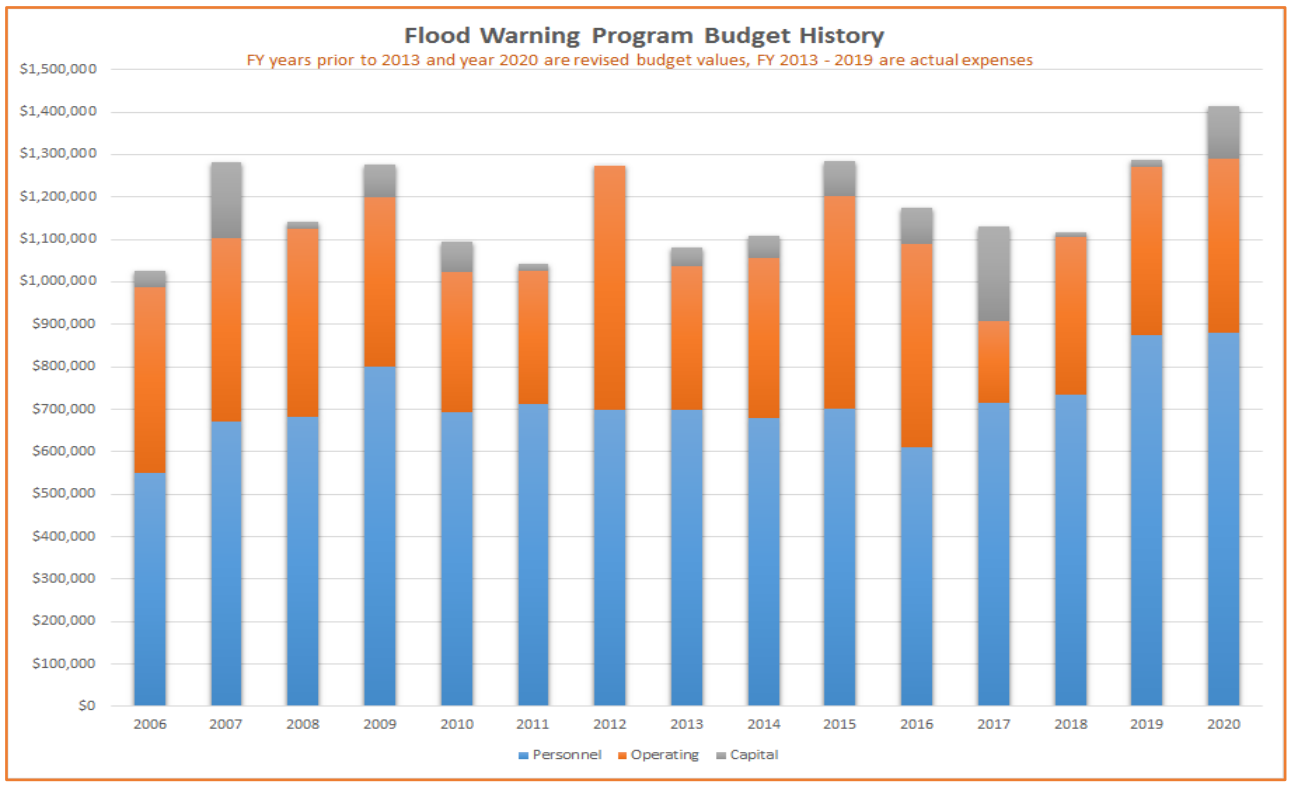

Figure 16 - Budget History, 2006-2020

Alternative Uses for ALERT Data

ALERT data has many uses outside of operational flood warning. Since 1994, the FWP has published annual data reports for precipitation, water-level and weather sensors. Storm reports that feature meteorology, precipitation, runoff, sometimes damages, and sometimes ALERT system performance have been published for every major storm since 1988. These reports (and the data, calculations and products within) have been used not only for checking/developing designs for flood control structures and as input for the NOAA 14 rainfall atlas, but they are also frequently used for hydrologic studies, climatology studies, drought monitoring, air quality monitoring and recreation monitoring. These reports are used less frequently for irrigation studies, wind studies and ground-water modeling as well as a whole host of forensic applications used by insurance companies, attorneys and law enforcement.

Studies and Similar Programs

Comparison to Similar Programs in the US

An electronic survey was sent to the operators of 10 similar ALERT flood warning programs throughout the western US (full survey and responses are in Appendix C). Responses were received from three agencies: Yavapai Flood Control District (Prescott, AZ), Harris County Flood Control District (Houston, TX) and Mile High Flood District (Denver, CO). The areal size/population of the responding districts offers good comparison across the respective programs. The chart below summarizes the responses along with data from Maricopa County.

Question	Maricopa County	Yavapai County	Harris County	MHFD Denver
Coverage (mi^2)	12,044	5,688	3,044	2,361
Population	4.4 million	221,000	4.5 million	3.0 million
# of Rain Gages	356	108	183	209
Sq. Mi./ Rain Gage	34	53	17	11
Persons/Rain Gage	12,360	2,046	24,590	14,354
# Water-level Gages	218	32	178	112
# Weather Stations	40	15	11	29
In-house Weather Forecasting?	Yes	No	No	Yes (via private service)
Clients/Customers	All respondents had similar answers: emergency responders, emergency management, law enforcement, fire departments, public works, the public.			
Flood Warning Staff	4 professionals 5 maintenance 1 intern	1 professional 1 FT maintenance 2 PT maintenance Other PT	4 professionals 8 maintenance	5 professionals maintenance by contract
Single automated rain gage installation	Equipment $7,500 Labor $500 Annual Maintenance $800	Equipment $9,500 Labor $600 Annual Maintenance $300	Equipment $7,000 Labor $600 Annual Maintenance $700	Equipment $5,300 Labor $3,000 Annual Maintenance $1,100
Is near real-time data available to the public?	Yes	No	Yes	Yes
Established FRPs and/or EAPs?	Yes	No	No	Yes
Agreements with other agencies to install, operate or maintain gages?	Yes	Yes	Yes	Yes

Some interesting points from this table:

1) Maricopa County has the largest jurisdiction in area, and a square miles to rain gage ratio of 34. Houston and Denver are 17 and 11 respectively, or approximately twice the density.

2) Staff sizes for Maricopa County, Houston and Denver are very similar, but FWP maintains more than twice as many rain gages over an area five times larger.

3) Costs to install a single automated rain gage are similar across agencies, with the exception of Denver's $3,000 labor cost which is attributed to contract pricing.

4) Only two of the four agencies use established Flood Response and Emergency Action Plans.

Flood Warning Services Market Survey Study (Montgomery Consulting, 1992)

The firm of Montgomery-Watson performed a Flood Warning Services Market Survey Study for FCD in 1992. The objective of the project was to evaluate flood warning technology, identify the understanding of and perceived need for flood warning within Maricopa County and to develop flood warning alternatives for possible implementation. The alternatives were defined as:

1) Status Quo
2) Flood warning with improved detection and hydrologic modeling (HM)
3) Flood warning with improved detection and meteorological prediction (MP)
4) Flood warning with improved detection, HM and MP
5) Flood warning with improved detection, HM, MP and GIS

Based on these recommendations the FWP incorporated MP as the Meteorological Services Program, HM as the Flood Forecast Partnership with National Weather Service, detection as overall system growth and GIS now serves in most of FWP's data display products.

In addition, a market survey and an economic evaluation were performed to identify the feasibility of improving flood warning services in the County and to obtain input and guidance from municipalities and agencies that ultimately would be end users of the service. The market survey results indicated that there was a strong interest in improved flood warning services. It also showed a strong correlation between the interest in improved flood warning services and the perception that the County is threatened by flooding. Preferred flood warning system improvements included additional precipitation and stream gages, more site-specific flood warnings and longer lead times prior to a flooding event.

ALERT Network Evaluation (OneRain and Telos Services, 2008)

The firms of OneRain and Telos Services performed an evaluation of the ALERT network in 2008. The purpose of this project was to analyze the ALERT system using weather radar images, radio path studies and ALERT data collected during quiescent and storm periods to determine the network's performance characteristics, especially its ability to provide accurate information during rainfall

events. The conclusion from the study was that "the network is well-designed, well-maintained and operated correctly for its objectives. We determined the current network capacity is such that a large-scale and/or very intense rainfall event will result in an unacceptable level of data losses." The study determined that nearly 40% of data losses due to transmission collisions (in the old ALERT format) occurred in the most intense hour of a storm on November 30, 2007. The project recommended the use of an additional radio frequency (implemented) and an ALERT 1/2 Hybrid solution where the data repeaters were outfitted with GPS clocks. The clocks are programmed to store data and transmit it only during a specific few seconds each minute so they would not transmit on top of each other. This solution was also implemented and provided reasonable results until the conversion to ALERT2 in early 2018.

Internal Audit 2011

In June 2011 an internal audit of FCD was conducted in three areas: Cash receipts, Emergency Action Plans and the ALERT system (the FWP). Recommendations for improving the ALERT System included a more clearly defined and rigorous maintenance schedule for the ALERT stations, a more complete and regularly updated inventory of ALERT station components and strengthened security controls for the ALERT base station computers. All ALERT recommendations were implemented and documented in fiscal year 2012.

ALERT System Operational Efficiency

The FWP has maintained statistics on operational efficiency since January 1997. Operational efficiency here is defined as the percentage (for each sensor type: rain, water-level or weather) of days providing accurate data during a month versus the total days in the month. This is accomplished during monthly data quality assurance/quality control where down periods are tabulated. For example:

> For 350 rain gages operating during the month of March (31 days),
> If 27.3 days of down-time were noted
>
> ---
>
> Then efficiency is 1-[(27.3)/(31*350))]*100 = 99.75%.

Figure 17 shows the efficiency for the three sensor types over the past 13 months.

Operational efficiency since 1997 has been 99.15%, and since January 2015, the rain sensors have operated at 99.52%, the water-level sensors at 99.29% and the weather sensors at 98.77% of possible operating time.

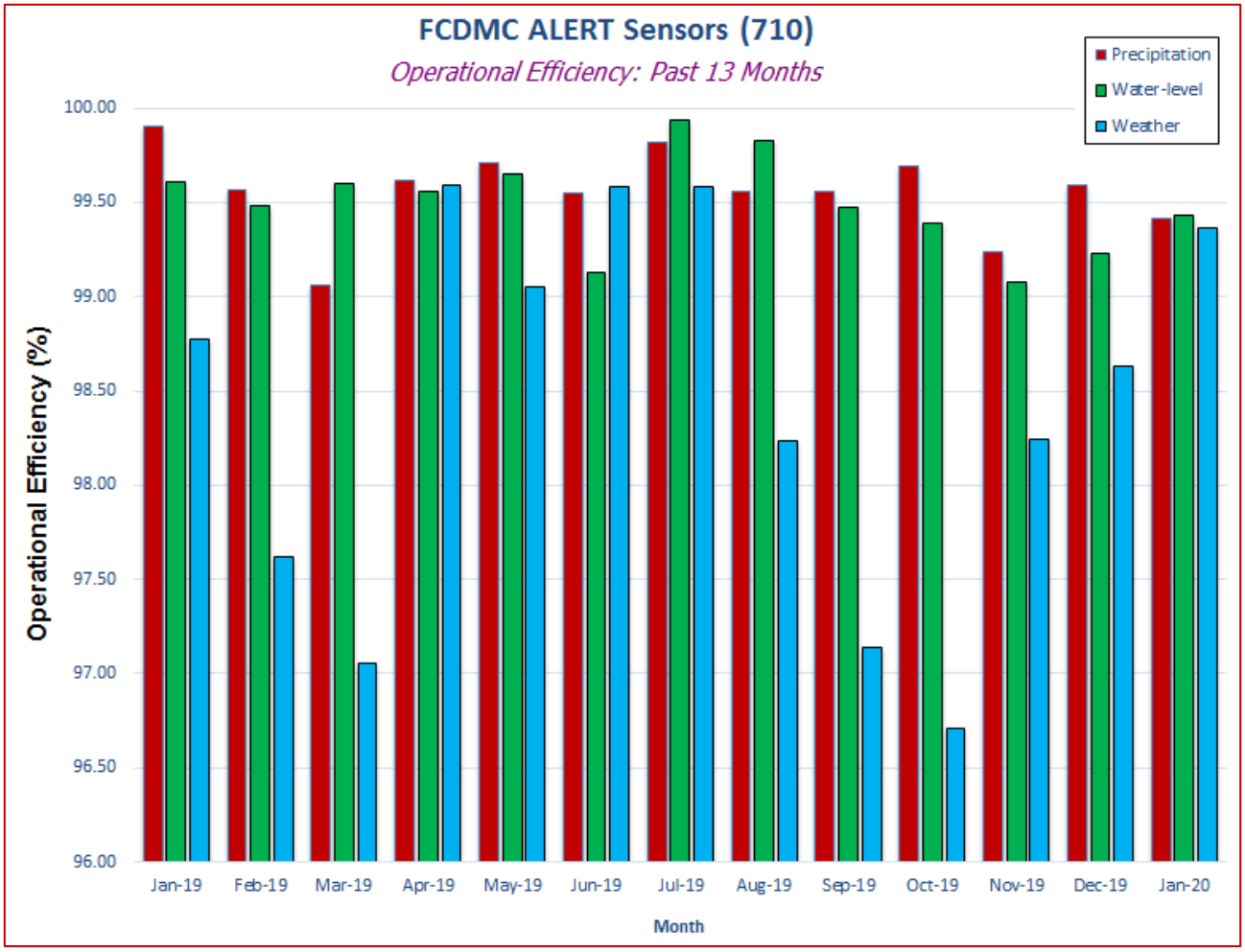

*Figure 17 - ALERT Sensors' Operational Efficiency **

** Note that the vertical Operational Efficiency scale begins at 96%, not zero.*

Future of the Program

Developing Technology – Impact on the ALERT system

Technology continues to improve and miniaturize. The ALERT system is made up of several technologies, and it is expected that ALERT components will become smaller, faster and less expensive. This is evident, especially at conferences and on the Internet. For example, Campbell Scientific has introduced an ALERT transmitter that is significantly smaller, lighter and less expensive than the ones currently deployed. This technology could be beneficial in its lower cost and higher reliability. USGS is developing software that can measure the surface velocity of a stream from live video. Knowing this velocity, the depth read from a staff gage and the underlying channel geometry, the software can generate a discharge value (cubic feet per second) at the camera location. In a similar way, Doppler RADAR is being tested that can also measure surface velocity. These technologies could lead to stream measurement sites that would require less surveying and equipment.

But the technology that could have the greatest impact on the ALERT system is improving estimates of rainfall intensity from weather RADAR. In order to increase the accuracy of current RADAR rainfall estimates, this methodology uses real-time data from rain gages to calibrate the final product. As the technology improves there could be a diminished need for calibration, hence the number/density of rain gages could be reduced in favor of virtual gages that could report rainfall intensity at a given point on the RADAR grid.

ALERT System of the Future

In the near future it is likely that ALERT data will not be housed on servers in the ALERT Room but rather on a cloud service. Cloud storage is inexpensive, reliable and secure, and many County servers are already taking advantage of these efficiencies. It is also likely that at some point all ALERT data in the US will be available from a common cloud database. ALERT stations will likely evolve into CPUs on a wireless network where all can be investigated, programmed and queried from a command point. Dashboards will most certainly become the standard for data display, where tables and graphs can be easily moved in or out, based on the operators. Dashboards can also display some type of artificial intelligence (AI) decision support that will help decide which are most relevant to a current flooding situation. Storm development, motion and rain intensity will likely be displayed visually ahead of an event, and coupled with advances in GIS, floodplain inundation will be applied to three-dimensional maps prior to the occurrence of any flooding. ALERT has existed as a tool for Maricopa County decision makers for approximately 40 years – 40 years from now it is likely there will be facets of the FWP that cannot be imagined today.

Appendix A – Agreements

FWP - Responsibilities to Recorded Agreements - Updated January 2020

Type	Date Recorded	Date Expires	Agency	Identifier	Terms and Provisions
MOU and IGA	7/7/1990	In Perpetuity	National Weather Service (NWS)	FCD-89017B	Defines a mutual assistance program for the development and operation of a cooperative local flood warning system for Maricopa County. Includes NWS support for radio frequency assignments. Parties to monitor, update and refine calibration of CBRFC hydrologic forecast models. FCD to assist MCDEM with development of a Flood Response Plan as part of the Peace-Time Disaster Plan.
IGA	1/22/1991	In Perpetuity	City of Mesa	FCD-89013	Mesa (specifically Mesa Parks) grants FCDMC permission to install ALERT rain stations at four Mesa Parks - Fitch, Kleinman, Mountain View and Carriage Lane.
IGA	7/10/1992	In Perpetuity	City of Goodyear	FCD-92005	FCDMC to purchase, install and maintain an ALERT rain/stream station on the Gila River bridge at Reems Road (also known as Estrella Parkway).
IGA	12/22/1993	In Perpetuity	City of Tempe	FCD-93017	Tempe grants permission to install and maintain an ALERT rain/stream station on the Priest Road bridge over the Salt River.
IGA	7/5/1996	7/5/2021	Town of Fountain Hills	FCD-96010	FCD to install a flood detection system for six earthen dams. Install and maintain ALERT stations purchased via ADWR funds. FCD to supply minor repair parts, and the Town is responsible for major components. FCD to supply data retrieval and long-term storage. FCD to develop and maintain rating curves. Town to secure land permits and FCC licenses.
IGA	7/3/1997	7/3/2022	City of Scottsdale	FCD-96011	Defines the roles of the Parties in establishing a Flood Warning System for the City. Terms establish a framework for expansion of the FCD ALERT system within Scottsdale, but specific station locations are not

FWP - Responsibilities to Recorded Agreements - Updated January 2020

Type	Date Recorded	Date Expires	Agency	Identifier	Terms and Provisions
					identified. Subsequent stations installed under this agreement were: • Pima Road at Union Hills Road • Pinnacle Peak Vista • Osborn Road at 64th Street • Highland Avenue at 68th Street. • Lake Margherite • Indian Bend Wash at Indian Bend Road, • Indian Bend Wash at McDonald Road • Aztec Park • Rawhide Wash • Reata Pass Wash • Stagecoach Wash • Granite Reef Wash
IGA	5/10/2005	9/11/2012	City of Phoenix	FCD-2004A018	Identify and define the responsibilities of the parties for the assessment of the City's flood control dams and the development of a City of Phoenix Dam Safety Program. FCD to provide installation and configuration support for one ALERT base station. In Amendment #1 (dated 9/11/2007), FCD agreed to cost share (50/50) the purchase of ALERT stations for the following City dams: • West Park • East Park • Dam #7 • Dam #3 • Dam #2a • Dam #2b • Dam #4 • Dam #99
IGA	8/25/2005	8/25/2030	State of Arizona	FCD-2004A009	The State will fund new ALERT stations in the Buckhorn-Mesa watershed, specifically above the Loop 202 levee, and FCD will install and maintain for 25 years (3 rain/stream, 1 stream, 4 rain). State will be responsible for monitoring the ALERT gages and subsequent notifications, and developing an EAP. Amendment #3 (recorded 3/29/2017) turned over monitoring of the ALERT stations and notification of ADOT to FCD.

FWP - Responsibilities to Recorded Agreements - Updated January 2020

Type	Date Recorded	Date Expires	Agency	Identifier	Terms and Provisions
IGA	12/31/2007	12/30/2032	Magma Flood Control District (Magma FCD)	FCD-2007A011	FCD to add a water-level sensor to the existing ALERT weather station at Magma Dam in Pinal County. Magma FCD paid initial costs for the water-level sensor. Magma FCD responsible for water-level sensor replacement due to vandalism, natural causes or age/wear and tear.
IGA	10/3/2008	10/3/2033	Central Arizona Water Conservation District	FCD-2008A003	CAWCD will fund the purchase of a full ALERT weather station for the south end of Lake Pleasant. FCD will maintain the station and make data available via the internet. CAWCD responsible for component replacement due to vandalism, natural causes or age/wear and tear. Station remains the property of CAWCD. Maintenance of ET sensors will be conducted by CAWCD.
IGA	2/14/2013	In Perpetuity	MCDEM	FCD-2012A015	Established to define the responsibilities of the parties in providing emergency services to the residents of Maricopa County during times of flooding and dam or levee safety-related emergencies. Operate and staff the ALERT system and the ALERT room at FCD offices to provide information to MCDEM and other agencies as specified in the EAPs.
RES	9/17/2013	None	FCD	2013R004	The Chief Engineer and General Manager is authorized and directed to include funds for ALERT2 implementation in the current and future five-year CIP, to purchase materials, hardware and software for ALERT2 and to award contracts for engineering and construction necessary to implement ALERT2.
IGA	2/26/2014	2/26/2019	National Resources Conservation Service (NRCS)	FCD-2014A001	Agreement/Plan for operation and maintenance at Buckeye FRS #1. FCD will, at least annually, inspect and maintain the ALERT station on the dam.

FWP - Responsibilities to Recorded Agreements - Updated January 2020

Type	Date Recorded	Date Expires	Agency	Identifier	Terms and Provisions
IGA	5/27/2015	5/26/2040	City of Phoenix	FCD-2014A017	Install 16 ALERT stations in the City of Phoenix. City to pay initial hardware cost and secure permits. FCD to install and maintain stations, develop/maintain rating curves, and make data available via the internet. Initial hardware cost not to exceed $200K, with a cap of $500K through the life of the Agreement. Amendment #1 (dated 8/17/2016) allowed the purchase/installation of an additional rain station for 19th Avenue at Dobbins Road under the established terms.
IGA	5/4/2016	5/4/2026	MCDOT	FCD-2015A014	Outlines the Automated Flooded Roadway Warning Assembly Program. Shared cost not to exceed $400K per year. Each agency will fund 50% of the program cost. MCDOT will serve as the lead agency. MCDOT will identify and obtain rights-of-way for structural components. MCDOT will install and maintain structural components. FCD will install and maintain the flood warning components of the warning assemblies.
LUL	5/25/2016	5/24/2040	CAWCD/Central Arizona Project	CAWCD 2016-123	3 ALERT stage stations and 1 rain/stage station were purchased by CAWCD and donated to FCD for installation on the Reach 11 Dikes. FCD will maintain the stations and make data available via the internet for the duration of the license.
IGA	6/22/2016	6/22/2041	City of Mesa	FCD-2015A017	Install 15 ALERT stations in Mesa at a quoted cost of approximately $125K. City will select sites and secure permits. FCD will secure radio licenses, purchase initial equipment, install equipment, maintain equipment, develop and maintain rating curves and maintain an accessible electronic repository for the data.
IGA	7/20/2016	7/20/2041	Town of Queen Creek	FCD-2016A011	Install two ALERT stations in the Town. The Town will reimburse equipment cost, select sites and secure permits. FCD will secure radio licenses, purchase initial equipment, install equipment, maintain equipment, develop and maintain rating curves,

FWP - Responsibilities to Recorded Agreements - Updated January 2020

Type	Date Recorded	Date Expires	Agency	Identifier	Terms and Provisions
					and maintain an accessible electronic repository for the data.
JFA	10/1/1990 - 10/1/2020	Renewed Each Year	United States Geological Survey	FCD-2018A003 18CMAZ03700	FCD and USGS share costs of installing, maintaining and developing rating relationships for multiple continuous-measurement and peak-measurement stream gages in Maricopa County. Special research projects with direct benefits for FCD are also funded.

Appendix B – Flood Response Plans

FCDMC Flood Response Plans - 2020					
Name	**Completion**	**Alert Levels**	**Mapping Levels**	**Active?**	**Author**
Adobe Dam / Desert Hills FRP	Jun. 2005	Green Alert Orange Alert Red Alert	100-year Floodplains & Floodways	**No**	JEF
Aguila Flood Response Plan **Aguila / Upper Centennial Wash FRP**	Feb. 2004 Apr. 2015	Green Alert Orange Alert Red Alert	100-year Floodplains 100-yr. Floodplains & Floodways	Yes	HDR FCDMC
Bullard Wash FRP: I-10 to Lower Buckeye **Bullard Wash FRP: Camelback Rd. to MC 85**	May 2004 Jul. 2012	Flood Condition 3 Flood Condition 2 Flood Condition 1	100-year Floodplains 100-yr. Floodplains & Floodways	Yes	LTM FCDMC
Cave Creek Flood Response Plan	Feb. 2007	Green Alert Red Alert	100-year Floodplains & Floodways	Yes	LTM/HDR
Fountain Hills Flood Response Plan	Apr. 2002 Jun. 2008	Green 1 Alert Green 2 Alert Green 3 Alert Red, Blue, Purple	Red - 100 yr. Blue - Dam Spillways Purple - Dam Failure	Yes	JEF FCDMC
Gilbert Flood Response Plan	Mar. 2019	Yellow Alert Red Alert	100-year Floodplains & Floodways	Yes	FCDMC
Glendale/Thunderbird Paseo Park FRP	Jan. 1999	Flood Condition 3 Flood Condition 2 Flood Condition 1	None - channel carries 100-year discharge and no response activities outside the channel	Yes	LTM
Peoria Flood Response Plan	Nov. 2013	Flood Condition 1 Flood Condition 2 Flood Condition 3	100-year Floodplains & Floodways	Yes	FCDMC
Scottsdale Flood Response Plan	Aug. 2004 Apr. 2020	Green Alert Orange Alert Red Alert	100-year Floodplains & Floodways	Yes	HDR FCDMC
Skunk Creek FRP **Upper New River/ Skunk Creek FRP**	Aug. 2001 Nov. 2009	Green Alert Red Alert	100-year Floodplains 100-yr. Floodplains & Floodways	Yes	TT/JEF FCDMC
South Mountain / Laveen FRP	Sep. 2016	Yellow Alert Orange Alert Red Alert	100-year Floodplains & Floodways	Yes	FCDMC
Wickenburg Flood Response Plan	Mar. 1999 Apr. 2009	Green Alert Orange Alert Red Alert Blue Alert	Green - Roadways Orange-Structures Red - 100-year	Yes	HDR FCDMC

Text in Blue are Updates to Original Plans

Appendix C – Survey of Similar Systems

Response Compilation - Flood Warning System Operators Survey, March 2020

Question	Maricopa County, Phoenix, AZ	Yavapai County, Prescott, AZ	Harris County, Houston, TX	MHFD, Denver, CO
Coverage (square miles)	12,044	5,688	3,044	2,361
Jurisdiction Size (population)	4,400,000	221,000	4,500,000	3,000,000
Automated Rain Gages	356	108	183	209
Square Miles/Rain Gage	33.8	52.7	16.6	11.3
Persons/Rain Gage	12,360	2,046	24,590	14,354
Automated Water-level Gages	218	32	178	112
Automated Weather Stations	40	15	11	29
Web Cameras	6	0	1	1
Majority Funding Source	Property Tax and Local Cost Share	District Levy Tax	Property Tax	Property Tax and Local Cost Share
Clients/Customers	FCD Divisions, County Departments, Emergency Responders, Recreational Lakes, Law Enforcement, Public Works, State and Federal Agencies, News Media, General Public	National Weather Service, Yavapai County Emergency Management Coconino Emergency Management , Local law enforcement, YC Flood Control District, ADWR, Arizona Department of Environmental Quality, Arizona Department of Game and Fish, Agua Fria National Monument, local fire districts, Swift Water Rescue and other state, federal and local agencies.	Residents, emergency personnel, and flood operations team	Public safety, public works, emergency management, elected officials from the seven-county Denver metro area, which includes 35 incorporated towns and cities. Federal and state agencies, local news media and the general public.
Size/configuration of staff	4 Professional (1 Manager, 1 Meteorologist, 2 Hydrologist) 5 Maintenance Technicians 1 Intern	1 Flood Warning Program Manager 1 Full-time Technician (Flood Control Specialist), 2 Part-time Technicians [50% ea.], 1 Stormwater engineer [5%] 1 Project Manager [5%]	The hydrologic operations division includes: Division director 8 hydrologic technicians 1 hydrologic manager 2 flood forecasters.	The primary flood warning support staff includes 5 full-time personnel. Most of the work (meteorological support and gauging station maintenance) is performed by outside contractors.

Response Compilation - Flood Warning System Operators Survey, March 2020

Question	Maricopa County, Phoenix, AZ	Yavapai County, Prescott, AZ	Harris County, Houston, TX	MHFD, Denver, CO
Does staff perform regular duties outside of flood warning?	Occasional outside project assignments (i.e. Air Quality Data Display Map)	Program Manager and Flood Control Specialist are devoted to Flood Warning. Others contribute as-needed.	Staff is dedicated to all things included with running the flood warning system.	All staff do.
Installation costs for a single automated rain gauge in terms of:				
Equipment	$7,500	$9,500	$7,000	$5,300
Labor	$500	$600	$600	$3,000
Annual Maintenance	$800	$300	$700	$1,100
Is automated data publicly available (in near-real time)?	Yes, all data is available via FCD website.	Not currently. However working with the vendor to make this a component of new website.	Yes: stage, rain, full weather and inundation.	Yes, all data is available via website.
Is any/all of automated data edited/formatted/published?	Yes. Edit/format/annually publish all precipitation, water-level and weather data. Storm reports prepared for severe events. Statistical summaries.	Edit - Clean up bad reports and insert missing data from transmitter data logger No formatting No publishing	On occasion we correct stage data if available. A QA/QC monthly rain report is generated at the end of each month and published to website.	Water-level reports, weather station reports, rainfall IDF statistics, all using edited data.
Are there any established flood response or emergency action plans where actions are initiated by your automated data?	Yes - 11 active Flood Response Plans, Emergency Action Plans for 22 dams.	No. Staff does send data to Emergency Management, local jurisdictions, and first responders via automatic alarms using text messages. Have added stage vs. inundation though GIS applications for the Agua Fria River and have models with the appropriate data for a few others but there is not enough density in the gauge network.	No. There are thresholds set at every stage site. Most have impacts tied to them. Email and text alerts are available which are received by emergency managers, the public, and our staff. Several agencies use stage data at critical locations to enact their emergency action plans.	Yes. Local governments that are supported have also established such plans.

Response Compilation - Flood Warning System Operators Survey, March 2020

Question	Maricopa County, Phoenix, AZ	Yavapai County, Prescott, AZ	Harris County, Houston, TX	MHFD, Denver, CO
Are any agreements or memorandums with other agencies to install, operate, or maintain automated stations in place?	Yes. Several cities, NWS, USGS, Magma FCD, MCDOT, USGS, NRCS, ADOT, CAWCD.	Yes. Agua Fria National Monument, V-Bar-V Ranch, Water Advisory Committee (groundwater), City of Prescott, City of Sedona, Town of Prescott Valley, ADOT, USFS.	Seven inter-local agreements in place with various cities and drainage districts. Have installed and currently maintain 80 rain and stage gauges for these agencies. This data is incorporated into public website so county and surrounding counties can easily find flooding information hosted in one place.	Yes (USGS, private contractors and IGAs with local government sponsors)
Are stations maintained using personnel from agency or is it contracted labor?	All maintenance performed by in-house staff of five.	For the most part stations are maintained by personnel from the agency. Sometimes have utilized a contractor to help install gauges (post-Gladiator fire). Also hire contractors to help with tower climbing and radar sensor installation on bridges.	Maintain stations with a staff of eight. This was accomplished after utilizing a few consultants in the industry to help train and develop criteria specific to their equipment.	All maintenance performed under contract services.
Does the agency own or support automated signage at hazardous roadway crossings?	Yes. FCD operates seven pairs of flashing warning signs that are activated by upstream sensors or a base-station operator.	None.	None. The Texas Department of Transportation has a few automated flashers with signs. Staff helped install a few of these locations.	Staff supports maintenance for one such site.

Appendix D – ALERT Station Lifecycle Costs

ALERT Station Lifecycle Cost				
YEAR	ALERT Rain Station	Accum. Cost	ALERT Rain/Water-level Station	Accum. Cost
Initial Cost	$8,300	$8,300	$9,620	$9,620
5	$3,725	$12,025	$4,950	$14,570
10	$3,725	$15,750	$4,950	$19,520
15	$4,370	$20,120	$5,595	$25,115
20	$3,725	$23,845	$6,485	$31,600
25	$8,915	$32,760	$10,140	$41,740
30	$4,370	$37,130	$5,595	$47,335
35	$5,995	$43,125	$7,220	$54,555
40	$3,725	$46,850	$6,485	$61,040
45	$4,370	$51,220	$5,595	$66,635
50	$8,915	**$60,135**	$10,140	**$76,775**
Ave. Annual Cost:		$1,203		$1,536

The following assumptions were used to create the Lifecycle table above:

- Prices and the dollar-values are from 2020.
- Stations require visits by technicians for maintenance, calibration and repair. A visit is assumed to include the time of driving and work performed (2 hours) and combines the billing rate of the technician ($205/2 hours) and the cost of a 50-mile trip (truck, fuel and incidental parts at$245). It was assumed that the ALERT rain station receives three visits annually, and that the addition of a water-level sensor increases that to four visits per year.
- The Station battery ($50) is replaced every five years.
- The station solar panel ($320) is replaced every 15 years.
- The station tipping bucket rain gage ($325) is replaced every 15 years.
- The station transmitter/radio ($5,190) is replaced every 25 years.
- The station standpipe ($2,270) is replaced at 35 years.
- The pressure transducer (water-level sensor, $1,535) is replaced every 20 years.

Awards and Recognition

1993 – NACO Award, "Networking Rain Gauge Information with Local Jurisdictions"

1997 – Association of State Floodplain Managers, Inc., "Tom Lee State Award for Excellence," Guidelines for Developing Comprehensive Flood Warning

1997 – National Weather Service Phoenix, "Special Service Award," Wenden Flood of Sept. 1997

1999 – ALERT Users Group, "Pioneer Award" for participation in the creation of the Arizona Flood Warning Program

1999 – Arizona Consulting Engineers Association, "Merit Award – Thinking Out of the Box" for Wickenburg Flood Response Plan

2002 – NACO Award, "Real-time Flood Forecasting Tool for Upper Skunk Creek"

2005 – MCDOT 'Spot Award', Flooded Roadway Warning System

2013 – Maricopa County certified as a "StormReady County" by the National Weather Service

2015 – NACO Award, "Sunflower Fire Interactive Data Display Map"

2016 – NACO Award, "Unincorporated Maricopa County Storm Response Partnership"

2016 – NACO Award, "Flash Flood Potential Tool"

2016 – NAFSMA Award, 2nd Place in Flooding Awareness Campaign, "Flash Flood Potential Tool"

2018 – NACO Award, "Interactive Flood Simulation Phases 1-3"

2019 – National Hydrologic Warning Council, "Operational Excellence Award"

2019 – NACO Award, "Gilbert Flood Response Plan"

Glossary of Terms and Acronyms Used in this Report

ALERT – Automated Local Evaluation in Real Time and refers to a standard for hardware and software that measures and communicates rainfall, streamflow and weather data through a radio network to a base computer.

ALERT Duty Officer (ADO) – the lead person tasked with operation of the ALERT system and with communicating ALERT information during a weather event.

ALERT Station – a unique transmitting structure that has one or more sensors connected and sending data.

CBRFC – Colorado Basin River Forecast Center, National Weather Service, Salt Lake City, UT.

Continuous Gaging Station – a station that stores and/or transmits data from a sensor at regular or event-driven intervals.

EOC – the Emergency Operations Center at MCDEM

FCC – Federal Communications Commission

FEMA CRS – Federal Emergency Management Agency Community Rating System; a program whereby communities submit flood prevention and mitigation activities to receive a class rating which lowers flood insurance rates for policy holders within the community.

FCD – Flood Control District of Maricopa County

FERM – the Flood Control District's Flood Emergency Response Manual

FWP – the Flood Warning Program operated by the Flood Warning Branch of FCD. The program in general is composed of these elements: Planning, Detection, Communication, Action, Maintenance and Exercises.

GIS – geographic information system

Hydrograph – a graph of water depth or discharge vs. time at a particular point on a stream.

IDF – Intensity/Duration/Frequency relationship for precipitation data at a station

Lead Time (Total) – Hydrologic Lead Time = the Basin Response Time + Flood-wave Travel Time. Hydrologic Lead Time + Decision Time + Action Time = Total Lead Time

MCDEM – Maricopa County Emergency Management Department

MCDOT – Maricopa County Department of Transportation

MFRRP – MCDOT Flooded Roadway Response Program

MSP – Meteorological Services Program

NACO – National Association of Counties

NAFSMA – National Association of Flood and Stormwater Management Agencies

NOAA 14 Rainfall Atlas – an NWS document considered the official source of design rainfall in the US. It covers Arizona and portions of other southwestern states.

NWS – National Weather Service

Peak-flow gaging station – a station that records only the highest depth of a passing flood flow. The instrument must be manually read and reset before the next flow.

Rating Curve/Table – a table of relationships for converting one physical property to another. Examples are Stage/Discharge, Stage/Area and Stage/Volume.

USGS – United States Geological Survey

WebEOC – commercial software used by MCDEM during emergencies to transfer messages, files and images to emergency managers throughout the County. Used for documentation purposes.