North Central Texas Council of Governments

# Integrating Transportation and Stormwater Infrastructure

# Flood Early Warning System Master Plan

*July 2026*

*The Texas General Land Office provided guidance, oversight, and funding for this study.*

*This study was also funded by the Texas Water Development Board and Texas Department of Transportation.*

integrating Transportation & Stormwater Infrastructure

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# Abbreviations

| | |
|---|---|
| **ALERT2** | Automated Local Evaluation in Real Time (Version 2) |
| **API** | Application Programming Interface |
| **ASOS** | Automated Surface Observing System |
| **ATMS** | Advanced Traffic Management System |
| **AWARE** | Advance Warning Equipment |
| **BLE** | Base Level Engineering |
| **CAPCOG** | Capital Area Council of Governments |
| **CASA** | Collaborative Adaptive Sensing of the Atmosphere |
| **CHPS** | Community Hydrologic Prediction System |
| **CWMS** | Corps Water Management System |
| **DFW** | Dallas/Fort Worth |
| **EGRT** | Emergency GIS Response Team |
| **EM** | Emergency Management |
| **EOC** | Emergency Operations Center |
| **EP** | Emergency Preparedness |
| **FAST** | Flood Assessment System for TxDOT |
| **FDST** | Flood Decision Support Toolbox |
| **FEMA** | Federal Emergency Management Agency |
| **FEWS** | Flood Early Warning System |
| **FRP** | Flood Response Plan |
| **HCFCD** | Harris County Flood Control District |
| **HEC-RAS** | Hydrologic Engineering Center–River Analysis System |
| **HMGP** | Hazard Mitigation Grant Program |
| **HMP** | Hazard Mitigation Plans |

| | |
|---|---|
| **INFRM** | Interagency Flood Risk Management Initiative |
| **IPAWS** | Integrated Public Alert and Warning System |
| **LCRA** | Lower Colorado River Authority |
| **MAP** | Mapping, Assessment, and Planning |
| **MMC** | Modeling, Mapping and Consequences |
| **NEXRAD** | Next Generation Weather Radar |
| **NLCD** | National Land Cover Database |
| **NOAA** | National Oceanic and Atmospheric Administration |
| **NRCS** | Natural Resources Conservation Service |
| **NTX** | North Texas |
| **NWM** | National Water Model |
| **OEM** | Office of Emergency Management |
| **PRISM** | Parameter elevation Regressions on Independent Slopes Model |
| **RFPG** | Regional Flood Planning Group |
| **RIM** | Rapid Inundation Mapping |
| **SETxFCD** | Southeast Texas Flood Control District |
| **SNAP** | Special Needs Assistance Program |
| **SOP** | Standard Operating Procedure |
| **SSURGO** | Soil Survey Geographic Database |
| **SWOT** | Strengths, Weaknesses, Opportunities, and Threats |
| **TDMA** | Time Division Multiple Access |
| **TFMA** | Texas Floodplain Management Association |
| **TRWD** | Tarrant Regional Water District |
| **TSMO** | Transportation Systems Management and Operations |
| **TWDB** | Texas Water Development Board |

| | |
|---|---|
| **TxDOT** | Texas Department of Transportation |
| **US&R** | Urban Search & Rescue |
| **USACE** | U.S. Army Corps of Engineers |
| **USGS** | U.S. Geological Survey |
| **UTRWD** | Upper Trinity Regional Water District |
| **WCID** | Water Control & Improvement District |
| **WMO** | World Meteorological Organization |

# Executive Summary: NCTCOG FEWS Master Plan

Flooding is a persistent and growing hazard across North Central Texas, driven by rapid development, aging infrastructure, increasingly intense rainfall, and watersheds that can be affected quickly by storm events. The Flood Early Warning System (FEWS) Master Plan for the North Central Texas Council of Governments (NCTCOG), as a critical output from the integrating Transportation and Stormwater Infrastructure (TSI) study, provides a regional framework for improving flood warning capabilities so communities can make faster, more informed decisions that reduce loss of life, property damage, and disruption during flood events.

The TSI study area includes the northern and western eight-county portion of the Dallas–Fort Worth metropolitan area and 85 cities across Dallas, Tarrant, Denton, Ellis, Johnson, Parker, Wise, and Hood counties. The TSI study area is contained within the 16-county NCTCOG region. Continued population growth, expanding impervious cover, and increasing reliance pressure on roads, crossings, and critical facilities are raising flood exposure across the region. Flood conditions vary widely, from rapid-onset flash flooding in smaller urban and suburban watersheds to broader riverine flooding influenced by reservoirs and major waterways.

The Master Plan is based on surveys, community site visits, stakeholder discussions, workshops, and review of existing systems and regional resources. These efforts show that flood warning capabilities are uneven across the region. Some jurisdictions already operate gages, dashboards, and alerting tools, while many others still rely on manual observations, general emergency notifications, and local procedures.

Several consistent needs emerged from stakeholder input. Communities want better sensor coverage, more reliable and accessible real-time data, stronger forecasting and predictive tools, improved upstream and downstream visibility, more integrated data sharing, and warning messages that are simpler and more actionable for both responders and the public. They also emphasized the need for stronger public education, more sustainable staffing, and dependable funding for operations, maintenance, and future upgrades.

The regional characteristics analysis confirms that North Central Texas presents demanding conditions for FEWS planning and operations. The region includes dense urban corridors, rapidly developing suburban areas, rural headwaters, reservoirs, low water crossings, and socially vulnerable populations that may require tailored communication strategies. In many smaller watersheds, flood response can occur within minutes to about an hour, leaving little time for manual interpolation, available action interpretations, and/or disseminating preventative warning actions where data/analysis or resource capacity gaps may exist.

The capacity analysis found that the region already has important assets to build on. Existing strengths include regional partnerships, shared monitoring and data platforms, river forecast products, flood mapping resources, regional preparedness and public education working groups/products, and growing interest in roadway flood warning and decision support tools. However, these assets are not yet functioning as a fully integrated regional system. Monitoring density, data management practices, operational maturity, communication approaches, and public-facing warning capabilities vary significantly among jurisdictions.

The gap analysis highlights several priority issues. Flood risk information is generally strong on a regional scale, but local accuracy and integration remain inequitable in some areas because mapping, models, and updates do not always keep pace with growth and changing conditions. Monitoring gaps remain a major concern as well, especially in fast-response watersheds where rain gage spacing, reporting frequency, and stream gage placement directly affect warning lead time. The plan also identifies weaknesses in last-mile communication, preparedness consistency, warning clarity, and long-term sustainment of local capabilities.

Overall, the Master Plan concludes that the region does not need to start from scratch. North Central Texas already has many of the technical, institutional, and operational components required for a strong FEWS, but these components are often fragmented and inconsistently connected across those responsible for providing and/or responding to the warning messages. Although public warning and preparedness is a local function, the central opportunity is to integrate existing tools, partners, and practices into a more coordinated regional system that improves shared situational awareness and supports local jurisdictions and counties.

To move toward that outcome, the plan organizes improvement around six broad areas: flood risk identification, detection and forecasting, coordination and decision support, preparedness and response, and public awareness and education. Recommended strategies include improving shared risk information, expanding and standardizing monitoring networks and equipment (e.g., flood gages), strengthening impact-based forecasting and decision tools, clarifying coordination roles, improving warning delivery and message design, and establishing stronger preparedness and outreach practices across jurisdictions.

In summary, the NCTCOG FEWS Master Plan provides a practical regional roadmap for moving from fragmented but capable flood warning activities toward a more coordinated, scalable, and sustainable system. Its findings support a future implementation phase focused on stronger monitoring, better interoperability, clearer communication, improved preparedness, and long-term operational resilience across North Central Texas.

# Chapter 1

# Introduction and Purpose

Flood early warning systems (FEWS) were identified by stakeholders in the region as a potentially useful tool for tackling flooding issues through the integrating Transportation and Stormwater Infrastructure (TSI) study. Accordingly, the scope of work for TSI was developed to include a standard operating procedure (SOP) document for FEWS as well as the development of this Master Plan. The SOP was written generally for application to any study area and provides guidance for an associated Master Plan to be developed.

The SOP and Master Plan philosophy follow the “End-to-End” (E2E) approach of FEWS design developed by the World Meteorological Organization (WMO). FEWS are described as a complete, connected chain of steps — from detecting a flood threat all the way through to communities taking protective action. The core idea is straightforward: a flood warning system is only as good as its weakest link. Even the most sophisticated weather forecast is useless if the warning never reaches the people in danger. The E2E framework therefore connects key steps into one unified system: collecting rainfall and river data; producing a flood forecast; composing a clear warning message; delivering that warning to the public and emergency managers; enabling communities to act on the warning; and reviewing the system's performance after each event to improve future response. The fundamental message of the E2E philosophy is that technical excellence in forecasting means little without equal investment in the human and communication systems that carry warnings to the people who need them most.

The SOP includes a broad range of issues to consider when developing a Master Plan. However, the level of effort needed to fully consider all the issues highlighted in the SOP is substantial and may not be necessary in each case. Some thought is needed to recognize the current state of the FEWS in the target community and incorporate the analyses suggested by the SOP in a phased or measured approach. Work on the highest priority issues first then tackle the rest as time and budgets allow. Aim for continuous improvement over time.

The Master Plan contained within this document has been developed specifically for the TSI study area by following the SOP. While this document serves as the foundation for planning FEWS in the TSI study area and can serve as an example Master Plan, the contents for FEWS Master Plans developed for other study areas may vary significantly.

# Chapter 2

# Objectives

Flooding remains one of the most persistent and complex hazards affecting communities across North Central Texas. Rapid development, aging infrastructure, and increasingly intense rainfall events have heightened flood risks, particularly in areas with flashy watersheds and limited monitoring capacity. Effective FEWS are a critical component of community resilience, enabling emergency managers, public works staff, and residents to make timely, informed decisions that reduce loss of life, property damage, and disruption during flood events.

This chapter summarizes key objectives and findings related to FEWS needs within the TSI study area. It draws on regional survey results, targeted community feedback, site visits, stakeholder discussions, and examples from across Texas. This objectives chapter serves as the foundation for this document to evaluate capabilities and identify gaps, challenges, and opportunities for improvement. The FEWS Master Plan is intended to inform the development of a coordinated, scalable, and sustainable flood warning approach that reflects local conditions while leveraging regional data, partnerships, and best practices.

## 2.1 Initial Survey Results (April 2025)

In April 2025, NCTCOG and the TSI study team requested feedback from emergency managers and other relevant staff across the NCTCOG region via a survey to evaluate FEWS currently in use, assess their effectiveness, and identify opportunities for improvement. The survey included questions about system usage, types of systems, operations and maintenance, performance and benefits, challenges and gaps, data quality, funding and sustainability, public engagement, and future improvements.

Forty-one communities, including five special districts, responded to this survey. Fifteen of those were communities or special districts within the TSI study area. Responses to the survey reflect a diverse range of operational environments, from communities with established monitoring networks to jurisdictions lacking any formal flood warning infrastructure. The results show considerable variation in system maturity, technological capability, staffing, and public engagement. Across respondents, a consistent theme emerged: while existing systems provide meaningful benefits, gaps may remain in coverage, resources, and community awareness. The summarized results of the survey are included in Appendix A.

Many jurisdictions, approximately 46 percent (%) of respondents, operate some form of FEWS, most commonly relying on National Weather Service (NWS) alerts, real-time gage and camera networks, or location-specific flood alert systems, as detailed in Figure 2-1. Others lack systems entirely, however, primarily due to funding limitations, insufficient staffing, or a lack of technical expertise, interest, or need, as shown in Figure 2-2. Where systems do exist, responsibilities are widely distributed across local governments, federal agencies, public works departments, and in some cases private vendors or volunteers.

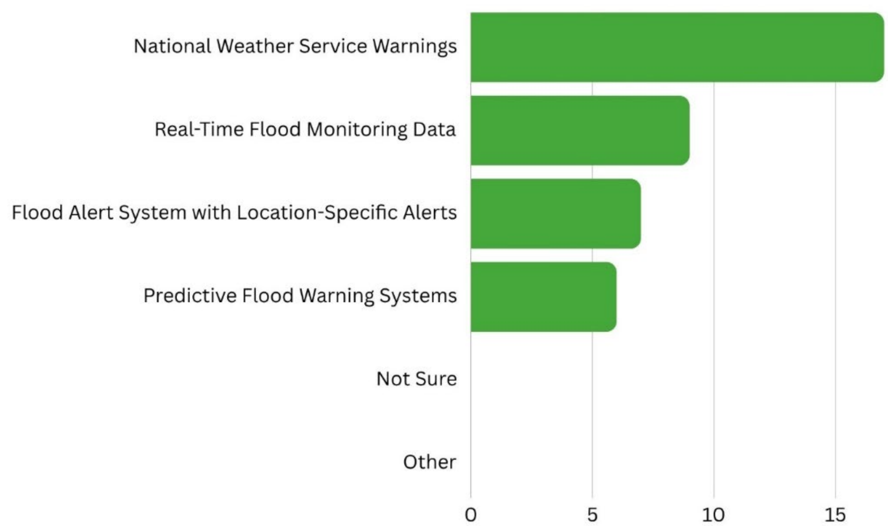


*Figure 2.1. Types of FEWS in use by survey respondents*

Respondents identified several strengths of their systems, including real-time information, improved decision-making during flood emergencies, and timely public notifications. However, many systems face operational constraints such as equipment maintenance needs, subscription costs, staffing limitations, and uneven technician availability. Data quality practices also varied, with some jurisdictions performing routine calibration and validation while others lacked formal procedures.

Public-facing tools such as websites and mobile apps exist in some areas, but access and functionality differ widely. Several respondents reported that their systems provide only general information rather than location-specific alerts. Challenges in public communication such as language barriers, difficulty interpreting technical warnings, and low engagement were also noted.

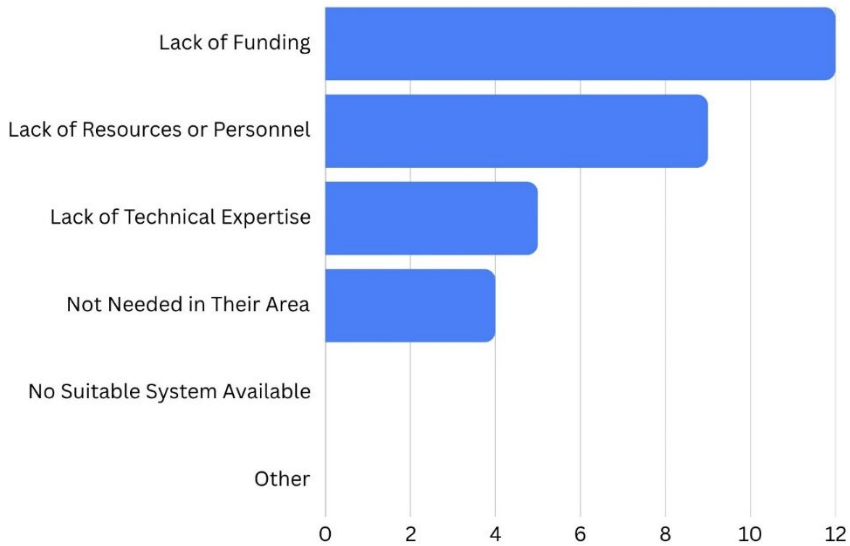


*Figure 2.2. Reasons survey respondents are not utilizing or participating in a FEWS*

Funding emerged as a central issue throughout the survey. While local governments remain the primary source of financial support, respondents indicated that available funding is frequently insufficient to operate, maintain, or expand systems effectively. Supplemental data from federal, state, and local partners is frequently used, but this does not entirely compensate for resource gaps. Most respondents rated their systems as fair to good, but almost all pointed to clear needs for modernization and expansion.

The survey responses revealed a strong desire for improved capabilities, including more monitoring locations, better modeling and forecasting tools, automated flood-activated gates, improved situational awareness platforms, and deeper inter-agency data sharing, as shown in Figure 2-3. Respondents also emphasized the importance of increasing public outreach and education, especially in areas where residents lack awareness of local flood risks and warning procedures.

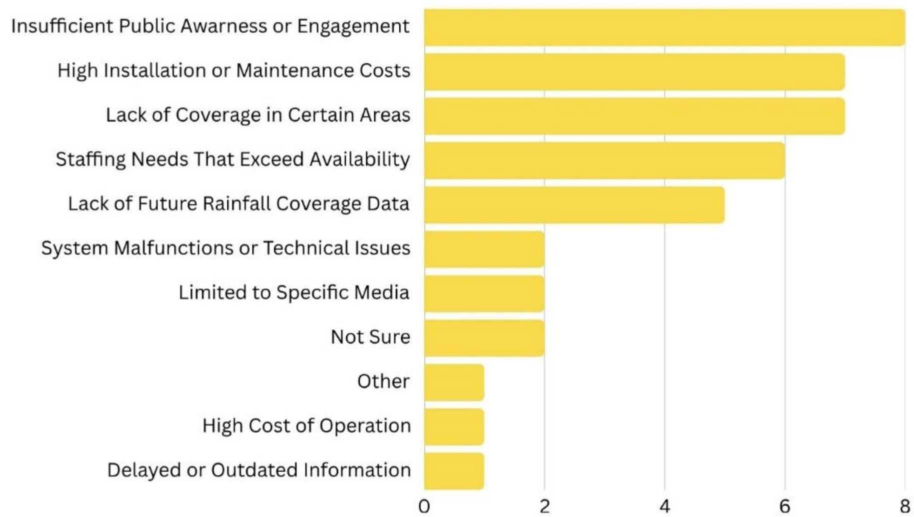


*Figure 2.3. Areas respondents indicated where FEWS improvement is needed*

Overall, the findings highlight meaningful progress in flood warning capabilities across the region but also underscore ongoing challenges especially in funding, staffing, public engagement, and system reliability. Addressing these gaps will be critical for strengthening community resilience and improving emergency response during flood events. Additional community outreach and engagement may be needed to elevate the value of FEWS locally.

## 2.2 Targeted Feedback (through January 2026)

Additional targeted information was gathered from local communities through a brief survey issued in January 2026 (Appendix B), as well as through informal conversations conducted over the past several years. These efforts aimed to better understand the support communities may need to participate in a regional FEWS, enhance their existing systems, or implement new ones. Informal discussions took place during community site visits from 2023 to 2025 and as follow-up to the FEWS Pre-Workshop Meeting held on January 15, 2026.

### 2.2.1 January 2026 Survey Results

Nine communities, including one special district, completed the survey. While it is difficult to draw conclusions based on a low response rate, the results reflect a strong but varied need in a FEWS. All but one respondent indicated a FEWS is needed, but many provided interest only in areas already prone to flooding, reflecting perceived differences in flood exposure. The summarized results of the survey are included in Appendix B.

Among respondents, the preferred operational scale is watershed-based, with this option receiving the highest number of selections. County-scale information is also valued, while regional and jurisdiction-specific scales are secondary preferences. This indicates a design strategy that models conditions at the watershed level but packages outputs in formats directly usable by counties and local operations.

Qualitative responses highlight eight consistent themes: alerts, partnerships, data sharing/interoperability, outreach and education, sensors, funding, staff/time capacity, and dashboards. Communities seek simple, actionable alerting systems tied to reliable, openly accessible data and interfaces that reduce technical complexity. Key barriers include limited staffing, funding for equipment and maintenance, and the need for more cohesive regional data integration, as shown in Figure 2-4.

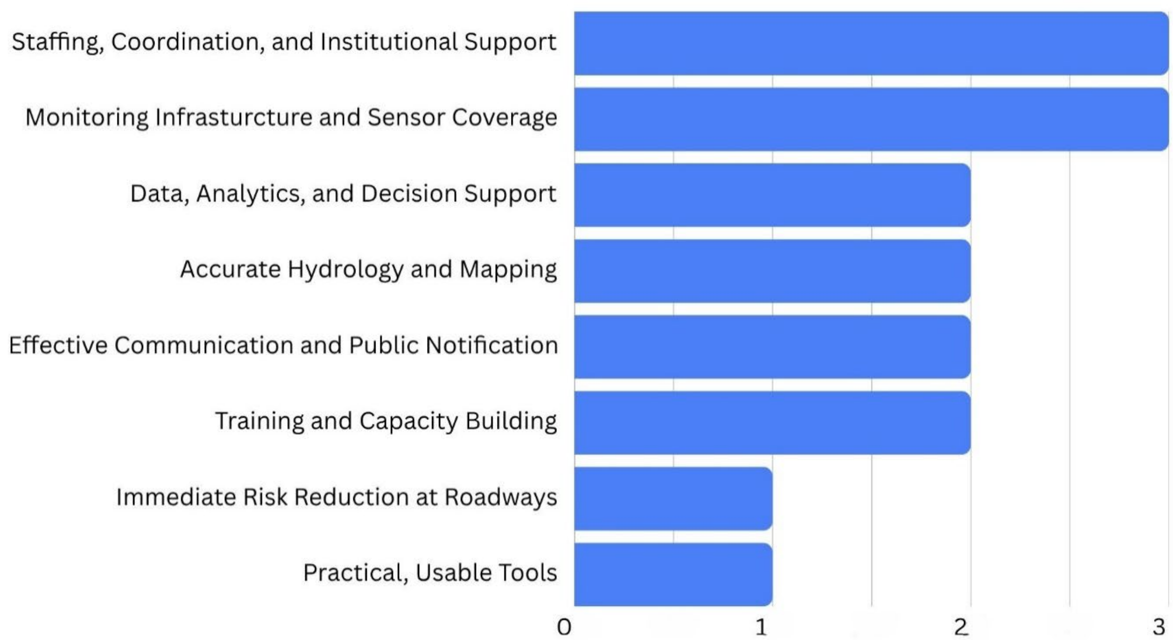


*Figure 2.4. Resources survey respondents identified as most needed to improve FEWS*

### 2.2.2 Community Site Visits

Throughout the TSI study, community site visits revealed clear patterns in how local governments experience and manage flood warning needs. Across the region many noted that flood warning capabilities are limited and fragmented, and that most systems still depend heavily on manual procedures. Staff often monitor roads in person, place barricades themselves, and issue alerts through general emergency systems rather than dedicated flood warning tools. A few places have isolated features such as automated arms, flashing beacons, or individual stream gages, but most described systems that are reactive, labor intensive, and unable to keep pace with fast rising or unpredictable flood events. Many communities emphasized that their flooding begins upstream and outside their control, which creates a strong need for shared regional real time data rather than isolated local systems.

Through all visits, communities stressed the need for more sensors, better sensor placement, and more reliable monitoring. Many described their existing gages as outdated or poorly maintained, and the data they produce is not consistent enough to support decisions. Others had no monitoring at all and expressed frustration that outdated floodplain maps, incomplete hydrologic modeling, and missing elevation information limit their ability to understand risk or justify investment in warning tools. Communities with flashy watersheds, where water rises quickly after a short burst of rain, said manual road checks and basic NWS alerts are not enough. As upstream development increases, many staff reported growing uncertainty about how storms will translate into local flooding without better monitoring networks.

Most communities expressed interest in predictive tools that translate rainfall forecasts into meaningful local warnings. Many said their current systems only identify flooding once it is already happening and that they would benefit from tools that can forecast road overtopping, stream response, and potential evacuation needs. Some want simple low-maintenance systems, while others are interested in more advanced models that simulate rainfall and identify which neighborhoods might be affected first.

Staffing and funding challenges were another common theme, especially in smaller communities without full-time stormwater personnel. Many said they do not have the expertise to design, install, or maintain flood-warning equipment or pursue grants that could fund improvements. Several noted that they need funding for staff as much as they need funding for equipment. Rapid growth also forces many communities to focus on basic drainage needs, leaving little capacity to explore new warning technology. Even where stormwater fees exist, they are often too low to support major upgrades.

Another repeated concern was the effect of upstream growth and the lack of regional coordination. Communities downstream of fast-growing areas described worsening flooding tied to development decisions they cannot influence. Many said a regional FEWS that integrates sensors, shared models, upstream hydrology, and coordinated alert protocols would greatly improve preparedness and create more consistent decisions during storms. Without this coordination, different jurisdictions often make different choices in the same event, which creates confusion and operational challenges.

Despite these concerns, communities noted promising elements that could support stronger regional FEWS. Some already use general emergency alert platforms that could incorporate flood-specific data in the future. Others have automated features at individual crossings that show the value of basic automation. Expanding sensor networks and isolated pilot systems across the region were mentioned as useful starting points. Several communities also expressed appreciation for the TSI study's regional modeling, Base Level Engineering (BLE) updates, and consolidated flood data, and see these as important foundations for future improvements.

Taken together, the regional feedback points to a shared set of needs. Communities want more reliable and widespread monitoring, better upstream and downstream data, affordable and maintainable FEWS, predictive tools that convert rainfall into localized impacts, updated hydrologic information, and coordinated regional planning. There is clear agreement that flooding is a regional problem that requires regional warning strategies, and that progress will depend on improved technology as well as stronger collaboration across jurisdictions.

### 2.2.3 January 15, 2026, Pre-Workshop Meeting Follow-Up

The TSI study team met with FEWS stakeholders on January 15, 2026, to introduce the TSI concept, summarize the FEWS Master Plan, and gather feedback on the proposed approach, resources, and January 2026 survey questions. Input received during this meeting helped shape the more comprehensive draft FEWS findings presented by the TSI study team at a workshop conducted on February 17, 2026.

Stakeholder feedback during the meeting was limited; however, several productive one-on-one conversations occurred afterward between community representatives and the study team. These discussions revealed that emergency management staff experienced confusion about project objectives, terminology, and expectations. To address this, attendees expressed that workshop presentations should use clearer, non-technical language and explicitly communicate how the project will support emergency management personnel during flood events. Because emergency management staff typically focus on response operations rather than technical system functions and often rely on stormwater or engineering departments for detailed monitoring information, this distinction should guide both the workshop content and the design of discussion prompts. **The conversations with emergency management personnel revealed a challenge toward FEWS implementation: a need for increased coordination between the technical and response personnel.**

## 2.3 Engagement in the Master Plan Process

This section summarizes stakeholder engagement conducted to inform the FEWS Master Plan process, including feedback collected through the February 2026 workshop and follow-up outreach with the region's emergency management community. Together, these activities helped clarify needs, improve shared understanding of FEWS concepts and tools, and identify priorities for continued coordination, communication, and implementation support.

### 2.3.1 Post Flood Warning System Workshop Survey Result Summary

The TSI study team held a FEWS Workshop on February 17, 2026, to introduce the proposed TSI FEWS Master Plan process and supporting tools. A post-workshop survey was conducted to assess the effectiveness of the session and gather participant feedback. Fifteen participants completed the survey, and overall feedback was positive. Most respondents rated the workshop favorably, with the majority rating it “Good” or “Excellent,” one respondent rating it “Fair,” and no negative ratings.

Participants generally agreed that the workshop met its communication and educational objectives. Most respondents agreed or strongly agreed that presenters clearly communicated key concepts and that the workshop improved their understanding of the TSI study and the proposed FEWS approach. Similarly, most participants indicated that the FEWS tools and results would be useful in informing flood warning planning or decision-making within their organizations or regions.

Open-ended feedback highlighted appreciation for the introduction to FEWS concepts and tools, with several participants noting the value of understanding how the data and approach could support long-term planning. Suggestions for improvement included a desire for more detailed and technical discussion of FEWS, clearer connections to existing U.S. Geological Survey (USGS) and NWS tools, identification of funding mechanisms to support local implementation, and expanded outreach, particularly to emergency managers, floodplain administrators, public works staff, and city engineers. Several participants also recommended hosting future workshops at regional conferences, such as the Texas Floodplain Management Association (TFMA), to broaden engagement.

### 2.3.2 NCTCOG Emergency Management Community Engagement

NCTCOG’s Emergency Management Department met with several emergency managers in April 2026 from across the TSI study area to conduct targeted discussions. These discussions focused on existing flood warning capabilities, operational challenges, and opportunities for improvement. Communities described a mix of current tools, such as hazard mitigation planning efforts, flood gages, barricades, emergency notification systems, and limited automated infrastructure, paired with continued reliance on manual monitoring and response. Participants shared recommendations and ideas to strengthen local and regional capacity, including improving fire and building codes beyond minimum state standards, upgrading gates and signage at low-water crossings, developing clearer processes for purchasing and maintaining flood sensors and supporting software, and expanding inundation mapping around dams and flood-prone roadway crossings.

Additional priorities included identifying properties suitable for buyout and long-term floodplain management, enhancing coordination for traffic incident management, and expanding training opportunities for emergency management and response personnel, local Incident Command System (ICS) Position Specific training (such as operations, planning, and staging area manager), localized swift water rescue training and related equipment, and grant support. While conditions and resources vary by community, the feedback consistently highlighted shared regional needs for improved monitoring, automation, data integration, locally hosted training, and sustainable funding to support more proactive and effective flood early warning and response efforts.

## 2.4 Texas Examples

Across Texas, many communities are already using a variety of FEWS, and several of their approaches could be applicable to the North Central Texas region. These examples illustrate both the range of available FEWS technologies and the implementation models that may best align with the region's needs and constraints. By reviewing the Texas Water Development Board's (TWDB) FEWS Guidance Document, TWDB's Alternative FEWS Guide, and examples from communities across Texas, approaches most relevant to North Central Texas can be identified. The following section highlights several Texas communities and summarizes their FEWS.

Harris County Flood Control District (HCFCD) runs a very large system with over 200 gage stations, some with additional atmospheric information. They monitor rainfall and stream stages in real time, have automated alerts, and provide a public dashboard. Their setup shows the benefits of having a dense gage network in urban areas and how helpful it is to tie into the NWS Advanced Hydrologic Prediction Services and make information easy for the public to see. (HCFCD, n.d.)

Austin's ATXfloods system is another good example, especially for roadway flooding. They use an online map that shows the status of low-water crossings, and in some locations, they have installed automated flashing lights or gates. ATXFloods.com provides information to Austin and surrounding Central Texas communities and is a partnership between the City of Austin's Watershed Protection Department, Capital Area Council of Governments (CAPCOG), and several local counties and communities. They pair all this with public education to bring notice to potential warnings. (Austin Texas Floods, n.d.)

The Warn Central Texas system, managed by CAPCOG, provides a regional model for coordinated emergency notification across a 10-county area. Using the Everbridge platform, it delivers rapid, multi-channel alerts including calls, texts, emails, and app notifications to residents based on both locally issued emergency messages and NWS warnings. While landlines are included automatically through 9-1-1 databases, residents can self-register mobile numbers, emails, and multiple addresses to receive more tailored notifications. Williamson County demonstrates effective community-level implementation by using pre-scripted messaging for evacuations, shelter-in-place instructions, law enforcement emergencies, and missing-person alerts, supported by public education on how to respond when alerts are received. WarnCentralTexas.org also serves as a preparedness hub, offering tools such as emergency planning guidance, supply-kit checklists, and links to regional flood-monitoring resources like ATXFloods.com, alongside national programs such as Weather-Ready Nation and Ready.gov. Collectively, this system offers a strong example of how Texas communities integrate technology, regional coordination, and public outreach to strengthen early warning capabilities and enhance resident safety during severe weather and other emergencies. (CAPCOG, n.d.)

The Lower Colorado River Authority's (LCRA) Hydromet system takes a more regional approach. They pull together rainfall, streamflow, and reservoir information across many jurisdictions, and everything is accessible through a public dashboard. Their model shows how useful shared data and coordination can be, especially when reservoir operations are part of the local flooding picture. The Hydromet provides near-real-time data on streamflow, river stage, rainfall totals, temperature and humidity from over 275 river and weather gages in the lower Colorado River basin, pulling in additional information from the City of Austin and USGS. (LCRA, n.d.)

Along those same lines, Flood Data North Texas, through NCTCOG, demonstrates the value of a regional flood-monitoring platform. Multiple cities and counties share the same portal and follow standardized system practices, which helps maintain consistent data and supports cost sharing. The Regional Flood Warning Software Platform shows rainfall and water levels provided by gages operated by local municipalities and agencies. (NCTCOG, n.d.-d) This foundational effort that covers the TSI study area is valuable but could be improved through additional coordination and expanded capabilities.

For rural areas, the Bandera County River Authority and Groundwater District demonstrate a smaller scale model. They have combined a gage network with inundation mapping and work closely with the USGS for installation and maintenance. The system produces flood inundation maps to guide the public and provide information to emergency management personnel through near real-time hydrologic data available online and through social media. (BCRAGD, n.d.)

The Southeast Texas Flood Coordination Study (SETx) is a larger rural/regional example, with Advance Warning Equipment (AWARE) gages across eight counties. Lamar University led the effort to install a low-cost sensor network. (SETx, n.d.) This setup shows how partnerships with universities can fill technical gaps and help define long-term roles and responsibilities.

Wise County also uses alternative FEWS equipment, mainly AWARE gages with radar sensors and cellular telemetry. They have been creative with partners, even involving schools for lightning detection, and have made use of platforms like FirstNet and Starlink to address connectivity gaps in rural areas (TWDB, 2025).

On a different end of the spectrum, the City of Amarillo uses a more traditional FEWS setup suited to playa lakes, including bubbler sensors, cameras, and rain gages. Their approach highlights the value of working with consultants for sites that require more specialized equipment (TWDB, 2022).

Across all these examples, several common themes emerge. Regional collaboration helps reduce costs and improve coverage. For rural areas, alternative FEWS that are solar-powered and use cellular telemetry can be much more affordable. Connectivity is a big consideration as well, and some communities are combining cellular and satellite options to ensure data gets through. Partnerships with schools, universities, or other local organizations can add capacity and lower costs. Public dashboards and education campaigns, such as “Turn Around, Don’t Drown,” help with community awareness. And finally, long-term sustainability matters. Agencies need to budget for ongoing operations and maintenance, generally 10-15% annually, and plan for equipment replacement on roughly a 10-year cycle. These takeaways, drawn from the TWDB’s FEWS and Alternative FEWS guidance documents, offer several practical ideas for the TSI study area moving forward. Collectively, these examples demonstrate a wide spectrum of FEWS approaches that can help inform planning and system development within the TSI study area.

For small jurisdictions that characterize much of the TSI study area, the most transferable examples are those that pair modest, maintainable technology with shared technical support and clear public-facing information. Bandera County and Wise County are particularly relevant because they show how smaller or more rural communities can build useful flood warning capability without developing a large urban gage network. Bandera County’s use of real-time gages, flood-inundation mapping, and USGS support demonstrates a practical model for communities that need credible data and mapping but have limited in-house technical staff. Wise County’s use of alternative FEWS equipment, cellular telemetry, and supplemental connectivity options such as FirstNet and Starlink is also transferable because it addresses common rural barriers, including sparse infrastructure, limited staff capacity, and unreliable communications. Flood Data North Texas and Warn Central Texas are also highly transferable at the regional scale because they reduce the burden on individual jurisdictions by providing shared platforms, consistent practices, and scalable public communication tools. In contrast, larger systems such as HCFCD and LCRA offer important best practices but are less directly transferable as full models because their scale, staffing, and funding requirements exceed what many small jurisdictions can sustain independently.

## 2.5 Conclusion

The information summarized in this chapter reflects a shared experience across the TSI study area. Flooding continues to pose a persistent challenge, and while some communities have implemented isolated features such as automated arms, flashing beacons, or individual stream gages, most flood warning efforts remain reactive and labor intensive. Many existing systems rely on manual monitoring and general alerts, making them difficult to sustain and often unable to respond quickly enough to fast rising or unpredictable flood events.

Feedback from surveys, site visits, stakeholder discussions, and workshops points to a common understanding that flooding is not confined to jurisdictional boundaries. There is clear agreement that flooding is a regional problem that requires regional warning strategies, and that progress will depend on improved technology as well as stronger collaboration across jurisdictions. Communities consistently emphasized the need for shared real-time (or near real-time) data, better upstream and downstream visibility, and more consistent approaches to warning and communication. Targeted discussions with emergency management staff further reinforced the importance of regional coordination and local partnerships, highlighting operational challenges and the desire for more integrated, automated, and sustainable flood warning capabilities.

Examples from across Texas further reinforce this perspective. Regional collaboration helps reduce costs and improve coverage, particularly where resources, staffing, and technical capacity are limited. Systems that combine shared monitoring networks, coordinated data platforms, and standardized practices tend to provide more reliable and useful information than isolated local efforts.

Together, these findings highlight both the need and the opportunity for a more coordinated approach to flood warning in the TSI study area. This objectives chapter provides the basis for the TSI FEWS Master Plan, which will evaluate existing capabilities, identify gaps and challenges, and explore practical opportunities for improvement. The goal is to support the development of a coordinated, scalable, and sustainable flood warning approach that reflects local conditions while making effective use of regional data, partnerships, and best practices.

# Chapter 3

# Regional Hydrology and Watershed Characteristics

This section summarizes the setting of the northern and western eight-county Dallas-Fort Worth metropolitan area, comprising the TSI study area, as it relates to FEWS. The intent of this chapter is to describe the characteristics of the study are so that the FEWS can be sized and sited for real-world conditions and to provide background for what FEWS features would and would not be appropriate for the region.

## 3.1 Geographic Extent and Political Boundaries

The study area covers eight counties and 85 cities across a portion of the metropolitan area upstream of the Dallas and Fort Worth urban cores. The working county set is shown in Table 2-1. Population is growing by approximately 130 people per day, which increases exposure to flood risk, adds impervious cover, and expands the number of crossings and facilities that require monitoring and warning (NCTCOG, n.d.-a; NCTCOG, n.d.-c).

*Table 2-1. Counties in TSI Study Area, NCTCOG 2025 Population Estimates*

| County | 2025 Population Estimate | TSI Study Region |
|---|---|---|
| Dallas | 2,762,279 | West |
| Tarrant | 2,260,330 | West, North |
| Denton | 1,068,355 | North |
| Ellis | 239,923 | West |
| Johnson | 217,867 | West |
| Parker | 163,878 | West |
| Wise | 72,674 | West, North |
| Hood | 66,549 | West |

Beyond counties and cities, other special districts and state partners overlap the administrative boundaries. Key regional entities include Tarrant Regional Water District (TRWD), Upper Trinity Regional Water District (UTRWD), NCTCOG, the Texas Department of Transportation (TxDOT), and the United States Army Corps of Engineers (USACE). TRWD and UTRWD each have key water supply missions, with TRWD focused more in the TSI West subarea and UTRWD in the TSI North subarea. TRWD also has a flood control mission as the local sponsor for the Fort Worth Floodway project and operator of multiple reservoirs. NCTCOG's mission is focused on planning for common needs, cooperating for mutual benefit, and recognizing regional opportunities for improving the quality of life in North Central Texas. TxDOT’s focus is to design, build, operate, and maintain the transportation system. USACE has a flood risk management mission that involves the operation of several reservoirs in the study area.

Coordination with these entities is essential for data sharing, operations during reservoir releases, consistent public messaging, and joint training. Notably, many of the smaller cities and populated unincorporated county areas are located more upstream in the watersheds and do not have major watercourses passing through them. The TSI study area, county boundaries, and city limits are shown overlaid with the stream network and reservoirs are shown in Figure 3-1.

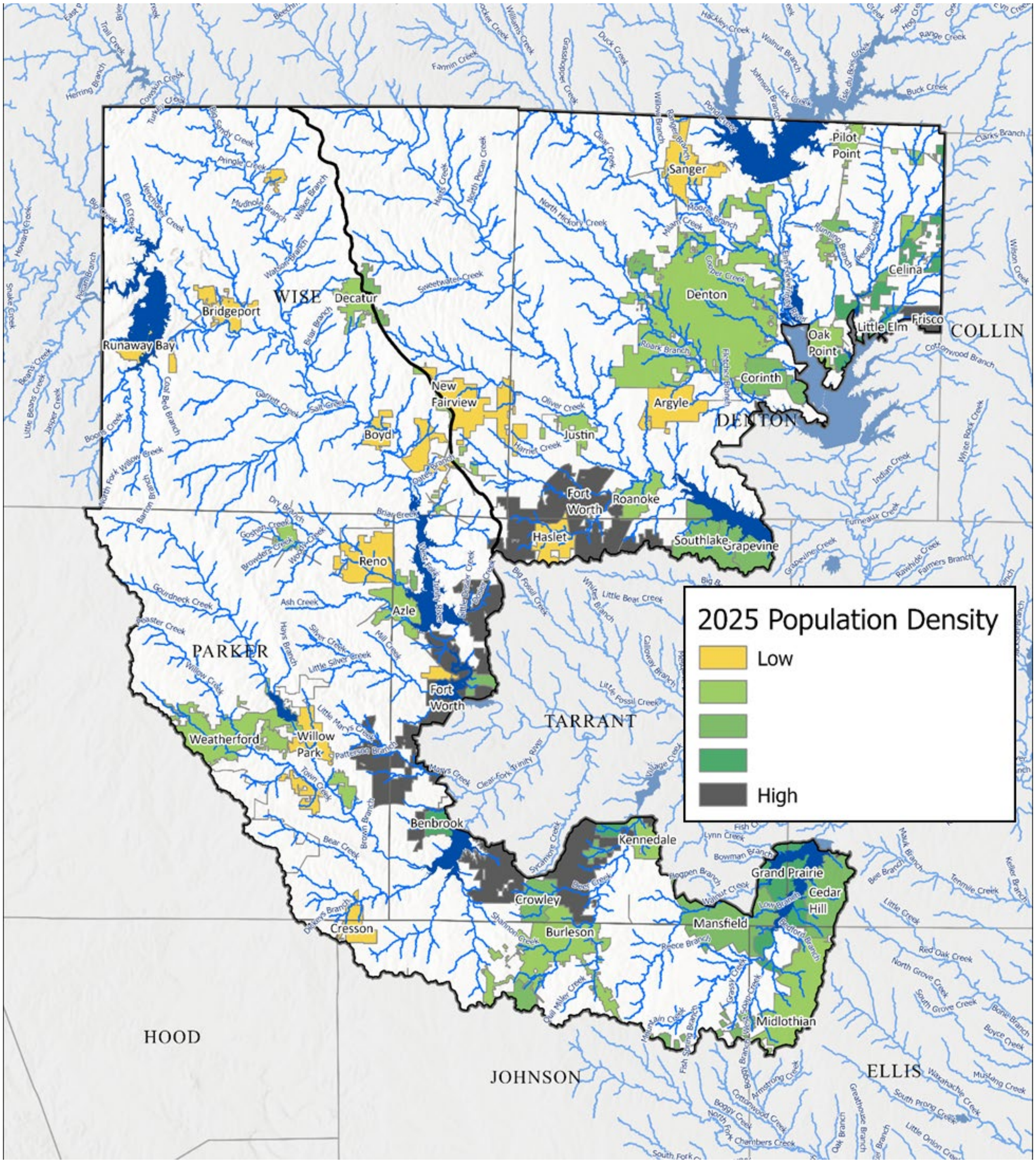


*Figure 3.1. Political Boundaries and Waterways in the TSI Study Area*

Populated areas in the study region include urban neighborhoods with limited car access, seniors in care facilities, schools and campuses, hospitals and clinics, mobile home communities, unhoused residents, outdoor workers, and travelers on major corridors. Diverse populations at risk will likely need bilingual alerts, plain language, large type materials, and targeted outreach to neighborhoods near recurring closures and low water crossings. In addition to the primarily English-speaking population, according to American Community Survey (ACS) data, a large proportion of the population in the study area speaks Spanish at home, especially in currently developed areas. In the more rural areas, there are fewer Spanish speakers (NCTCOG, n.d.-b).

## 3.2 Climate

Climate in the TSI study area is classified as humid subtropical, characterized by hot summers and occasional droughts. Precipitation in the form of liquid rain is the primary driver for flood risk and is seasonally variable with relatively drier winters and summers and wetter springs and fall seasons. (NWS, n.d.) According to the NWS Fort Worth/Dallas Weather Forecast Office, the frequency of thunderstorms and associated severe weather peaks during the spring. Large hail, damaging winds, flooding, and tornadoes occur nearly every year in the Dallas/Fort Worth Metroplex, but a specific location is unlikely to experience all these events every year (NWS, n.d.).

Increasingly intense rainstorms create a high flash flood risk, especially in urban areas with poor drainage and areas with high topographic relief. Flash flooding occurs from both riverine (e.g., creeks, large drainage ditches, and rivers) and pluvial sources (i.e., streets, storm drains, and overland runoff). Climate projections suggest this risk will increase in coming decades due to more extreme precipitation events. Flash flooding kills more people annually than any other severe weather type in North Texas. The rapid onset and urban factors make warnings and response difficult.

In addition to flash floods, the major rivers and reservoirs are subject to traditional riverine flooding from longer duration storms with large rainfall totals and may have a longer lead time for warning.

## 3.3 Natural Environment

Blackland Prairie clays dominate many urban corridors and are prone to low infiltration and fast runoff during high intensity rainfall. Limestone uplands and sandy loams occur in outlying areas and influence baseflow and slope stability. Shrink-swell clays can affect foundations, culvert joints, and sensor footings, and erodible banks can destabilize gage installations and change local stage-discharge relations. Figure 3-2 shows the hydrologic soil groups identified in the Soil Survey Geographic Database (SSURGO) dataset, which relates soil types to runoff production potential (NRCS, n.d.). Per unit of rainfall, type D soils produce the most runoff, whereas type A soils produce the least runoff. Type C or D soils cover most of the study area, indicating high runoff potential. This high runoff potential will require more accurate measurement of precipitation to have enough time for implementing flood warnings.

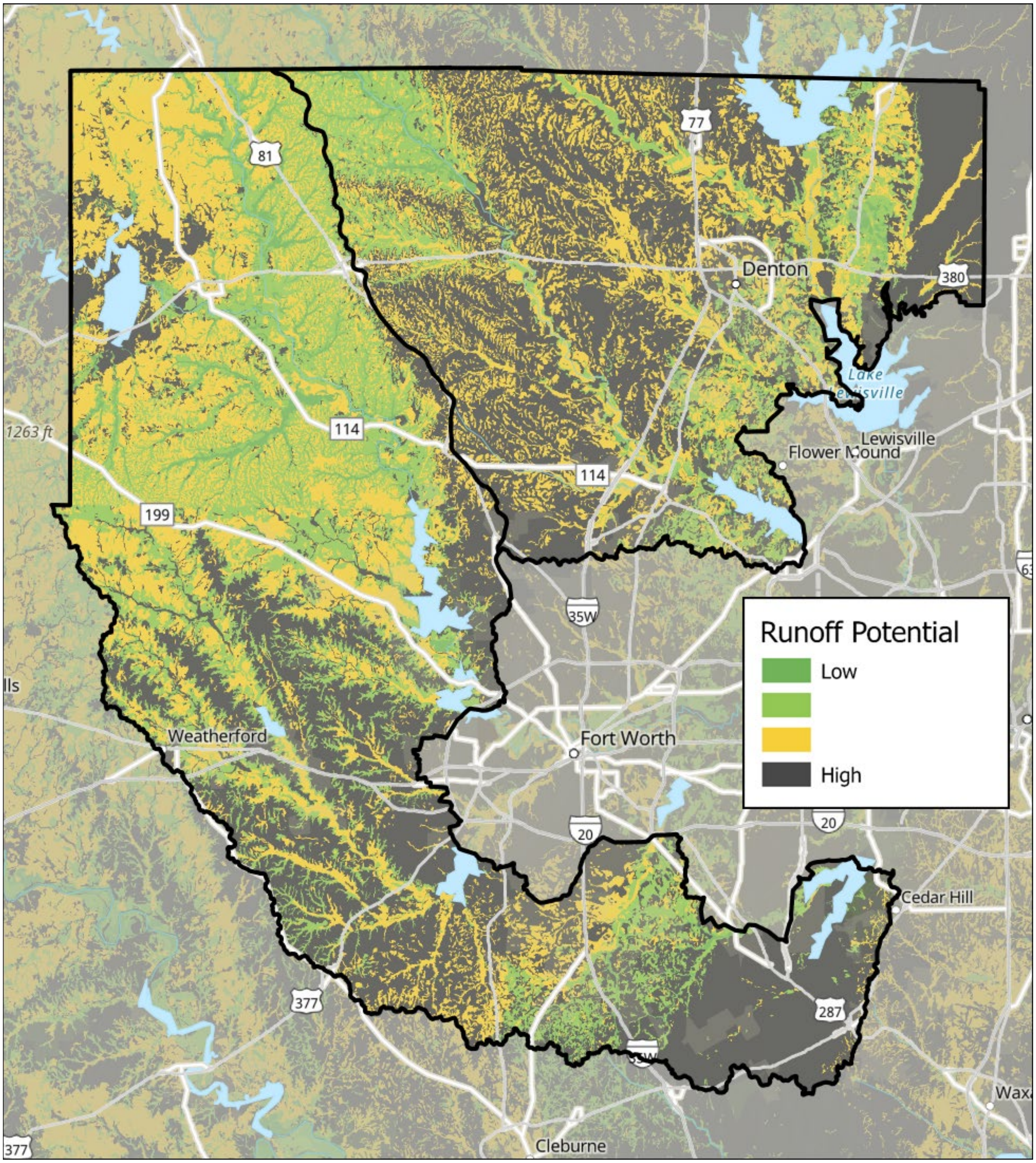


*Figure 3.2. Hydrologic Soil Groups in the TSI Study Area*

Native prairie, oak and juniper woodlands, and riparian corridors persist in patches, while the urban core and growth corridors show high imperviousness with roofs, parking, and roadways. Vegetation growth in channels and at culverts can reduce channel conveyance during the warm season. Right-of-way (ROW) access, tree canopy, and line of sight constraints should be considered when siting rain gages, stage sensors, antennas, and cameras Figure 3-3 shows land classifications according to the National Land Cover Database (NLCD) dataset from 2021 (MRLC, n.d.).

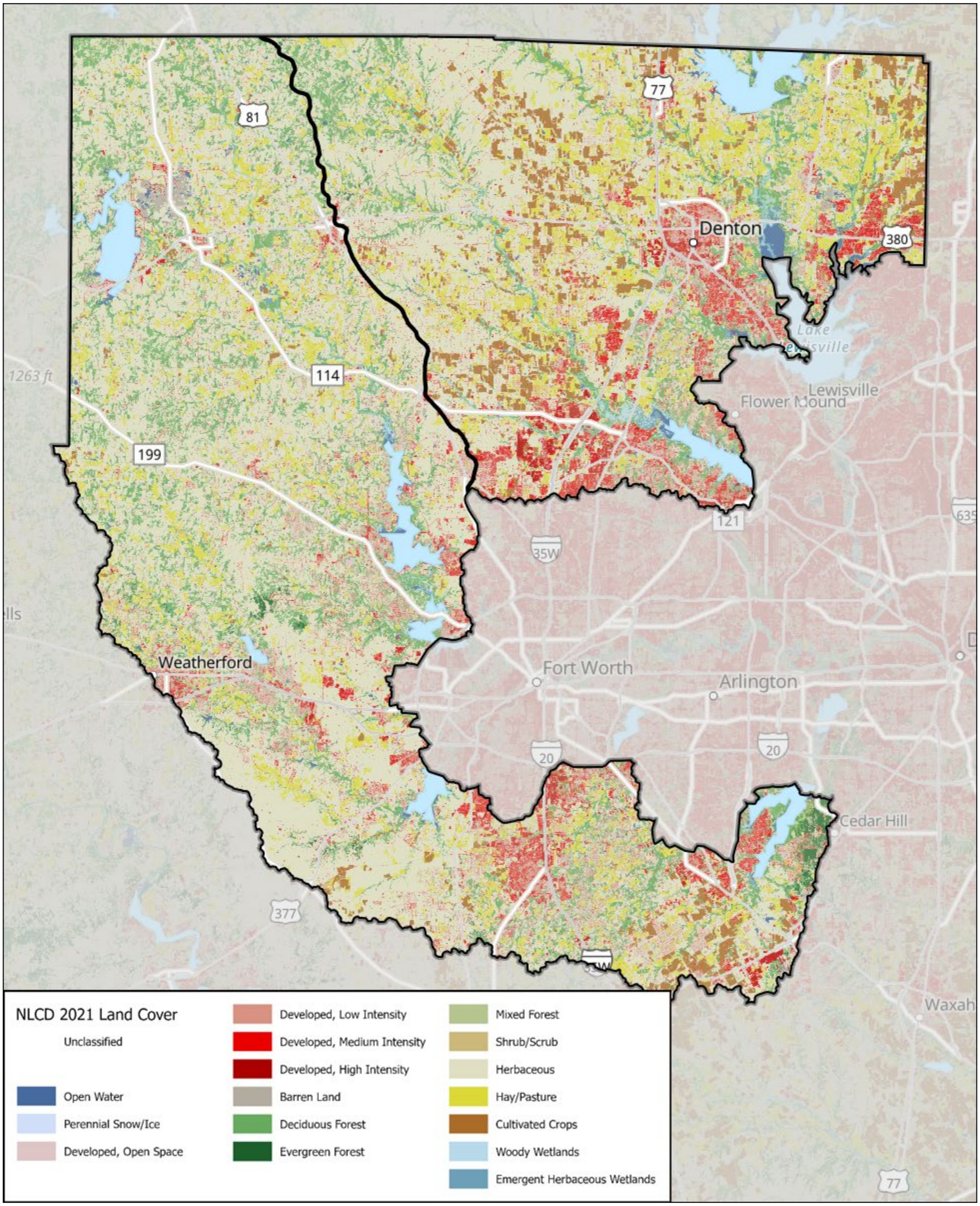


*Figure 3.3. Land Use in the TSI Study Area*

Topography in the TSI study area has steeper upland areas, with floodplain valleys for the major streams being significantly flatter. There is more relief (steepness) in the TSI West subarea compared to the TSI North subarea, particularly for tributaries to the Clear Fork Trinity River like Mary's Creek.

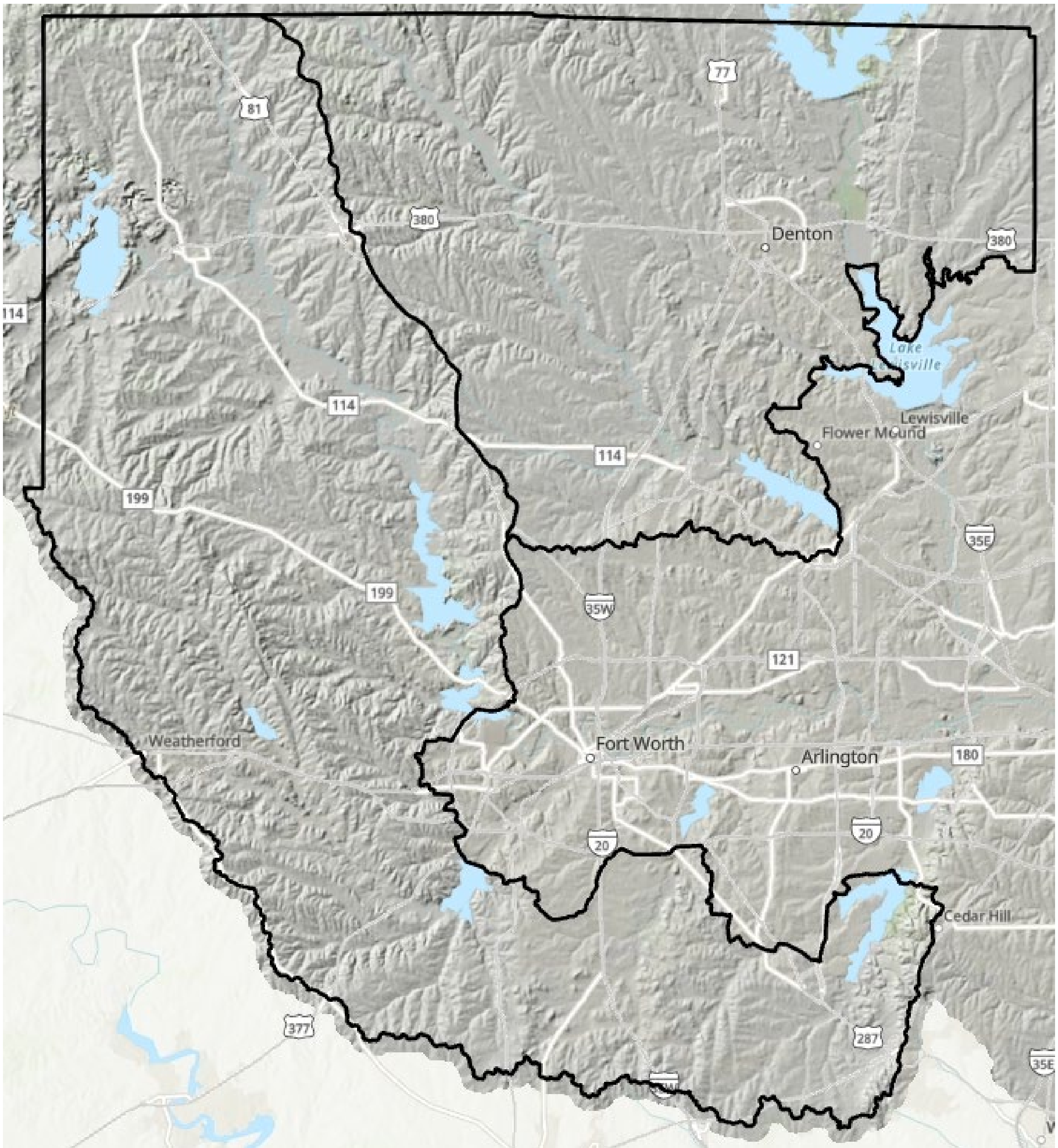


*Figure 3.4. Topography in the TSI Study Area*

## 3.4 Built Environment

The TSI study area includes dense central business districts, suburban residential and commercial areas, industrial and logistics hubs, military and aviation facilities, and rural headwaters. Continued development increases runoff volumes and peak flows unless it is offset by detention and green infrastructure.

Critical facilities include hospitals and trauma centers, water and wastewater plants, power substations, telecommunications nodes, airports and airfields, freight rail lines and yards, interstate and state highways, transit routes, schools and universities, and emergency operations centers. Figure 3-5 shows structures located within a floodplain in the study area, as identified in the TWDB Regional Flood Planning dataset, with specific identification of Critical Facilities (Police, Fire, Hospital, School, Shelter, Power Generation, etc.) and Low Water Crossings. (TWDB, n.d.-d) In addition to being at risk of flooding directly, ingress and egress to critical facilities can be a limiting factor and should be considered for site-specific systems. The figure highlights that flood risk in the TSI study area is pervasive due to the intense rainfall events possible in this area, underscoring the need for a flood warning system.

As part of the development process, built-up areas typically use storm drain systems consisting of inlets and pipes to convey water safely, however due to the intensity of rainfall, dual drainage is allowed, meaning that curb and gutter roadways are permitted to flow in the surface in addition to the captured pipe flow. Roadway access to many locations may be severely limited if rainfall rates are too high.

Rural areas tend to be drained according to the natural topography and have not been significantly altered to facilitate the lower level of development. These areas also tend to have smaller dams throughout the watershed to reduce sedimentation of the streams due to agricultural practices, which have typically been put into place through partnership with the U.S. Department of Agriculture’s Natural Resources Conservation Service (NRCS). These dams can have a significant effect on downstream flowrates in the receiving streams, provided they have been maintained and meet state dam safety standards. The distribution of these dams is clustered in the upper Clear Fork Trinity River watershed in eastern Parker County, as well as northern Wise County. While these dams allow for additional storage capacity when in good condition, their maintenance and safety is also a regional consideration. There are limited funds for NRCS to improve these dams, and efforts to understand and address potential need for remediation are ongoing.

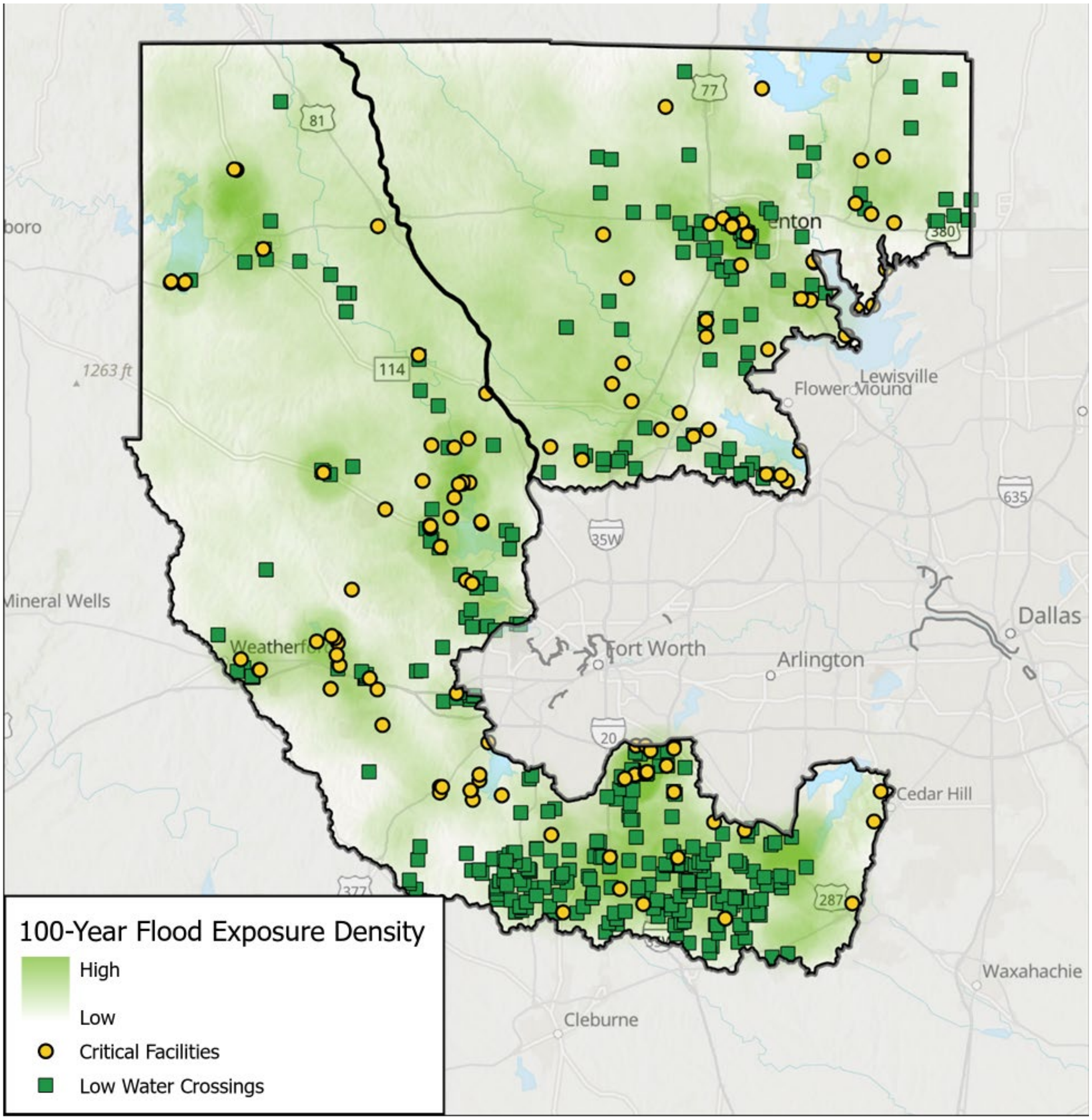


*Figure 3.5. TWDB Structures at Risk, Critical Infrastructure, and Low Water Crossings*

Future land use projections in terms of percent impervious cover, shown in Figure 3-6, show a significant increase in the amount of impervious cover in the upstream areas previously identified. With the conversion of this currently undeveloped, pervious land into highly developed, impervious land, runoff volumes will certainly increase, and increased peak flow rates and flood stages are likely. Depending on development standards, lag time between peak rainfall and peak runoff may or may not change.

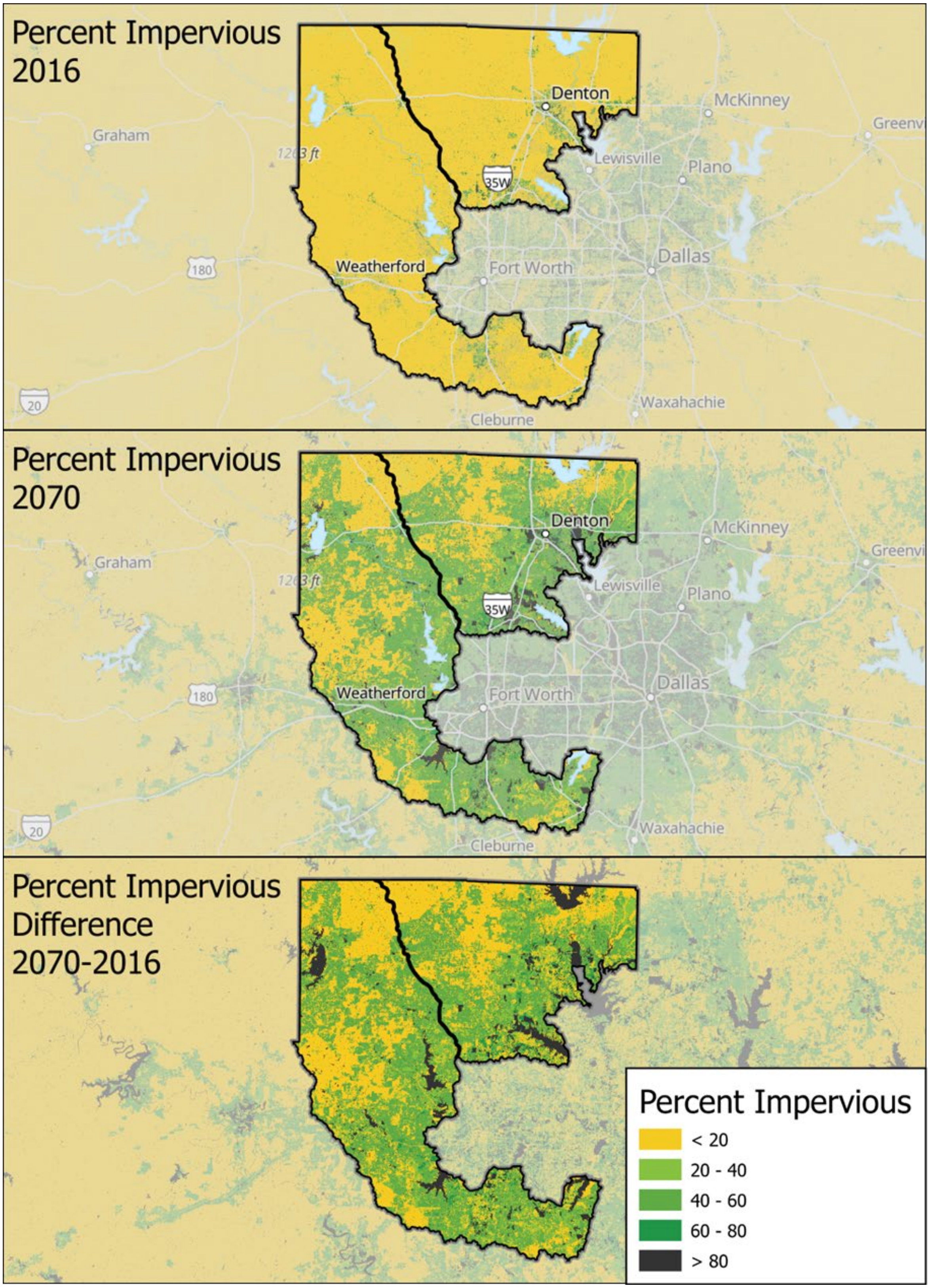
Percent Impervious 2016
Denton
McKinney
Graham
Lewisville
Plano
Greenv
35W
Dallas
Weatherford
Fort Worth
180
20
Waxahachie
Cleburne
Percent Impervious 2070
Denton
McKinney
Graham
Lewisville
Plano
Greenvi
35W
Dallas
Weatherford
Fort Worth
180
20
Waxahachie
Cleburne
Percent Impervious Difference 2070-2016
Percent Impervious
< 20
20 - 40
40 - 60
60 - 80
> 80

*Figure 3.6. Impervious Cover Percentage Estimates (2016-2070)*

## 3.5 Hydrology and Watershed Response

The core hydrologic system is driven by the West Fork Trinity River, the Clear Fork Trinity River, Elm Fork Trinity River, Denton Creek, Village Creek, and Mountain Creek with numerous urban tributaries that respond within minutes to an hour. Though many of the existing reservoirs are for water supply, mainstem reaches downstream of reservoirs have longer lead times and are influenced by release schedules and backwater at confluences. Important reservoirs include Benbrook Lake, Eagle Mountain Lake, Lake Worth, Grapevine Lake, Lewisville Lake, Ray Roberts Lake, and Joe Pool Lake. The USACE reservoirs within that group (Benbrook, Grapevine, Lewisville, Ray Roberts, and Joe Pool) are specifically designed for flood risk management and include additional flood storage volume to detain stormwater inflows and regulate downstream flows. Lead times for major releases are often days beyond high precipitation events, and when those releases do occur USACE staff coordinate closely with local EM's and communities, even to the point of producing inundation mapping associated with forecasted dam operations. Typical travel times on urban creeks range between fifteen to sixty minutes from peak rainfall to peak flow at a given crossing location, while mainstem travel times range from two to twelve hours between index points. Figure 3-7 shows the time difference between the peak rainfall rate and the peak flow rate, indicating which areas have more time between rainfall and runoff.

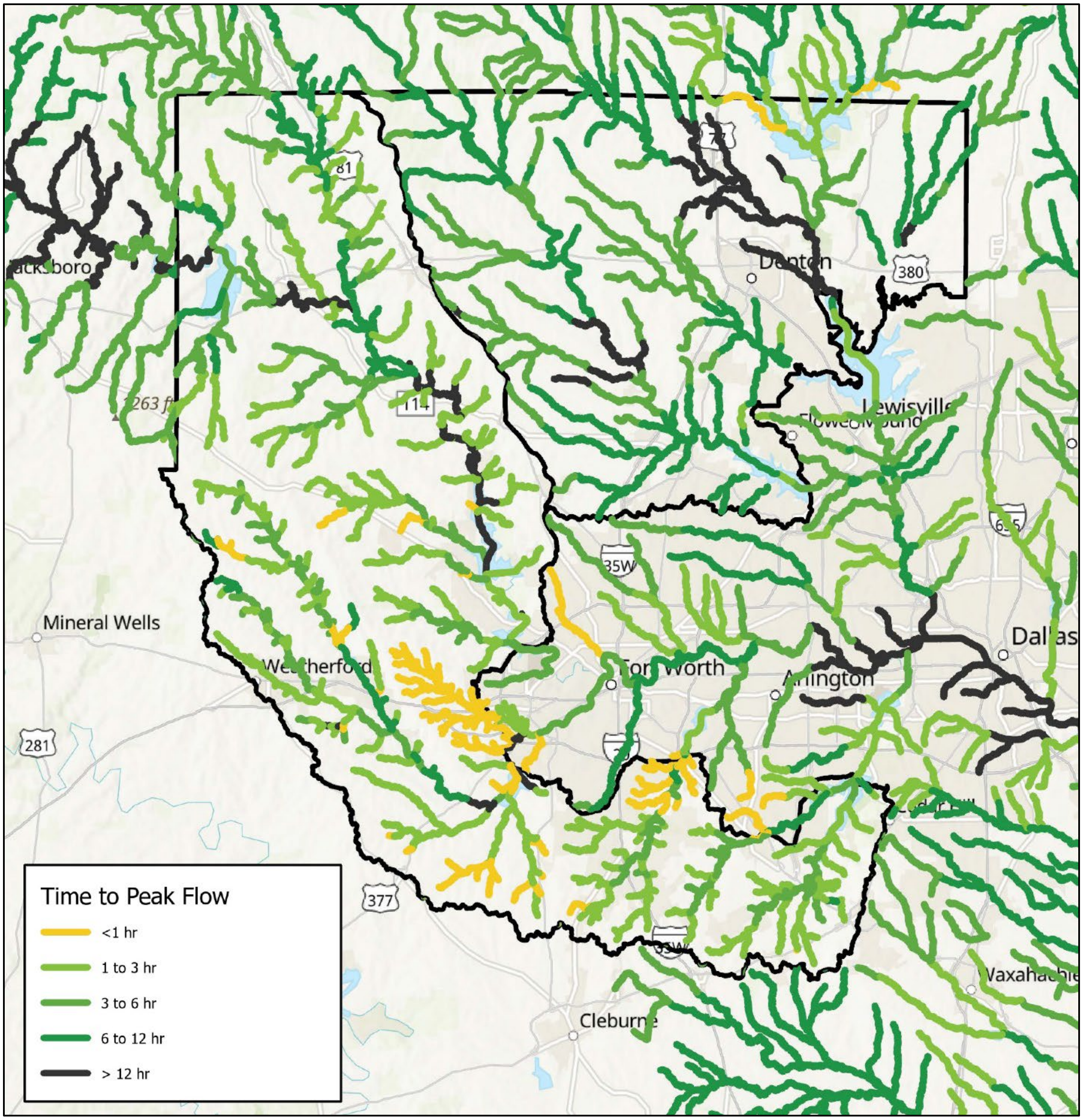


*Figure 3.7. Time to Peak Flow From HEC-HMS Model*

# Chapter 4

# Existing FEWS Capacity Assessment

An essential component of a FEWS is comprehensive data collection and continuous monitoring. With reliable monitoring data, cities, counties, and agencies can make informed decisions about how to protect their communities. This chapter summarizes the available FEWS resources in the TSI study area, such as key regional partners, monitoring hardware, software, and flood mapping resources. The purpose of the capacity analysis establishes a shared baseline of existing resources and practices across jurisdictions. This shared understanding helps the TSI study area jurisdictions and stakeholders identify strengths, gaps, and opportunities for coordination or modernization, while supporting data coordination among partner agencies. The Capacity Analysis also helps communities understand what their neighbors use, align communication standards, share data more effectively, and build consistent regional protocols that help create more interoperable flood warning systems across the region.

Effective FEWS operation relies on coordinated collaboration among regional partners. Key contacts within the TSI study area are identified in Table 4-1. These individuals represent cities, counties, and agencies responsible for monitoring, emergency management, and interagency coordination. Their roles are integral to the ongoing collection, communication, and management of flood-related data within the TSI region.

In the NCTCOG region, flood-warning dissemination and communication have a strong technical and procedural backbone. NCTCOG and its member agencies operate through established structures that support warning-issuance and coordination, but performance on the “last mile” of public action and inclusivity remains unclear due to lack of defined metrics and reporting.

*Table 4-1. Key Contacts of Regional Partners and Entities with Flood Monitoring*

| Type | Entity | Location | Contact | Title |
|---|---|---|---|---|
| City | City of Fort Worth | Fort Worth, TX | Carlos E. Gomez | Acting Emergency Management Coordinator |
| City | City of Grand Prairie | Grand Prairie, TX | SJ Tapia | Public Works Contingency & CRS Coordinator |
| | | Grand Prairie, TX | Chase Wheeler | Director of Emergency Management |

| Type | Entity | Location | Contact | Title |
|---|---|---|---|---|
| County | Denton County | Denton County, TX | Samantha Taylor | Office Director/Emergency Management Coordinator |
| County | Wise County | Wise County, TX | Cody Powell | Office of Emergency Management Coordinator |
| | | Wise County, TX | Jennifer Klemke | Office of Emergency Management Planner |
| Federal | National Weather Service (NWS) River Forecast Centers | NWS West Gulf River Forecast Center (WGRFC) | Jason Johnson | Hydrologist in Charge |
| | | NWS West Gulf River Forecast Center (WGRFC) | Greg (Wally) Waller | Service Coordination Hydrologist |
| Federal | National Weather Service (NWS) Weather Forecast Centers | Fort Worth, TX | Tom Bradshaw | Meteorologist in Charge |
| | | Fort Worth, TX | Jennifer Dunn | Warning Coordination Meteorologist |
| Federal | U.S. Geological Survey (USGS) | Austin, TX | Meghan C. Roussel | Deputy Director of OTWSC |
| | | San Antonio, TX | Douglas Schnoebelen | Branch Chief |
| | | | Stephen Opsahl | Hydrologist |
| Regional | Trinity River Authority (TRA) | Arlington, TX | J. Kevin Ward | General Manager |
| | | Arlington, TX | Amanda Livingston | Safety & Emergency Management |
| Federal | United States Army Corps of Engineers (USACE) | Fort Worth, TX | Bret W. Higginbothan, P.E., CFM | Chief of the Water Resources Branch |
| | | Fort Worth, TX | Maxwell Strickler, P.H., CFM | Lead Hydrologist |

## 4.1 Existing Flood Warning System Hardware Assets

### 4.1.1 Monitoring Hardware

Common data collection methods rely on various types of monitoring equipment, such as rain and stream (stage) gages, as well as weather stations that capture local atmospheric conditions. Active monitoring sites in the region use a range of technologies with tipping-bucket systems being the most prevalent for measuring precipitation. Pressure transducers and bubblers are the most common hardware for measuring flood stages. Across the TSI study area, at least 300 active rainfall (rain) and stream (stage) monitoring locations exist. These monitoring sites are owned and operated by the following entities:

- City of Fort Worth (COFW)
- City of Grand Prairie (COGP)
- National Weather Service (NWS)
- Tarrant Regional Water District (TRWD)
- Texas Water Development Board (TWDB)
- Trinity River Authority (TRA)
- U.S. Geological Survey (USGS)
- Wise County

Detailed breakdown of available monitoring assets by entity is summarized in Table 4-2. Locations of stage and precipitation monitoring equipment across the TSI study area are depicted in Figure 4-1. Locations of precipitation and stage monitoring assets are shown in Figure 4-2 and Figure 4-3, respectively.

*Table 4-2. Monitoring Equipment by Entity*

| Entity | Hardware Assets[1] | | | | | | | | Description |
|---|---|---|---|---|---|---|---|---|---|
| | Type of Gage | | | Weather Stations | | | Total Gages Measuring Rain | Total Gages Measuring Stage | |
| | Rain (Precip.) | Stream (Stage) | Rain & Stream (Stage) | Weather Stations with Rain | Weather Stations with Stage | Weather Stations with Rain & Stage | | | |
| City of Fort Worth (COFW) | 1 | 27 | 29 | 7 | 1 | 5 | 42 | 62 | Pressure transducers, radar with some sites including float switches, weather stations, low water crossing sites<br>Data Source: COFW |
| City of Grand Prairie (COGP) | 0 | 2 | 23 | 0 | 0 | 0 | 23 | 25 | Mix of pressure transducers, rain buckets, and radar. Low water crossing sites also have flood flashers, gates<br>Data Source: COGP |
| National Weather Service (NWS) | 0 | 0 | 0 | 33 | 0 | 0 | 33 | 0 | Weather stations that measure precipitation (Automated Surface Observing System (ASOS) stations)<br>Data Source: https://www.texmesonet.org/# |
| Tarrant Regional Water District (TRWD) | 11 | 2 | 24 | 5 | 0 | 0 | 41 | 26 | Data Source: TRWD |
| Texas Department of Transportation (TxDOT) | 0 | 0 | 0 | 80 | 0 | 0 | 80 | 0 | Roadside environmental sensors[2] |
| Texas Water Development Board (TWDB) | 0 | 0 | 0 | 6 | 0 | 0 | 6 | 0 | Weather stations that measure precipitation<br>Data Source: TexMesonet |
| U.S. Geological Survey (USGS) | 21 | 56 | 42 | 0 | 0 | 0 | 63 | 98 | Data Source: https://www.usgs.gov/ |
| Wise County | 0 | 16 | 0 | 0 | 0 | 0 | 0 | 16 | Data Source: Wise County |

1. Quantities represent hardware assets within the NCTCOG counties, only.
2. Roadside environmental sensor arrays are fixed installations along transportation corridors that collect real-time atmospheric and surface condition data. These arrays typically include sensors for temperature, humidity, wind, precipitation, visibility, and, in some locations, water level, as well as cameras for visual verification. These have been categorized as Weather Stations w/Rain.

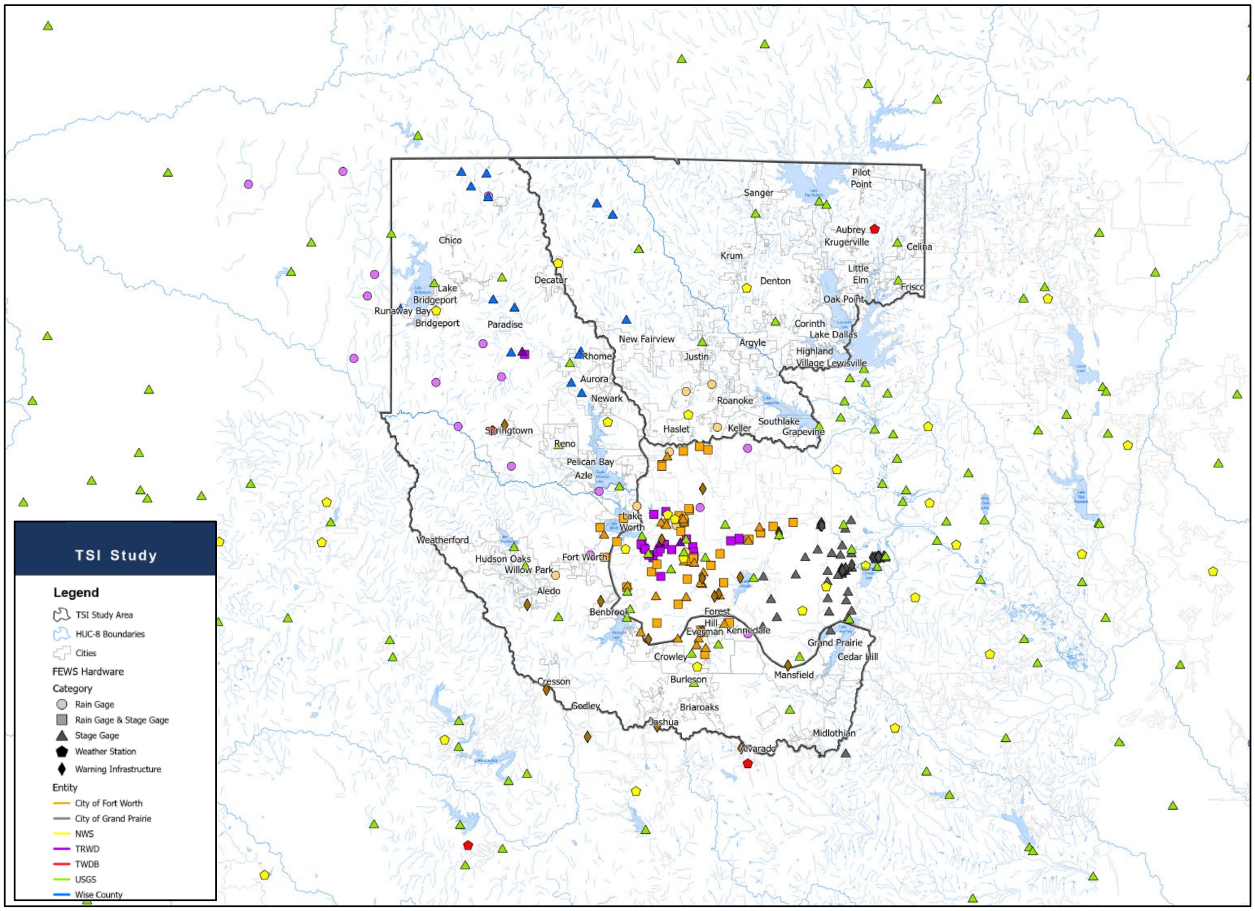


*Figure 4.1. Monitoring Locations*

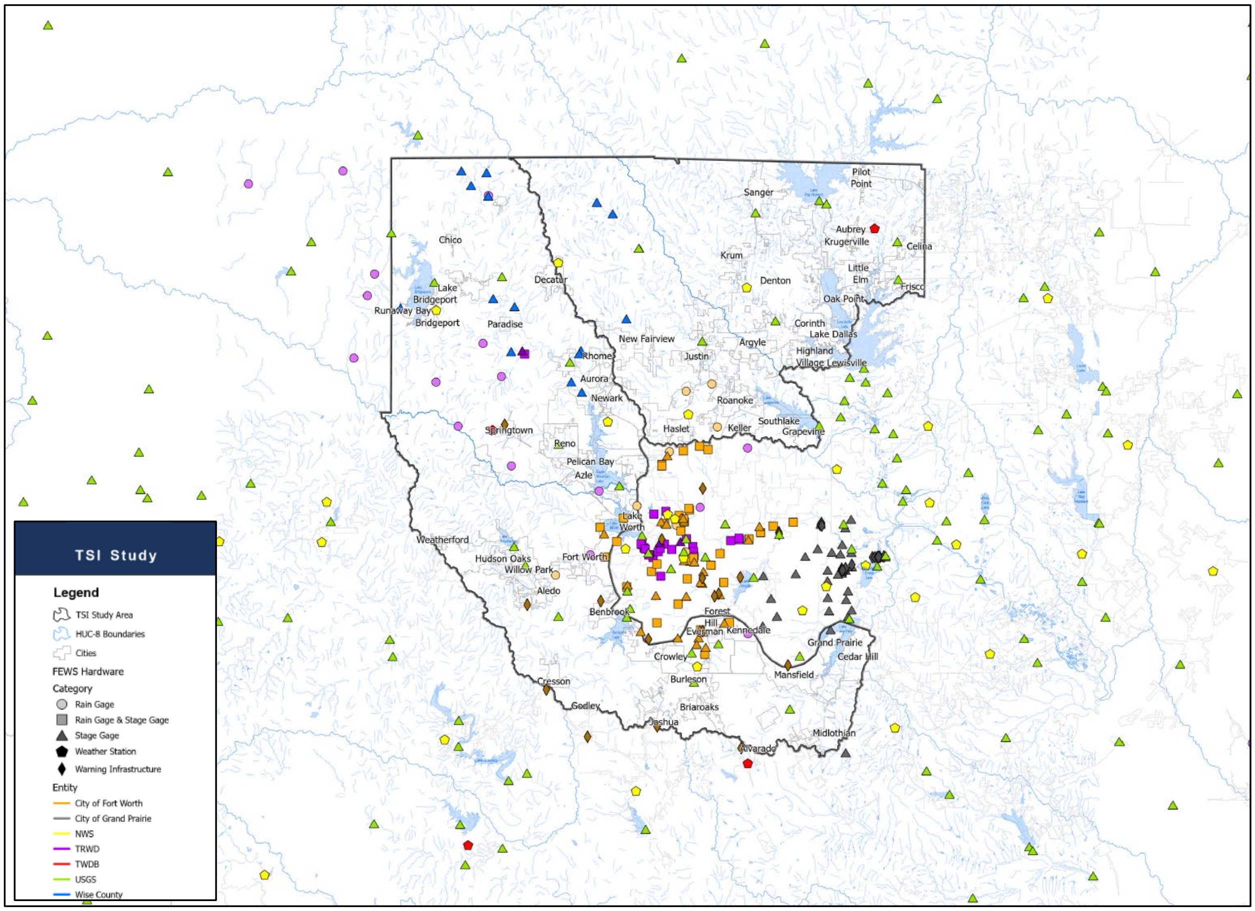


*Figure 4.2. Precipitation Monitoring*

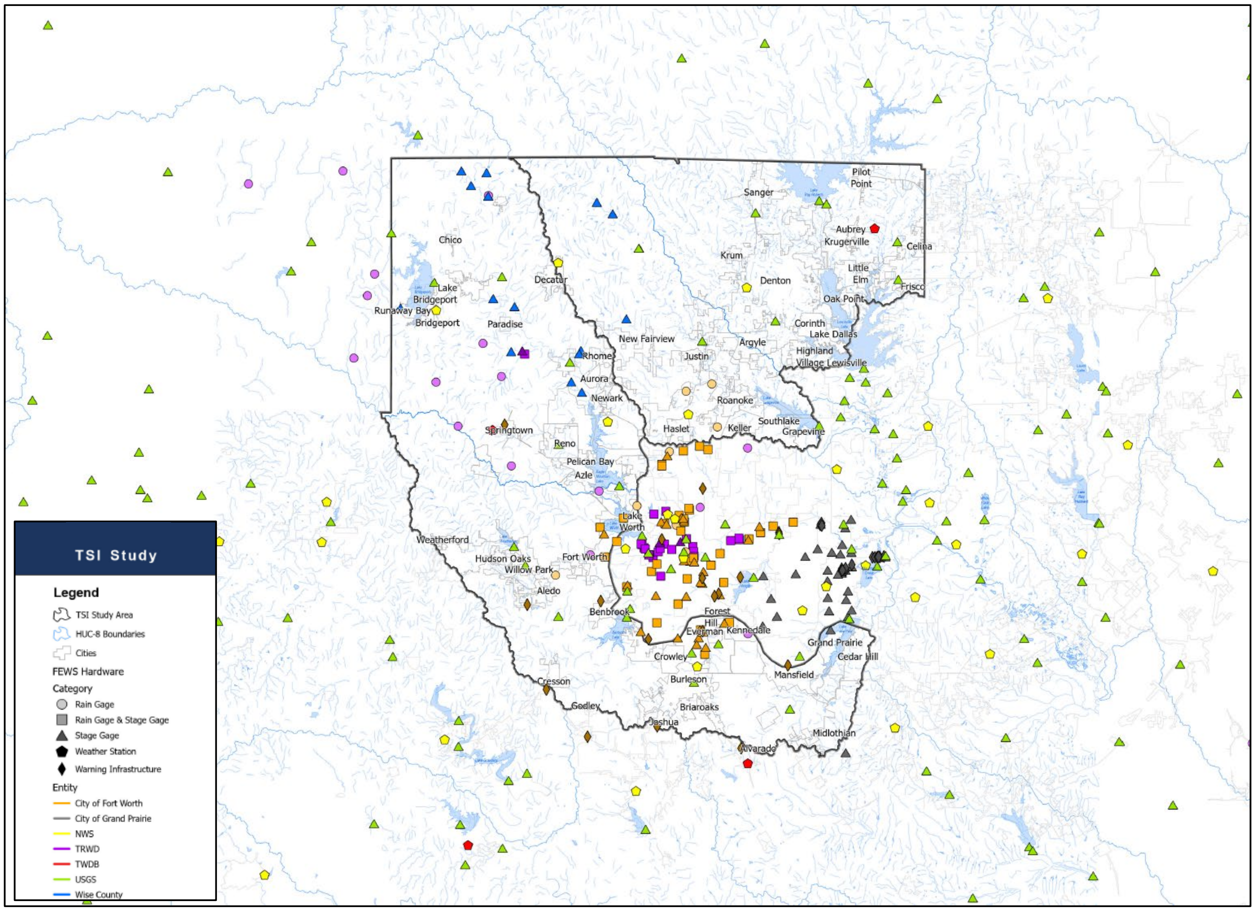


*Figure 4.3. Stage Monitoring Locations*

Collected gage data is transmitted to entities operating FEWS programs through wireless or wired communication. Within the Dallas-Fort Worth region, widely used data transmission methods are cellular, radio, or satellite. Data collected from monitoring equipment via cellular or radio transmission typically reports at intervals ranging from five to 15 minutes, whereas satellite-transmitted sensors generally report on an hourly or daily basis. A detailed summary of the communication methods employed is provided in Table 4-3.

*Table 4-3. Communication Methods by Entity*

| Entity | Communication Method | Reporting Frequency | Notes |
|---|---|---|---|
| City of Fort Worth (COFW) | Radio | Every 10 minutes | ALERT2 protocol with Time Division Multiple Access (TDMA) time offsets; during flooding events, water level is reported by change in 1/10th foot or on an accelerated schedule (up to 16 reports/hour). |
| City of Grand Prairie (COGP) | Radio | Every 2 minutes during rainfall events and every 1 hour during non-rainfall events | ALERT2 protocol |
| National Weather Service (NWS) | Satellite | Hourly | N/A |
| Tarrant Regional Water District (TRWD) | Cellular; radio | Every 15 minutes | ALERT2 protocol |
| Texas Department of Transportation (TxDOT) | Cellular; IP | Every 1 to 5 minutes | LTE/4G cellular supported by LoneStar Advanced Traffic Management System (ATMS); wireless IP-based links for rural areas in Wise County |
| Texas Water Development Board (TWDB) | Cellular | Every 5 minutes | N/A |
| U.S. Geological Survey (USGS) | Satellite | Every 15 minutes | Geostationary Operation Environmental Satellite (GOES) |
| Wise County | Cellular | Every 10 minutes | N/A |

## 4.2 Collaborative Adaptive Sensing of the Atmosphere (CASA) Urban Test Bed in the Dallas Fort Worth Region

In partnership with the NCTCOG, CASA has deployed a network of dual-polarization X-band radars in the Dallas Fort Worth region to support detection of severe weather and urban flash flood conditions. The network collects high-resolution, near-surface atmospheric data and provides rainfall estimates and hazard information at spatial and temporal scales finer than traditional Next Generation Weather Radar (NEXRAD) systems. CASA is especially effective at identifying high intensity rainfall, a primary source of flash flooding. Radars have been installed at the University of Texas at Arlington (UTA), the University of North Texas (UNT), the Justice Center at Midlothian, the Addison Service Center, the Johnson County Emergency Operations Center in Cleburne, Mesquite Airport, and at a City of Fort Worth owned site. As a supplemental data source, CASA demonstrates how emerging sensing technologies can strengthen regional situational awareness and complement existing FEWS infrastructure across the TSI study area.

### 4.2.1 Observational Capacity

- Radar Network - Currently seven operational X-band, dual-polarization radars providing dense spatial coverage across the region (Table 4-4).

*Table 4-4. CASA Radar Locations*

| Location | Approximate Coordinates (WGS 1984) | |
|---|---|---|
| | Latitude | Longitude |
| Addison Service Center (Town of Addison, TX) | 32.98 | −96.84 |
| UT Arlington – Carlisle Hall (Arlington, TX) | 32.73 | −97.12 |
| UNT – Discovery Park Campus (Denton, TX) | 33.25 | −97.15 |
| Midlothian Justice Center (Midlothian, TX) | 32.49 | −96.99 |
| Johnson County EOC (Cleburne, TX) | 32.34 | −97.41 |
| Mesquite Metro Airport (HQZ) (Mesquite, TX) | 32.75 | −96.53 |
| Fort Worth – Boat Club Road site (Fort Worth, TX) | 32.90 | −97.45 |

- Low-Level Sensing - Measures atmospheric conditions below 32,000-feet, allowing for detection of rainfall in lower-level atmospheric weather.
- Rainfall Data Resolution - Approximately one to three acres.
- Adaptive Operations - Radars are activated ahead of forecasted precipitation and deactivated during extended dry periods, optimizing system longevity while maintaining readiness.

### 4.2.2 Temporal Resolution and Update Frequency

- Radar Scan Frequency - Radar products update every one–two minutes.
- Website Refresh Rate - Data auto-refreshes every 30 seconds.
- Network Products - Update times vary by product but products auto-refresh when network level processing and analysis is complete.

### 4.2.3 Hydrologic and Rainfall Products

- Rainfall Accumulation Product
    - Available accumulation intervals include 15 minutes, 30 minutes, one hour, three hours, six hours, 12 hours, 24 hours, 48 hours, and 72 hours.
    - Max 15 Minute Accumulation product identifies maximum rainfall accumulation over any 15-minute interval during the last hour.
- Data Methodology
    - Rainfall estimates combine CASA X-band radar data with NEXRAD S-band data, improving quantitative precipitation estimation accuracy.

### 4.2.4 Forecast and Short-Term Predictive Capability

In addition to estimating rainfall accumulation, CASA forecasts where rainfall is heading, at what speed and at what intensity. This is critical to anticipating where flooding may develop in the coming minutes and hours.

- Reflectivity Nowcast - Predicts 15-minute ahead radar reflectivity in five-minute intervals, continuously running in real time.
- 90 Minute Reflectivity - Experimental product predicts reflectivity out to 90-minutes in five-minute intervals.
- 15-Minute Rainfall Accumulation - Predicts rainfall accumulation out to 15-minutes.

## 4.3 Data Management

Data collected from monitoring stations via various telemetry methods are consolidated into dashboards, public websites, and internal databases. These datasets can be shared or archived to support flood forecasting and warning efforts. Entities such as the City of Fort Worth, USGS, TRWD, TWDB maintain a geographic information system (GIS)-based dashboard that allows users to view monitoring sites on an interactive map. Through these portals, users can access both real-time and historical precipitation data, as well as flood stage information. The public can sign up to receive alerts via text message, email, and other notification methods. Table 4-5 provides a list of flood alert systems and dashboards by entity.

*Table 4-5. Flood Alert Systems and Dashboards by Entity*

| Entity | Dashboards | | | | | Public Alerts | |
|---|---|---|---|---|---|---|---|
| | Dashboard Name | Dashboard Type | Data Format(s) Available for Download | Dashboard Web Link | Publicly Available? | Alert System | Alert Type |
| City of Fort Worth (COFW) | WARN Dashboard | GIS-based ArcGIS dashboard | CSV, GeoTIFF | https://cs-029.onerain.com | Yes | Office of Emergency Management CodeRed app; HAAS Alert | Text; GPS notification |
| City of Grand Prairie (COGP) | Contrail OneRain | Web-based dashboard | N/A | https://gptx.onerain.com | Yes | N/A | N/A |
| National Weather Service (NWS) | TexMesoNet | Web-based dashboard | N/A | https://www.texmesonet.org | Yes | N/A | N/A |
| Tarrant Regional Water District (TRWD) | AEM Elements 360 | Web dashboard (cloud-based) | CSV, JSON, SHEF, Excel | https://trwd.onerain.com | Yes | AEM Elements 360 Alerts | Text; Email |
| Texas Department of Transportation (TxDOT) | LoneStar ATMS | Web-based dashboard | CSV, Excel (sensor logs), database records | N/A | No | N/A | N/A |
| | Statewide Transportation Systems Management and Operations (TSMO) Data Platform | Web dashboard + statewide integration | CSV, Excel, database exports | N/A | No | N/A | N/A |
| Texas Water Development Board (TWDB) | TexMesoNet | Web-based dashboard | N/A | https://www.texmesonet.org | Yes | N/A | N/A |

| Entity | Dashboards | | | | | Public Alerts | |
|---|---|---|---|---|---|---|---|
| | Dashboard Name | Dashboard Type | Data Format(s) Available for Download | Dashboard Web Link | Publicly Available? | Alert System | Alert Type |
| U.S. Geological Survey (USGS) | NWIS | Web dashboard + API | CSV, Excel, API (REST/JSON) | https://waterdata.usgs.gov/nwis | Yes | WaterAlert | Text; Email |
| Wise County | WiseTX Dashboard | Web-based dashboard | N/A | New dashboard with public weblink expected in 2026 | No | N/A | N/A |

Note: N/A means “not available.”

## 4.4 Flood Warning System Operations

### 4.4.1 Institutions and Operational Structure

Table 4-6 presents the FEWS organizational structure and operations for local entities with an established flood warning system as provided to the study team.

*Table 4-6. FEWS Operations by Entity*

| Entity | FEWS Department and Staff Organization |
|---|---|
| City of Fort Worth (COFW) | • Three personnel in Stormwater Management/Transportation and Public Works (TPW).<br>• Stormwater Field Operations staff barricade roads during flood events. |
| City of Grand Prairie (COGP) | • Public Works Contingency & CRS Coordinator oversees the maintenance and contract of the FEWS, monitors OneRain during rain events, coordinates road closures, and after an event inspects low water crossings.<br>• Signals Supervisor completes the maintenance of the FEWS. |
| Tarrant Regional Water District (TRWD) | • Internal Gage Network Manager oversees budget, troubleshooting, and manages/coordinates with Sutron.<br>• Systems Monitors monitor incoming data and alerts.<br>• Operations and Field staff install and maintain instrumentation. |

## 4.5 Available River Forecast Services

In addition to the monitoring hardware and data management systems, an effective FEWS also depends on forecasting and mapping tools that transform raw information into spatial context that helps communities identify flood-prone areas, the progression of flood conditions, and the areas that may be affected. The discussion below provides a brief overview of a few existing and upcoming forecasting and mapping tools.

### 4.5.1 River Forecasts

#### 4.5.1.1 NWS CHPS (Legacy Forecast System)

The NWS Community Hydrologic Prediction System (CHPS), operated by the NWS, serves as the primary hydrologic forecasting platform supporting river and streamflow prediction across the United States. CHPS integrates real-time hydrometeorological observations such as precipitation estimates, stream gage data, and radar-derived rainfall with hydrologic and hydraulic models to generate river stage forecasts, flood advisories and warnings, and decision support products.

The system provides river forecasts and facilitates coordination among River Forecast Centers, Weather Forecast Offices, and regional partners. The CHPS capacity reflects the ability to assimilate real-time data, execute calibrated basin models, and disseminate reliable forecast guidance to support emergency management and infrastructure operations. Site-specific forecasts for the TSI study area may be accessed through the Texas Flood Information Viewer or the National Water Prediction Service. (TWDB, n.d.-f; NOAA, n.d.)

#### 4.5.1.2 National Water Model Forecasts (Operational Forecast System)

The National Water Model Flood Inundation Mapping framework combines forecasted hydrologic information with predeveloped inundation map libraries to support flood impact assessment and situational awareness. This approach links National Water Model streamflow guidance with spatial representations of potential flooding to help users understand where high flow conditions may translate into "on the ground" impacts. Stream level forecasts based on the National Water Model may be accessed through the National Water Prediction Service (National Water Prediction Service - NOAA) by enabling the National Water Model Stream Reach layer and Flood

When applied together, National Water Model guidance and Flood Inundation Mapping provide a complementary framework for transportation decision support. National Water Model outputs indicate where and when high flow conditions are forecast while Flood Inundation Mapping translates those conditions into spatial representations of potential flooding. This combined approach supports identification of roadway and bridge assets that may be exposed to flooding and informs pre-event coordination situational awareness and response planning.

### 4.5.2 Mapping Resources

#### 4.5.2.1 NCTCOG Regional Flood Warning Software Program

NCTCOG Regional Flood Warning Software Program: NCTCOG provides enterprise-level hydrologic/flood warning software (HydroLynx, OneRain, TriLynx) to participating entities, leveraging existing gauging networks for real-time alarm and dissemination, directly assessing communication capabilities. The NCTCOG Regional Flood Warning Software Program, a subscription-based program, equips local entities with enterprise-level data management software (e.g., Contrail) for meteorologic networks and a shared Flood Data North Texas (Flood Data NTX) portal for real-time gauging and alarm visualizations as shown in Figure 4.4.

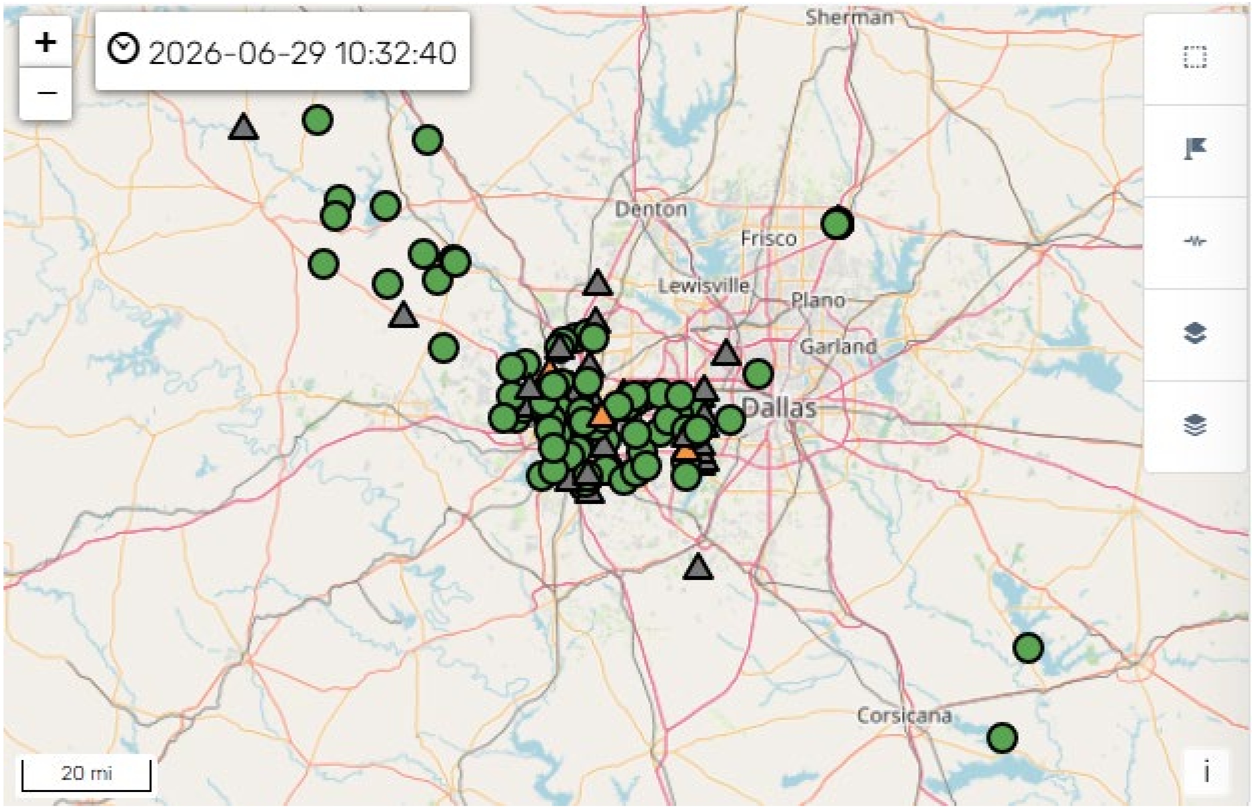


*Figure 4.4. NCTCOG Regional Flood Warning Software Program Visualization*

#### 4.5.2.2 Rapid Inundation Flood Mapping

An existing flood warning system software in the TSI study area is the Rapid Inundation Mapping (RIM) tool developed by the USACE Modeling, Mapping and Consequences (MMC) production center.

The RIM tool is an on-demand inundation map building tool developed by the MMC to support USACE water control management mission. The intent of the RIM tool is to provide a rapid inundation map within minutes of obtaining forecasted stages or flows from the NWS at key USGS gage sites within the watershed. The RIM tool contains a library of inundation layers based on a range of stages and flow rates. The inundation layers housed in the RIM tool database are derived from Hydrologic Engineering Center–River Analysis System (HEC-RAS) models developed under the Corps Water Management System (CWMS) National Implementation Plan.

The HEC-RAS models and inundation layers cover the Trinity River and its main tributaries (Clear Fork, West Fork, and Elm Fork), downstream of the USACE dams. The Trinity River basin consists of eight major USACE projects: Benbrook Dam, Bardwell Dam, Grapevine Dam, Joe Pool Dam, Lavon Dam, Lewisville Dam, Navarro Mills Dam, and Ray Roberts Dam. Additional funding is needed to improve the quality of the HEC-RAS models and better calibrate the HEC-RAS rating curves to USGS gage rating curves. However, the current flood inundation map libraries can provide a quick estimate of potential inundation.

The inundation layers in the RIM tool are separated into smaller segments along the river, centered around the USGS gage sites. Once a forecasted stage or flow at a gage site is provided by the NWS, the corresponding inundation layer can be selected around the gage site. The flow at the gage site can be used to estimate the flow throughout the Trinity River system, and inundation layers can be selected for the other segments in the RIM tool to provide a continuous inundation map throughout the system.

The further away from the gage, the less accurate the inundation layer may become, but it may still provide value in potential flood inundation estimates where timing is critical. The tool is not meant to supersede a more accurate CWMS inundation map or USGS/NWS maps that are calibrated to higher standards but is meant to provide the first estimate of anticipated inundation during an event. In some cases, where the basin response may be very flashy, the tool may benefit the CWMS modelers who cannot produce inundation mapping within the response time required. It may also benefit CWMS watersheds that require extensive HEC-RAS computation times to produce inundation mapping by providing inundation layers that are already computed. Engineering judgment should always be used to provide the best available quality-controlled layers within the given time constraints for each watershed prior to distribution.

During a flood event, the RIM tool can be used to generate a quick estimate of inundation layers which can be shared with emergency managers in static maps through the Flood Inundation Mapping website (https://fim.wim.usgs.gov/fim/). These inundation maps can enable emergency managers within the TSI area to begin the process of emergency planning, transportation rerouting, and protection of critical facilities. As the flood event continues, the USACE water managers will improve HEC-HMS forecast modeling to provide better flow estimates and inundation estimates using the CWMS software. This ongoing effort, in conjunction with the management of reservoir releases, is an existing flood warning capability in the TSI study area.

In addition to the static maps that can be shared externally, the RIM tool can also be used by USACE internally to pull in additional GIS layers, such as critical infrastructure, current traffic data (e.g. Waze), live gage data, and weather warnings. Additional consequences data and estimates can be developed internally from the RIM tool. The tool can be used to develop more effective emergency response and warning plans, which would increase warning times provided to stakeholders and potentially reduce life loss during an emergency response. However, these additional capabilities in the RIM tool are only available for internal use by USACE. No date or plan has been determined for expanding access to these capabilities to emergency managers or the public. More information on the RIM tool can be found on the USACE website. (USACE, n.d.-b)

#### 4.5.2.3 Texas Department of Transportation (TxDOT) Flood Assessment System (FAST)

TxDOT FAST is a research/prototype flood decision support mapping capability that demonstrates the integration of NOAA's National Water Model (NWM) forecasts with flood inundation mapping to identify roads and bridge structures that could be potentially impacted by flooding.

FAST was developed to support TxDOT's goal of moving from reactive flood operations to a more proactive posture by providing a web-based overlay of current and predicted flood information relevant to transportation assets. Published research describing FAST notes a prototype bridge warning service using real-time water levels associated with a large set of span bridges in Texas. It also describes the use of a data assimilation approach to adjust NWM forecasts in real time using TxDOT gage observations.

#### 4.5.2.4 NCTCOG Flooded Roads Information System Project

The NCTCOG is developing the Flooded Roads Information System Project to enhance public safety and mobility in the Dallas Fort Worth region. This advanced flood warning system will identify high-risk areas, predict roadway flooding, and provide real-time alerts to the public and transportation agencies. Given the region's history of extreme weather and rapid urbanization, this system is crucial for mitigating roadway hazards, improving traffic flow, and enhancing emergency response. By leveraging real-time weather data, soil saturation levels, and historical flood records, the project aims to forecast roadway flooding to protect the public from dangerous flood conditions. The system will integrate flood alerts into navigation platforms (Waze, Google Maps), dashboards, text messages or other means of communication, improving traffic management, and enhancing alternative routing. The project emphasizes data-driven decision-making and regional collaboration among local agencies, first responders, transportation planners, and engineers to enhance flood prediction, alerts, and response efforts.

#### 4.5.2.5 Interagency Flood Risk Management Initiative (INFRM) Flood Decision Support Toolbox (FDST)

FDST is a web-based application developed under the INFRM to support flood risk communication, situational awareness, and decision-making across federal, state, regional, and local agencies. The toolbox provides a centralized environment for visualizing flood inundation mapping in combination with both real-time and forecasted hydrologic and meteorological information.

The FDST integrates predeveloped flood inundation map libraries with observed stream gage data, forecast water levels, and related contextual information. These map libraries are typically based on hydraulic models developed by partner agencies and are designed to depict potential flood extents associated with specific water levels. By linking inundation maps to current and forecast conditions, the toolbox allows users to explore where flooding may occur, and how conditions may change over time.

The toolbox supports both micro-scale and macro scale applications. At localized scales, FDST allows users to view detailed inundation extents associated with individual stream gages or modeled river reaches. At broader scales, the toolbox supports regional or statewide situational awareness by incorporating forecast driven information such as NWM guidance to provide context on evolving flood conditions.

The FDST is publicly accessible and is intended to support emergency managers, transportation agencies, and other practitioners during flood events, as well as in preparedness and planning activities. The application emphasizes visualization and decision support rather than regulatory mapping or design analysis.

Training materials for the toolbox are available through the INFRM program website. (USGS, n.d.) These training videos provide guidance on navigating the toolbox interface, interpreting flood inundation maps, and using available data layers to support operational decision-making.

# 4.6 Other Data Resources

In addition to the gage and weather station networks owned and operated by cities, counties, and other public agencies, additional rainfall observations are available through community-based platforms, such as Community Collaborative Rain, Hail & Snow Network (CoCoRaHS), and Weather Underground. The data shared through these platforms comes from privately owned or locally managed monitoring equipment. While the observations are not real-time and may be subject to reporting delays, they provide valuable supplementary information for identifying localized rainfall patterns and validating broader precipitation trends within the region. They are not primary resources for flash flood warning.

## 4.6.1 Community Collaborative Rain, Hail & Snow Network (CoCoRaHS)

CoCoRaHS is a volunteer-based network that collects and shares rain, hail, and snow data from thousands of monitoring stations across the United States, Canada, and other participating regions. The network applies standardized observation protocols and manual rain gages to produce consistent and accurate precipitation measurements. This data is widely used by meteorologists, hydrologists, emergency managers, and researchers for climate studies, water resource management, and storm analysis.

The website provides cumulative precipitation totals for the previous 24 hours, along with historical records. Users can explore an interactive map displaying stations with available data and zoom into specific states or counties to select a station of interest. Figure 4.5 shows the map interface of the CoCoRaHS network.

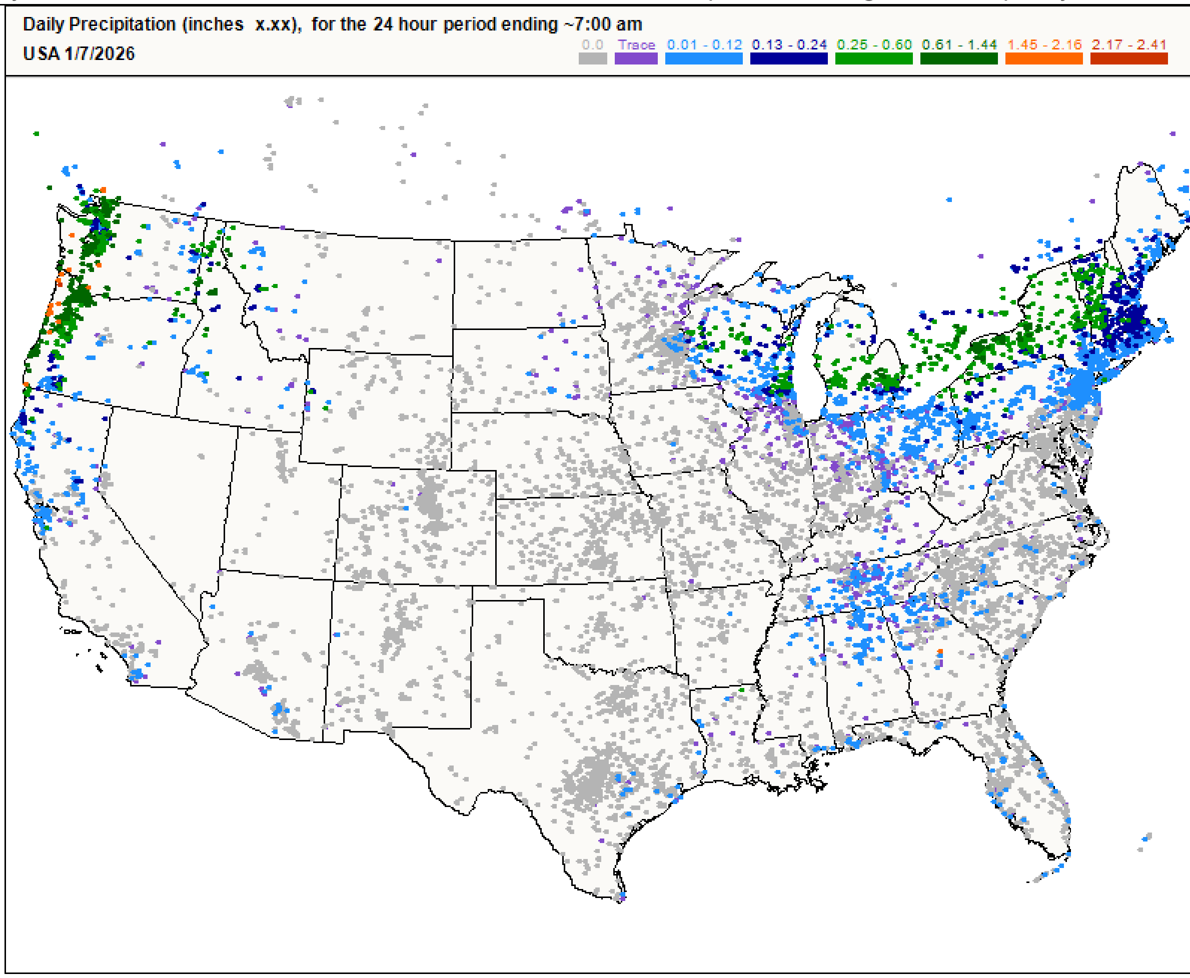


*Figure 4.5. Map Interface of CoCoRaHS network (CoCoRaHS, n.d.-b)*

Key Features of CoCoRaHS:

- Detailed Precipitation Reports: View daily, weekly, monthly, and year-to-date precipitation totals for any station.
- Historical Data Access: Query precipitation records over a user-defined date range within the station's period of record.
- Climatology Tools: Access long-term precipitation averages and summaries for climate analysis.
- Precipitation Type Tracking: Includes rain, hail, and snow observations, with hail size and snow depth details.
- Interactive Map: Displays station locations and precipitation data visually for easy navigation.
- Observation Calendar: Allows users to review and download precipitation data by date.

- Community Participation: Anyone can join as a volunteer observer by registering and reporting daily precipitation using a CoCoRaHS-approved rain gage.
- Educational Resources: Offers training materials, videos, and guides for accurate data collection.
- Data Sharing: Information is used by agencies like the NWS, NOAA, and local water management authorities for flood forecasting and drought monitoring.
- Mobile-Friendly Access: The website is optimized for mobile devices, making it easy for observers and users to report and view data on the go.
- Integration with Other Networks: CoCoRaHS data complements other weather networks and is often integrated into broader climate and hydrology models.

## 4.7 Weather Underground

Weather Underground is a leading weather service that provides highly accurate and hyperlocal forecasts by leveraging a vast network of over 250,000 privately owned weather stations worldwide. The platform offers real-time data including temperature, rainfall, wind, humidity, and other atmospheric conditions. Users can access interactive maps, radar, and satellite imagery for detailed weather visualization as shown in Figure 4.6.

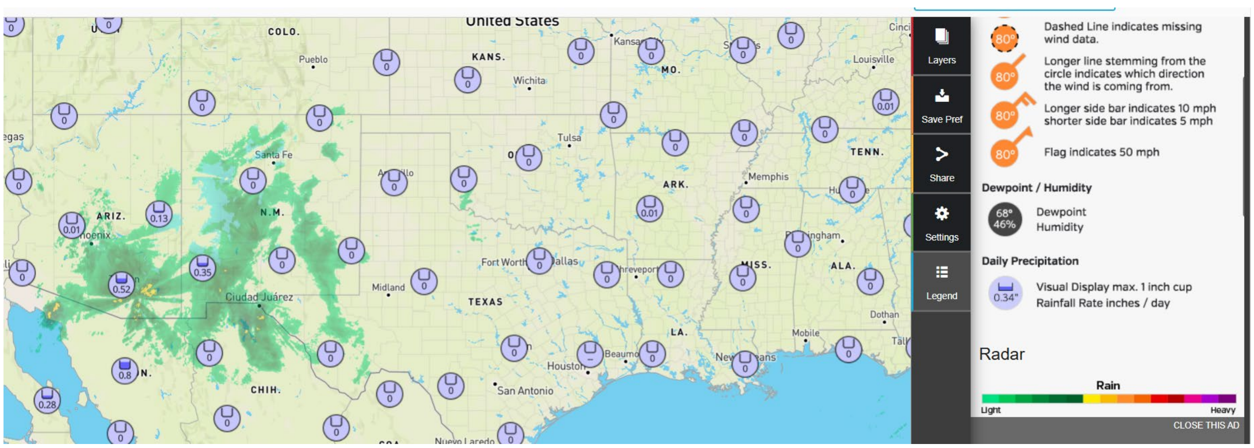


*Figure 4.6. Weather Underground Interactive Map (NCAR, n.d.)*

In addition to standard forecasts, Weather Underground provides a U.S. Severe Weather Map, which compiles official NWS alerts and integrates NEXRAD for real-time severe weather tracking. This feature covers tornadoes, extreme temperatures, floods, and other hazardous conditions, allowing users to register for email notifications of severe weather warnings.

Key Features

- Hyperlocal Forecasts: Uses personal weather stations for neighborhood-level accuracy.
- Historical Weather Data: Access past weather records for research and trend analysis.
- Customizable Alerts: User can set personalized notifications for temperature, rainfall, and wind conditions.
- Mobile App Integration: Available on iOS and Android for real-time updates and radar maps.
- Community Participation: Users can contribute data from their own weather stations and engage in forums.
- Air Quality & Pollen Data: Provides Air Quality & Pollen Air Quality Index (AQI) readings and pollen forecasts for health-conscious users.
- Developer Application Programming Interface (API): Offers an API for integrating weather data into apps, websites, and Internet of Things devices.
- Global Coverage: Delivers forecasts and radar imagery for locations worldwide.

## 4.8 Summary

The Capacity Analysis provides a planning level overview of existing FEWS capabilities across the TSI study area, focusing on monitoring infrastructure, data collection, software platforms, and operational practices. While the region benefits from a strong foundation of rainfall, stream (stage), and roadway monitoring assets, FEWS capacity varies by jurisdiction in terms of coverage. The current analysis establishes a baseline understanding of current conditions to support future coordination and investment decisions.

During the development of this Capacity Analysis, several challenges were encountered in compiling and standardizing information across entities. Data on monitoring assets were sourced from multiple agencies using differing formats, levels of detail, and definitions of equipment types, which limited the ability to verify consistency across the dataset. In some cases, information on gage type, location, and measured parameters was incomplete or unavailable, and quality control of reported inventories was outside the scope of this effort. Additionally, inconsistencies in how monitoring systems categorize rain and stage measurements introduced uncertainty in quantifying available rainfall/stage monitoring capacity. These challenges highlight a key regional gap in standardized data collection, validation, and sharing practices, which affects confidence in the current inventory and limits the ability to fully assess FEWS readiness across the region.

# Chapter 5

# Gap Analysis

The following gap analysis is based on findings from the Regional Characteristics and Capacity Analysis sections of this Master Plan. The gap analysis is structured according to four broad elements of FEWS, as follows:

1. Identification of the flood risk,
2. Detection, monitoring, analysis and forecasting of flooding and possible consequences,
3. Warning dissemination and communication, and
4. Preparedness and response capabilities.

These categories were based on a gap analysis checklist adapted from WMO (2018) (see Appendix C). The checklist includes questions that can be used to assess a FEWS, regardless of the location or scale (i.e., the checklist is not tailored specifically to the TSI study area). The following sections summarize potential gaps, although it should be recognized that the region generally has very robust, comprehensive FEWS capacity. As such, the following are more opportunities for refinement and continuous improvement rather than gaps in baseline capability. It should also be recognized that these findings are based on information and stakeholder engagement conducted as part of this study and may not reflect all FEWS capacity at the local level.

## 5.1 Identification of Flood Risk

Flood hazard and related threat assessments in the NCTCOG area are generally robust at the regional and watershed scale, but their quality and accuracy vary in detail and currency. The Texas State Flood Plan and the Trinity Regional Flood Planning Group (RFPG) provide a structured, multi-layered view of flood hazards, explicitly separating riverine, flash, and increasingly urban/pluvial flooding, and integrating exposure and vulnerability data such as population, critical facilities, and socially vulnerable populations (NCTCOG, 2023, n.d.-f; TWDB, n.d.-c; TRFPG, 2023).

At the data layer, TWDB's Floodplain Quilt consolidates Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMs), BLE studies, Cursory Fathom rasters, and local flood studies into a single statewide hazard map, prioritizing higher-quality regulatory data where it exists. This is tightly tied into the Trinity RFPG's regional flood plan, which uses the Quilt as a base and supplements it with local studies, community-submitted data, and Discovery-style risk assessments to refine hazard extents and identify data gaps. (Note, a discovery style assessment is a front-end, reconnaissance effort, not a full engineering study.) (NCTCOG, n.d.-f; TWDB, n.d.-c; NCTCOG, 2023; TRFPG, 2023; TWDB, n.d.-b; Fathom, n.d.)

However, accuracy is uneven at the local level. Many older studies in the region rely on outdated hydraulic models or broad-scale Fathom/ BLE outputs that do not fully capture recent urbanization or channel changes. Additionally, the update cadence is driven by FEMA project cycles and community-initiated map revisions, not by a continuous, automated review process, so some areas may technically understate current flood risk. Overall, the region has a high-quality, centralized, and reasonably accurate regional-scale hazard-and-threat assessment framework, but pockets of lower-resolution modeling and uneven local-plan integration mean that local-level accuracy and risk communication can still lag behind the best available data. (NCTCOG, n.d.-f; TWDB, n.d.-c; NCTCOG, 2023; TRFPG, 2023; Fathom, n.d.; CTCOG, n.d; TWDB, n.d.-e)

## 5.2 Flood Monitoring and Prediction

### 5.2.1 Insufficient Rain Gage Network

Effective flash flood warning in the NCTCOG area requires a rain gage network that can capture the high spatial and temporal variability of storm events. In small watersheds, an insufficient gage network can underestimate runoff potential and delay warnings.

Flash floods are usually triggered by severe thunderstorms containing cores of extremely intense rainfall that move across the watershed. The primary challenge is accurately estimating both the total rainfall and intensity of the rainfall during a storm. These factors often vary significantly across the watershed and even within a single storm.

Two critical characteristics of a rain gage network for flash flood warnings are:

1. **Temporal Resolution** – This pertains to how frequently rainfall data are observed and reported. Reporting must be frequent enough to enable timely decisions as flash flood conditions develop.
2. **Spatial Resolution** – This relates to how closely gages are spaced, typically expressed as gage density in square miles per gage ($mi^2$/gage). Adequate gage density is essential to reliably estimate the highly variable rainfall volume across the region.

### 5.2.2 Temporal Resolution

To support flash flood warnings in a fast-responding watershed, rainfall should be measured, transmitted, and received at least every 15 minutes, or less, but even that might not be fast enough. In the Dallas-Fort Worth area, two inches of rain in one hour is equivalent to a five-year rain event which can be enough to initiate flooding, especially in urban environments. At that rate, a half-inch of rain falls every 15 minutes. Waiting more than 15 minutes to determine if even more rain has fallen sacrifices valuable potential warning time when minutes count. This suggests reporting intervals of around five minutes are warranted.

Figure 3-7 in the Regional Characteristics section shows that the time to reach peak flow can be less than an hour in smaller watersheds in the region. A good rule-of-thumb for reporting frequency is to obtain four-five rainfall observations within the time to reach peak flow. If the time-to-peak is one hour, a target data reporting interval is 15 minutes or less. If the time-to-peak is 30 minutes, then reporting intervals of five minutes are warranted.

### 5.2.3 Spatial Resolution

Establishing appropriate rain gage spacing is critical for timely rainfall estimation, accurate hydrologic modeling, flash flood forecasting, and improved public safety outcomes during rapidly developing flood events. There are no established standards for determining rain gage densities to support flash flood warning. However, there are guidelines that can help.

**WMO Guidance.** The WMO is a specialized agency of the United Nations responsible for promoting international cooperation on atmospheric science, climatology, hydrology, and geophysics issues. WMO frequently offers guidance helping agencies establish rain gage networks. For example, the WMO (1974) offers the following minimum recommendations for general meteorological and hydrological purposes:

1. For flat regions of temperate, mediterranean, and tropical zones, a density of 230-350 $mi^2$/gage is suggested.
2. For mountainous regions of temperate, mediterranean, and tropical zones, a density of 40-100 $mi^2$/gage is mentioned.
3. For small mountainous islands with irregular rainfall, 10 $mi^2$/gage is suggested.
4. For arid and polar zones, 600-4000 $mi^2$ /gage is identified.

None of these terrain types match NCTCOG watershed conditions. However, given existing and projected urbanization patterns, demonstrated rapid and localized watershed response (e.g., Figure 3-7) and the highly variable intense rainfall rates observed in the NCTCOG region, it is reasonable to assume gage densities on the lower end of the WMO recommendations, perhaps 10-25 $mi^2$/gage, are appropriate.

For comparison purposes, NCTCOG reviewed rain gage networks used in other urbanized regions of the country that are prone to flash floods, including Maricopa County in Arizona; the Denver metropolitan area in Colorado, and the Charlotte-

Mecklenburg metropolitan area in North Carolina. All three are successful longstanding systems. Rain gage densities for these networks range from about 10 $mi^2$/gage to about 40 $mi^2$/gage, in general agreement with the WMO guidelines.

The HCFCD operates a comprehensive flood warning system in partnership with several neighboring communities. The system automatically collects data from 389 rain gages, of which 201 are owned and maintained by HCFCD and 188 are operated by partner agencies. Together, these gages monitor watersheds covering approximately 3,200 square miles, resulting in an average gage density of about 8.2 $mi^2$/gage. Within Harris County, gage density is even higher, approaching five $mi^2$/gage. By most measures, rain gage densities in Harris County exceed those typically found in local FEWS, particularly at the scale of Harris County and its cooperating partners. Notably, the HCFCD monitoring network was not designed to achieve a target rain gage density, but rather to meet a strong need for extensive stream-level monitoring. Once the infrastructure for stream monitoring was established, adding rain gages at these locations became a relatively low-cost enhancement, resulting in the high rain gage densities observed today.

In a recent study for the Upper Guadalupe River Authority (Kisters and WEST, 2025), target rain gage densities for the Upper Guadalupe basins in Kerr County were derived from the geometric properties of storms. Storm cell sizes and shapes were drawn from extensive reviews of NWS radar imagery across Texas, Arizona, and Eastern Colorado (WEST et al, 2022; WEST, 2023; Curtis, 2011). These studies evaluated tens of thousands of 15-minute storm cells and their cell shape, size, peak intensity, and intensity distribution. Through data taken from these numerous storm cells, an idealized characteristic shape emerged as depicted in Figure 5-1. The sharp peak in the ellipse center represents the peak rainfall intensity of the cell, which then gradually diminishes as the horizontal distance from the cell center increases.

The remarkable finding from this work is that, on average, the highest intensities are confined to a relatively small fraction of the cell footprint. Figure 5-1 illustrates this finding by showing a conceptual storm where the top 70% of the cell intensities occupy only about 10% of the elliptical cell footprint. In other words, in a typical storm cell, most of the rain falls on a small fraction of the cell footprint at any given time.

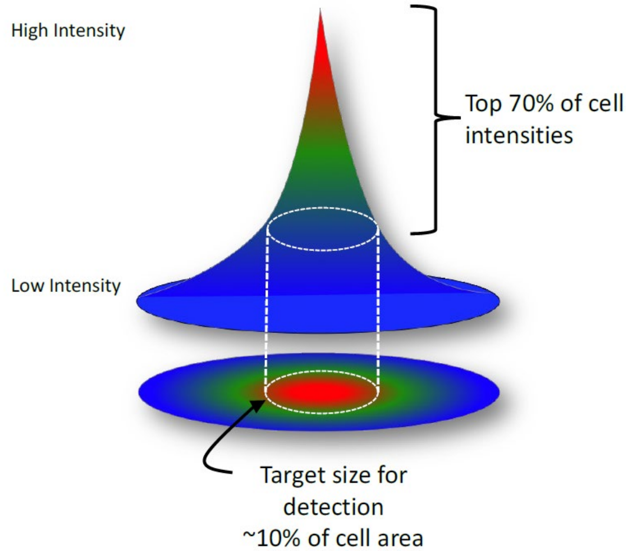


*Figure 5.1. Idealized Storm Cell*

The design objective for a rain gage network supporting flash flood warning in the Upper Guadalupe River Basin is to reliably detect the small high intensity cores of storm cells by at least one rain gage in any 15-minute period with a probability of 90%. This led to recommended gage densities on the order of 12 $mi^2$/gage which approximates the WMO guidelines but from a physically-based data-driven approach.

**Key Gap:** The lack of a unified approach to manage the existing hydrometeorological data networks made the rain gage network review difficult. Gage naming conventions varied among entities operating rain gage networks. Gages often appear in multiple databases with inconsistent naming and asset assignments. For example, some sites were listed as rain gage sites but included stream gages as well. The opposite was true in some cases where sites were designated as rain and stream gage sites but one or the other did not exist. Even latitude and longitude coordinates for sties were not consistent. In at least one spot check using Google Street View, a stream gage was identified that did not appear in any of the gage databases. The basic question of how many unique rain gages are present in the TSI project area remains unanswered.

### 5.2.4 Stream Gages

Unlike rain gage networks, for which general density guidelines exist, there are no universal standards for stream-gage network density. Stream-gage placement is instead driven by watershed characteristics, flood risk, and water-management and public-safety objectives, rather than by uniform spacing or fixed intervals. In flash-flood-prone watersheds, gages are most effective when located at strategically selected sites, such as downstream of major tributary confluences, at known low-water crossings, near populated areas, or at critical infrastructure junctions where rapid inundation poses the greatest risk.

In addition, upstream gage locations can play a critical role by providing early detection of rapidly rising water levels, thereby increasing lead time for warning dissemination and downstream emergency response. A well-designed stream-gage network therefore prioritizes risk-based siting and operational value over numerical density, aligning monitoring investments with the locations where timely information can most effectively support life-safety decisions.

More information is needed from local agencies to assess needs for additional stream gages. Also, the on-going flooded roads initiative will heavily influence the need for additional stream gages.

### 5.2.5 Other Sensors

Meteorological sensors that measure wind speed and direction, relative humidity, and barometric pressure are not core requirements for flood warning performance; however, their integration into a local FEWS represents a strategic capacity enhancement at relatively low incremental cost. When deployed alongside rain and stream gages, these sensors broaden the system's functional scope to support additional public, operational, and institutional uses (e.g., transportation safety, outdoor recreation, agriculture, education, and research).

From a policy perspective, this expanded utility helps sustain higher levels of routine engagement with the FEWS data portal among non-emergency users, thereby increasing the overall user base and institutional visibility of the system. Regular, non-crisis interaction with the platform builds familiarity with data displays, alert thresholds, and system limitations, which is a recognized best practice for reducing confusion and improving response during rapidly evolving flash flood events.

The absence of such ancillary sensors does not constitute an operational deficiency for flood warning, but it represents a missed opportunity to strengthen system relevance, stakeholder buy-in, and long-term sustainability. Incorporating these sensors can therefore be viewed as an opportunity to leverage existing infrastructure investments to enhance preparedness, resilience, and public trust without materially increasing system complexity or operational burden.

## 5.3 Warning Dissemination and Communication

Local jurisdictions provide substantial warning dissemination with strong support from NCTCOG. Opportunities likely exist to expand and/or refine coverage and the effectiveness of messaging. Rural areas, seasonal populations, and unincorporated communities may depend on a mix of county level alerts, radio, and word-of-mouth communications. Documented formal assessments of whether all subpopulations (e.g., elderly, people with disabilities, non-English speakers, low-income households, visitors, campers, RV users, etc.) are reliably reached is important. In addition, while NCTCOG and some partners are moving toward "Next-Gen" warning systems with sensor driven alerts and automated road closure, some entities do not operate rain and/or river gages or have deferred flood warning projects due to funding constraints. This is common in large, regional areas like the TSI area where diverse populations and rapid growth have occurred. (San Antonio River Authority, n.d.; Halff, n.d.; Wag the Dog, n.d.; Scripps News, 2025).

Another aspect of delivering effective warnings is providing actionable, impact-based messages. For example, flooded road warning systems specifically aim to tell drivers to avoid flooded crossings and channels, and advanced gage systems are designed to trigger automated alerts when thresholds are crossed. NCTCOG and TWDB guidance emphasize that warning messages should enable timely and appropriate evacuation and protective actions. (NCTCOG, n.d.-l; San Antonio River Authority, n.d.; Halff, n.d.; NCTCOG, n.d.-j)

Public awareness and trust in "who issues the warning" is often a challenge in large, regional communities and additional efforts in this area may provide high value. Residents rely on local media, county- or city specific smartphone apps, or social media posts since alerts are handled at the local level, but this may lead to confusion or missed information as residents and visitor transit between jurisdictions. Considering a regional approach to "branding" alerts and messages may be a useful strategy to consider. Ultimately, NCTCOG's FEWS-related guidance notes that "last-mile" communication, that connect data to compliant behavior, remains an opportunity for improvement. (TWDB, n.d.-a; Wag the Dog, n.d.; USACE, n.d.-a)

In summary, the NCTCOG region has strong organizational and technical foundations for flood warning dissemination; however, opportunities may exist to formalize cross-jurisdiction coordination and consistency, fully assessing Last Mile reach, and ensuring that impact-based messages are consistently tailored to all subpopulations, especially vulnerable and rural groups. (NCTCOG, n.d.-d; Scripps News, 2025; NCTCOG, n.d.-g; NCTCOG, n.d.-e; TWDB, n.d.-a; Wag the Dog, n.d.)

## 5.4 Preparedness and Response Capabilities

Local jurisdictions within the TSI area have robust, comprehensive preparedness and response capabilities. Jurisdictions are also supported by the NCTCOG activities and tools. Based on information obtained publicly and through the TSI project discussions with stakeholders, opportunities for improvement relate to continuous improvement and refinement versus “filling gaps.” The following are a few examples, but additional effort is recommended to engage local emergency management to identify what ideas, needs, and/or opportunities they believe are best suited to improving capacity and outcomes in the TSI region.

A recent analysis identified gaps in preparedness for individuals with disabilities, homebound seniors, and multicultural populations (Disability Rights Texas, 2026). In the analysis, HMPs among the state’s 25 highest-risk counties are noted as lacking comprehensive evacuation protocols for carless populations, with no documented standardized door-to-door notification systems or transportation assistance plans .

It is unclear whether evacuation protocols and public evacuation information for floods and flash floods is comprehensive. While evacuation authority exists, specific documented evacuation routes, safe areas, shelter locations, and vertical evacuation strategies for floods and flash floods were not publicly identified. While these may exist within local emergency management plans, it is unclear if they are actively communicated to the public in advance of flooding and whether they are tailored to specific types of flood events (e.g., riverine 24- to 72-hour floods versus flash floods).

Strategies for longer return-period events (e.g., 500-year floods) or cascading hazard scenarios (e.g., combination flash flood, power outage, and hazardous material spill) are not prominently documented in public summaries. Consideration may be needed whether more effort could be applied for compound disasters where flooding triggers secondary hazards.

Overall, the region excels at preparedness and response. The minor areas for potential improvement noted above may not apply to all jurisdictions in the TSI area, and they represent refinements vs “filling the gaps.” Given the limited scope of this effort, it is highly recommended that additional effort be spent to define any opportunities not recognized here that could help increase local capacity and consistent outcomes across the region.

**Summary**

Across the five pillar FEWS value chain, the region has strong regional planning, coordination, and emerging flood monitoring, forecasting, and warning tools. Key areas for potential improvement and refinement include flash flood monitoring and forecasting and public warning.

## Identification of Flood Risk

### Key Strengths

- NCTCOG has been a core FEMA Risk MAP partner, leading discovery and flood risk reporting for Upper Trinity watersheds (e.g. East Fork Trinity, Lower West Fork). These projects systematically gather flood history, development plans, mitigation activities, and data gaps, and feed into updated flood maps and risk products.
- The Floodplain Management program maintains multiple regional initiatives to reduce flood damage and supports communities with training, mapping, and policy guidance.
- Projects like Storm Shifting (Upper Trinity Silver Jackets) explicitly target information gaps for extreme storm scenarios, enhancing understanding of where risk is understated under existing design storms.

### Key Gaps

- Risk identification is still uneven across jurisdictions; some areas benefit from up to date FEMA Risk MAP products and Discovery [Clarify what “Discovery” study is by referencing the agency or full study name] studies; others rely on older or less detailed mapping.
- Existing risk products emphasize riverine flooding; while pluvial/urban flash flood risk is increasingly recognized, it is not comprehensively mapped or consistently integrated into local planning across the region.
- There is not yet a single, regional, routinely updated multi hazard flood risk product that fuses mapping, socio economic exposure, critical infrastructure, and climate change stressors in a way that all jurisdictions use as a common basis. The TWDB Flood Quilt and TSI mapping may be the closest products.

## Flood Monitoring and Prediction

### Key Strengths

- The Regional Flood Warning Software Program gives participating entities enterprise level software to visualize real time rain and stream gage data, alarm on thresholds, and disseminate information across multiple networks which greatly strengthens regional situational awareness.
- Local partners in and around NCTCOG have deployed modern flood monitoring systems that integrate rain/stream/ponding sensors with public facing maps and automated alerts, demonstrating the technical feasibility of advanced FEWS capabilities in Texas.

- The NCTCOG TSI and Flooded Roads projects demonstrate a commitment at the regional level to support flood understanding, monitoring, and prediction.

Key Opportunities

- Monitoring and forecasting capabilities are fragmented by jurisdiction and watershed. Not all NCTCOG communities participate in the Regional Flood Warning Software Program or CASA program, for example.
- Forecasting is still limited in many areas to threshold-based alarms on observed levels rather than event driven, basin scale quantitative forecasts with lead time, particularly for small, flashy watersheds and urban drainage systems.
- Integration of radar based QPE/QPF, ensemble forecasts, and impact-based thresholds into a shared regional platform is emerging but not yet standard practice for all emergency managers across the NCTCOG area. While standard practice has been to rely on National Weather Service for rainfall observations (i.e., radar) and forecasting, upcoming tools and technologies such as the USACE Rapid Inundation Mapping and NCTCOG Flooded Roads indicates an opportunity for local emergency managers to gain valuable situational awareness via regional partners.

Warning Dissemination and Communication

Key Strengths

- The regional FEWS initiatives and flood warning software, where implemented, support automated recognition and warning applications, including web dashboards and alerts to officials, which aligns with best practice FEWS architectures.
- NCTCOG's emergency preparedness guidance and EOC handbooks stress development of clear roles, communication lines, and situational awareness, which underpin effective warning decisions. This guidance is reflected in local jurisdictional (Country) Emergency Operations Plans.
- NCTCOG also maintains active public facing communication channels (e.g., websites, social media), and many member jurisdictions participate in iPAWS/WEA or local notification systems, providing a base for multi-channel public warning. While local warning and public communication is the responsibility of local emergency management, the NCTCOG strengthens these efforts.

Key Opportunities

- There is no clearly documented, region wide, multi-channel warning dissemination strategy specifically for flood/flash flood events that ties together

NWS products, local FEWS, iPAWS, media, and digital channels in a consistent way. Although local warning and response occurs at the local level, the flood risk and exposure in the region warrants considering whether formal regional strategies could strengthen local outcomes.

- Warning content is not yet consistently impact based and audience tailored across the region; some agencies have sophisticated messaging; others rely on NWS products.
- Feedback mechanisms and systematic evaluation of warning performance (e.g., reach, timeliness, public understanding) are ad hoc; they are not yet part of a structured regional monitoring and evaluation process for flood warnings.

Preparedness and Response Capabilities

Key Strengths

- NCTCOG's Emergency Preparedness programs provide training, exercises, and EOC tools, supporting local response and coordinated regional support for disasters, including floods. Local jurisdictions have up-to-date Emergency Operations Plans and routine alert testing and table top exercises are performed.
- The Local Disaster Recovery Framework and Toolkit and regional Recovery Framework guide communities in aligning preparedness, response, and recovery planning, improving institutional readiness for major events.
- Vulnerable and multicultural populations are accounted for in planning through the State of Texas Emergency Assistance Registry (STEAR), KnoWhat2Do campaign, and the Regional Catastrophic Grant Program.
- Extensive public education and outreach programs at the local, regional, state, and federal levels complement each other to provide effective engagement with community members.
- Systematic use of post event analysis and After Action Reviews to refine flood specific response and public awareness exists and is consistently applied.

Key Opportunities

- Flood and especially flash flood scenarios do not appear consistently exercised region wide with a focus on testing end to end warning to response performance (i.e., from basin scale signal to road closure and public protective action). This is a complex process, especially across jurisdictions, that could likely benefit from additional consideration.
- Resource and capability levels (e.g., equipment, staff, procedures) likely vary by jurisdiction, and there is no single regional standard for minimum flood response capability, particularly for rapidly evolving, low lead time flash floods.

- Evacuation routes, safe areas, shelter locations, and vertical evacuation strategies for floods and flash floods could be made more public and integrated into public education and outreach efforts.
- Additional efforts to consider compound disasters where flooding triggers secondary or tertiary hazards may be warranted for some jurisdictions.

# Chapter 6

# Strategic Options for Capacity Enhancement

NCTCOG's current flood warning system has strong regional planning and technical foundations, with opportunities to achieve a more fully integrated, user-friendly flash-flood early warning "value chain" across the region.

Below is a synthesis of the key gaps and practical improvement strategies structured along the five WMO pillars: risk identification, detection/forecasting, warning dissemination, decision support, and preparedness/response.

## 6.1 Identification of Flood Risk

- Build a living regional flood risk atlas.
    - Stand up a single regional FEWS risk layer that merges flood risk mapping products (e.g., TWDB Floodplain Quilt, FEMA Risk MAP, RFPG products), local studies, and pluvial modeling into a unified GIS service that all partners are expected to use as the "authoritative" picture.
    - Include layers for critical facilities, socially vulnerable populations, key transportation links, and typical flash-flood "hot spots" (low water crossings, underpasses, etc.).
- Close local-scale mapping gaps with a pluvial/flash-flood focus.
    - Prioritize small, flashy basins and urban drainage systems where time-to-peak is under one hour and where current mapping is coarse or outdated.
    - Use simplified, "discovery-grade" pluvial models and high-resolution terrain to at least flag likely ponding and overland flow paths, even when full regulatory studies are not yet funded.
- Institutionalize a regional risk-data governance process.
    - Designate a regional custodian (e.g., NCTCOG Floodplain Management with TWDB support) responsible for annual risk-layer updates, data standards, and archiving of flood impacts, near-misses, and after-action intel.
    - Encourage major regional programs (transportation, land use, mitigation grants) pull from this atlas so consistent risk information is embedded in policy and funding decisions.

## 6.2 Detection, Monitoring, Analysis, and Forecasting

- Design and build a region-scale flash-flood monitoring architecture.
    - Confirm the number of existing rain gages in the TSI study area that are suitable for supporting a flash flood warning system and prepare a regional database of real-time rainfall observations, leveraging the existing regional flood warning software program.
    - Include other available hydrometeorological data such as stream level, lake level, temperature, wind speed/direction, humidity, barometric pressure, etc. to add value, further leverage the data infrastructure, and support a broad variety of users.
    - Establish a consistent gage naming system, including meta data, and data sharing protocols with NCTCOG members.
    - Based on WMO guidelines and to be consistent with similar community flood warning systems, the total number of existing plus new rain gages should be in the 100-300 gage range considering the size of the TSI project area.
    - Reinforce the value of the existing CASA system and leverage CASA to supplement a more manageable rain gage network.
    - Add stream gages where stage information is needed, at low water crossings or at locations that provide some additional lead time for downstream interests.
    - Use these targets to propose a regional build-out plan (e.g., priority corridors, shared sites at existing stream gages, road crossings, USGS stream gages, and North Texas Municipal Water District, etc.) and align funding requests with TWDB and FEMA mitigation programs.
- Reduce fragmentation through minimum participation standards.
    - Establish a regional expectation that all flood-prone jurisdictions either participate in the regional flood warning software program or connect their local systems through interoperable data feeds (e.g., SHEF, ALERT2, APIs) into the common FEWS.
    - Expand the CASA program. The CASA radar program is a proven commodity with documented successes. It is an underutilized regional asset. CASA’s value is amplified further by needs presented by NCTCOG’s flooded roadways project. Explore funding options to ensure that CASA products are available and utilized by all NCTCOG members.
- Standardization on a regional forecasting toolkit.

- Implement at least a tiered forecasting capability at the regional level:
    1. Tier 1: Threshold-based alerts on observed rain and stages (for small entities with limited staff).
    2. Tier 2: Event-driven unit hydrograph or conceptual runoff models at key watersheds using radar -rainfall estimates and short-term rainfall forecasts.
    3. Tier 3: Advanced hydrologic modeling at the highest-risk watersheds with explicit link to impact thresholds (road closures, structure flooding).
- Host these in a common FEWS software platform so outputs look and feel consistent across counties and cities.

- Integrate radar-rainfall products and impact thresholds into operations.
    - Ingest CASA and NWS rainfall estimation, short-term rainfall forecast, and other key (NWS) products into the regional flood warning software program, with automatic transformation into actionable information, such as:
        1. “Basins approaching bankfull in 30–60 minutes”
        2. “Road segments and bridges expected to flood”
    - Configure impact-based alarm tiers (advisory, watch, warning) tied directly to USGS/NWS warning thresholds and/or local infrastructure and life-safety thresholds rather than raw stream stage only.
- Communicate flood forecast uncertainties in ways like the “cone-of-uncertainty” used in hurricane track forecasting.

## 6.3 Warning Dissemination and Communication

- Adopt a regional flood warning concept of operations and standard operating system suite.
    - Use the emerging FEWS SOP/Master Plan to coordinate and encourage consistency in messaging, such as:
        - Who triggers which type of message (e.g., NWS vs. local/regional FEWS vs. county emergency management).
        - How messages are pushed across channels, such as NWS products, IPAWS/WEA, outdoor sirens, local apps, social media, media partners, and in-vehicle navigation systems.

  - Include specific decision trees for short-lead flash-flood scenarios (e.g., small basin exceeds threshold within 30 minutes) and associated last-mile actions.

- Standardize impact-based message templates and branding.
  - Develop a common library of short, plain-language, impact-based flood messages (i.e., road closed; stay off low-water crossings; move cars from street) that jurisdictions can localize but that keep consistent phrasing and looks.
  - Consider a regional FEWS brand (e.g., “Flood Data NTX” or similar) so the public gradually recognizes flood alerts as part of one trusted system, even when issued by different counties.
- Formalize coordination with NWS and media.
  - Establish a standing regional Flood Warning Coordination Group (quarterly virtual huddles) that includes NWS Fort Worth, major media outlets, EMs, and key transportation/utility representatives.
  - Use these meetings to align thresholds, messaging language, graphics, and pre-event briefings ahead of heavy-rain episodes.
- Implement a regional warning performance monitoring program.
  - After selected events and statewide tests, collect standardized metrics to assess performance, such as:
    - Time from hazard detection to initial message.
    - Channel reach (e.g., WEA penetration, social media analytics, and call-center logs).
    - Observed public behavior (e.g., traffic counts at flooded crossings, shelter uptake, etc.).
  - Use a regional dashboard to track these metrics and feed them into after-action reviews and system updates.
- Close equity and accessibility gaps.
  - Co-design warning formats with disability advocates, senior groups, and multicultural community organizations, building off the 2026 disability-rights analysis. (Disability Rights Texas, 2026)
  - Expand multilingual, low-literacy, and non-digital warning pathways (e.g., door-to-door templates, faith-based networks, workplace channels, etc.)

and ensure flood warning siren policies include specific flood use where appropriate.

## 6.4 Decision Support

Build a shared "decision layer. Treat existing systems as data engines and focus on building a thin, interoperable decision layer on top of them. A shared decision framework acknowledges that the region will always have multiple tools but ensures there is one regionally consistent way of seeing "what matters now" and what actions are expected by role.

This layer should:

- Combine core flood information feeds (e.g., FEWS/Flood Data NTX, FAST, FRIS, 511DFW, key EM layers) into a common event graph, essentially a regional decision tool.
- Continuously maintain a ranked list of "decision objects": crossings, corridors, neighborhoods, and facilities ordered by current and forecast flood risk and potential impacts.
- Attach simple, pre-agreed recommended actions to each object based on trigger logic (e.g., "Close and detour," "Warn and monitor," "Evacuate block group X," "Stage high-water vehicles").

Begin a structured co-design process with TxDOT, cities/counties, EM, and public safety to agree on a minimal, shared decision framework, including:

- A small set of event tiers (e.g., Watch, Targeted Flooding, Widespread/Compound) expressed in terms of combined signals from existing tools.
- A library of playbooks at three levels:
    1. Segment/crossing/corridor (transportation focus).
    2. Neighborhood/zone (community warning and evacuation).
    3. Facility (critical infrastructure and special-needs locations).
- Encode these playbooks directly into the decision layer so that, when tools light up in certain patterns, the platform displays the type of flood risk along with the agreed playbook (i.e., action(s)).

A common mental model across agencies ensures everyone sees the same tiers, the same priority lists, and the same expected minimum actions, even if local EOPs/EAPs vary. Make sure the decision layer can ingest local triggers and flags (e.g., "City X has moved to Flood Response Level 2") so it can display local status in a consistent regional way. This shrinks the variance in local capability and gives the regional decision support system cleaner, more uniform inputs to work with.

### 6.4.1 Institutionalize a regional learning loop.

After significant flood events, bring data and people together in a structured after-action process that asks three simple questions:

- What did the tools say, and when?
- What decisions were made, and when?
- What happened, and where did outcomes diverge from intent?

Using the decision layer as the backbone: replay the event timeline with thresholds, playbooks, closures, evacuations, rescues, and communications aligned in time and space. From each event, extract concrete changes, such as:

- Adjust thresholds or playbooks as appropriate.
- Update priority locations or facility profiles.
- Identify specific data or integration gaps to be addressed.

This creates a regular feedback loop, so each flood helps improve the decision support system, the tools behind it, and the playbooks people use.

Overall, this approach adds a shared decision and learning layer on top of the tools the region already has. It turns a set of strong but separate tools into one clearer, more coordinated flood response system for the TSI study area.

## 6.5 Preparedness and Response Capabilities

- Set minimum regional standards specifically for flash-flood response capability and use those standards as a mechanism for additional funding requests.
- Develop and document, specifically, flash-flood evacuation concepts.
    - Identify priority neighborhoods where evacuation will be vertical or hyper-local (e.g., move to second story or nearby school) versus those needing short-distance relocation out of a floodplain.
    - Map and publish key safe areas, rally points, and shelter options for fast-onset events, and integrate them into the regional risk atlas used by dispatch and FEWS operators.
- Expand and/or refine efforts to ensure flash-flood, long-duration, and compound disasters where flooding triggers secondary or tertiary hazards are accounted for.

- Create a regional flood specific lessons-learned and training program.
    - Stand up a simple regional knowledge base focused on flood and flash-flood cases such as what worked, what failed, annotated hydrographs, radar loops, message timelines, etc.
    - Use this repository to drive targeted training modules for dispatchers, field responders, and Public Information Officers tied directly to the FEWS SOP.

## 6.6 Public Awareness and Education

- Set clear regional measures for flood awareness.
    - Track simple shared measures, such as how many jurisdictions promote alert sign-ups, how many people use the FEWS website during flood events, how well people recognize “Turn Around, Don’t Drown”, and whether they recognize the regional flood message or brand.
    - Encourage major campaigns to report on these measures each year and use the results to improve their outreach.
- Create targeted campaigns with vulnerable groups.
    - Work with disability rights groups, senior centers, schools, and multicultural organizations to create accessible materials, including large print, pictograms, multiple languages, and ASL/video. These materials should focus on flash flood safety and local high-risk locations.
    - Make sure all these materials tell people where to get trusted flood information, including Flood Data NTX and local alert options.
- Connect public education to real alerts and actions.
    - Teach residents what each kind of alert means and what action to take right away, especially for driving, school pickup, and safety at home.
    - Use stories, videos, and short post-event summaries to show what people should do during floods and how the system is improving based on what was learned.

## 6.7 Conclusions

Overall, the TSI study area has many of the core pieces of a strong FEWS, including regional partnerships, growing technical tools, and active local programs. The main need is not to replace these efforts, but to connect them more consistently across the flood warning system value chain so they support shared decisions, clearer public messages, and more coordinated action across jurisdictions.

The improvement strategies in this document provide a few practical strategies toward that goal. These strategies should be seen as continuous improvement ideas versus “filling gaps.” By strengthening shared risk information, improving forecasting and communication, building a common decision framework, and reinforcing preparedness and public education, the region can move from a collection of capable but distinct efforts to a more unified flood warning and response system that leverages the best practice efforts conducted by NCTCOG member communities.

# Chapter 7

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# Appendix A

# April 2025 Flood Warning Systems Survey Results

Purpose: This survey was conducted in April 2025 to seek feedback from communities in North Central Texas in order to understand flood warning systems currently in use, to assess their effectiveness, and identify areas for improvement.

Overall Findings: The survey results highlight the need for more localized and real-time information, better public engagement, and additional funding and resources to support the implementation and maintenance of flood warning systems.

Flood warning systems in use:

- 46% said yes, their community utilizes or participates in a flood warning system
- 54% said no, their community utilizes or participates in a flood warning system

Reasons selected for not utilizing or participating in a flood warning system:

- Lack of funding (12 responses)
- Lack of resources or personnel (9 responses)
- Lack of technical expertise (5 responses)
- Not needed in their area (4 responses)
- No suitable system available (0 responses)
- Other (0 responses)

Types of flood warning systems in use:

- National Weather Service (NWS) warnings (17 responses)
- Real-time flood monitoring data (e.g., stream gages, rainfall gages, cameras) (9 responses)
- Flood Alert System (FAS) with location-specific alerts (7 responses)
- Predictive flood warning systems (e.g., flood forecasts, models) (6 responses)

- Not sure (0 responses)
- Other (0 responses)

Responsible parties for operating and maintaining flood warning systems in use:

- Local government/emergency management (14 responses)
- National Weather Service (11 responses)
- Third-party service providers are responsible for operating and maintaining these systems (3 responses)
- Other:
    - Stormwater & Streets Department/Public Works (3 responses)
    - Tarrant Regional Water District (1 response)
- U.S. Army Corps of Engineers (2 responses)
- U.S. Geological Survey (2 responses)
- Volunteers or community organizations (1 response)
- Local utility provider (0 responses)
- Not sure (0 responses)

Ongoing costs associated with flood warning systems in use:

- Subscription/service fees (9 responses)
- Staff training or operational costs (8 responses)
- Maintenance fees (8 responses)
- Hardware replacement/upgrades (7 responses)
- Communications infrastructure costs (4 responses)
- Not Sure (4 responses)
- No Ongoing costs (3 responses)
- Other (0 responses)

Benefits of flood warning systems in use:

- Provides real-time, accurate information (12 responses)

- Helps in decision-making support for evacuations and flood control (12 responses)
- Provides specific alerts tailored to affected areas (9 responses)
- Alerts the public in a timely manner (9 responses)
- Low cost of operation (5 responses)
- Coverage in all areas (4 responses)
- Not sure (0 responses)
- Other (0 responses)

Areas for improvement of flood warning systems in use:

- Insufficient public awareness or engagement (8 responses)
- High installation or maintenance costs (7 responses)
- Lack of coverage in certain areas (7 responses)
- Staffing needs that exceed availability (6 responses)
- Lack of future rainfall coverage data (5 responses)
- System malfunctions or technical issues (2 responses)
- Limited to specific media (radio, TV, etc.) (2 responses)
- Not sure (2 responses)
- Other:
    - Need more data and sensors and monitoring capabilities (1 response)
- High cost of operation (1 response)
- Delayed or outdated information (1 response)

Ensuring data quality and accuracy with flood warning systems in use:

- Regular calibration and maintenance of equipment (8 responses)
- No formal data quality procedures (6 responses)
- Data checked by trained personnel (6 responses)
- Use of multiple data sources to confirm information (4 responses)
- Not Sure (3 responses)

- Data validation processes in place (2 responses)
- Other:
    - Equipment and software updates (1 response)

Additional resources used to supplement the flood warning system data in use:

- Federal (USGS gages, NWS, InFRM, Other, please specify) (12 responses)
- Local (NCTCOG Flood Data, Utility Data, Other, please specify) (7 responses)
- Other:
    - Dam operator updates of water releases (1 response)
    - WeatherStem (1 response)
    - Public input (1 response)
- State (TWDB, TCEQ, TXDOT, Other, please specify) (6 responses)
- None (5 responses)
- Not sure (1 response)
- Public input (0 responses)

Frequency for updating, maintaining, or inspecting flood warning systems:

- Regular updates (e.g., every 6 months or annually) (6 responses)
- Not Sure (6 responses)
- Updates are infrequent or ad-hoc (5 responses)
- No regular maintenance or updates (2 responses)

On-call technician availability to address system failures or maintenance issues for flood warning systems in use:

- Technicians are available 24/7 (6 responses)
- Technicians are available during business hours (4 responses)
- There is no dedicated on-call technician (5 responses)
- Not sure (4 responses)

Detailed, location-specific information about flood risk provided by flood warning systems in use:

- Yes, system provides detailed and specific information for my location (12 responses)
- No, system provides general information for larger areas (e.g., city-wide, regional) (6 responses)
- Not sure (0 responses)

Website or app with real time information for flood warning systems in use (several listed URL in survey):

- Yes, with real-time flood data (rain gage, stream gage, cameras, etc.) (7 responses)
- No (6 responses)
- Yes, with an advanced internal system for FWS personnel use and a simplified public facing system (3 responses)
- Yes, with one system for FWS personnel and the public (2 responses)
- Yes, with an interactive map to identify flood hazard locations, closures, etc. (3 responses)
- Not sure (3 responses)
- Yes, with current notifications of evacuation and/or emergency orders (1 response)
- Other (0 responses)

Challenges in understanding or acting on flood warnings:

- No significant challenges (9 responses)
- Language barriers (3 responses)
- Difficulty understanding technical warnings (3 responses)
- Alerts received too late or not specific enough (3 responses)
- Lack of detailed, location-specific information (3 responses)
- Not sure (3 responses)
- Other:

  - Drivers not obeying or following the warnings (1 response)
  - Cost of public education (1 response)

Funding obtained for flood warning systems in use:

- Local government funding (12 responses)
- Federal programs or grants (2 responses)
  - Hazard mitigation funding for parts of the flood warning system program, especially the flood gates within one section of our city
  - CRI Grants, offset with some funding from local road and bridge precincts
- State programs or grants
  - Not sure of exact grant
- Fee-based systems (2 responses)
- Not sure (5 responses)
- Private sector partnerships or sponsorships (0 responses)
- Community fundraising (0 responses)
- Other (0 responses)

Enough funding and resources to support implementation of predictive flood models and maintain the flood warning systems in use:

- No (8 responses)
- Not sure (6 responses)
- Yes (5 responses)

Level of public engagement with flood warning and alert system in use:

- Somewhat involved (5 responses)
- Not very involved (5 responses)
- No involvement (4 responses)
- Not sure (4 responses)
- Very involved (1 response)

Rate of overall performance of flood warning systems in use:

- Good—system works well but could use improvements (10 responses)
- Fair—system is occasionally unreliable or incomplete (4 responses)
- Excellent—system is highly reliable and informative (2 responses)
- Not sure (2 responses)
- Other:
    - Limited system that works well for our operations, but needs expansion (1 response)
- Poor—system is unreliable and does not meet needs (0 responses)

Improvement suggestions for flood warning systems in use:

- Our current flood warning system is the same as our general public emergency notification system, so it is not specific to floods. We can only send out messages based on known flood-prone areas when NWS sends flood warnings. It would be helpful to have a flood specific warning system that has flood zones built in.
- Additional monitoring locations for high water. Installation of rain and flood gages throughout the city.
- I would like a better situational awareness platform that allows us to pull cameras and sensors into one program. Ideally, if we get an alert for high water in an apartment complex, I want to quickly click the alert and see a camera to get a visual and see on a map where in the city we are looking at.
- Tying flood gates into the FWS to automate road closures.
- More modeling and pinpoint forecasting.
- This is a relatively new project for our County and additional flood monitors are currently being installed. There is a need for more flood monitors countywide.
- Emergency notifications on cell phones that have a broader area for the public traveling from one side of DFW to the other.
- System upgrades and modernization.
- I would like to see more localized and real time information. This does not have to be high tech. Simple solutions like water depth gage signs have been a helpful common-sense solution that I see too few of. Flood gates to block roads

would also be very good for people new to the area without the local knowledge of problem areas. I feel that often the flooding incidents are brought about by people not from the area, not on any local warning system, attempting to drive through the area and assuming it is safe. Overall, I think we need to look at less high-tech solutions and just go back to more common-sense solutions.

- One that includes visual pictures of the flooded area.

Additional comments or suggestions regarding flood warning systems in use:

- Our city has 3 flood warning sirens that are verbal and can be activated to alert the public to evacuate the area. We also had to initiate a public education campaign where we mail out postcards annually to those within the area of these 3 sirens to be better educated on the flood risks and actions they need to take when they hear the siren.
- Opportunities for public outreach, especially in small areas that do not have alerts.
- Have the ability to share data with neighboring communities and other agencies.
- There is a need for education public outreach so residents know more about the flood mitigation, warning systems, types of warnings, flood insurance, city mitigation and capital improvement plans, etc.

# Appendix B

## January 2026 Flood Warning Systems Survey Results

Purpose: This survey was conducted in January 2026 to seek feedback from communities in North Central Texas in order to understand support communities need to utilize/participate in a regional flood warning system, improve their current flood warning system, or implement their own flood warning system.

Overall Findings: The survey results highlight strong agreement that flood warning systems provide clear community benefit, with respondents emphasizing life safety as the primary measure of success, particularly at flood-prone roadways. Respondents consistently prioritized timely, actionable, impact-based information over raw data, stressing the need for real-time, hyper-local monitoring that translates forecasts into clear local consequences and supports rapid decision-making. The results also underscore that staffing, training, sustainable funding, and ongoing maintenance are critical constraints that can limit system effectiveness as much as technology itself. Finally, respondents identified communication, equity, and “last-mile” challenges, reinforcing the need for regional coordination, partnerships, and multi-channel outreach to ensure warnings lead to protective action.

Would a flood warning system benefit their community:

- Yes (8 responses), with additional context:
  - Awareness
  - Great to connect a system to stream gages recently installed by USGS
  - Automated flood gages along the river and at low water crossing prone to flooding; tie into IPAWS for phone alerts
- Not really (1 response), with additional context:
  - Most of our major crossings are above the 50- and/or 100-year fully developed floodplain—some of this information is based on outdated hydrology

How a successful flood warning system would be defined (main bullet represents a summarized response, while the sub-bullets are verbatim responses):

- Actionable, impact-based information (5 responses)
  - Actionable Data Access: User-friendly dashboards that translate regional hydrological data into local impact alerts (e.g., "Main St. Bridge will overtop in 2 hours")
  - Converts technical data into clear, decision-ready triggers (e.g., “Road X likely to overtop in 45 minutes”)
  - Uses impact-based thresholds, not just rainfall totals
  - When engaged decision makers in the community act on the information provided
  - Provides sufficient warning so that alerts can be sent to the public and City/County staff can set barriers up at crossings that could become inundated
- Includes real-time sensing to identify flood conditions as they develop (2 responses)
  - Sensors and real time monitoring
  - Detects flood threats early enough to act (minutes to hours for flash floods; hours to days for riverine flooding)
- Monitoring coverage is sufficient to support evacuation and response decisions (2 responses)
  - Sufficient coverage to notify people of flooding potential, and far enough upstream to notify people of potential evacuation
  - Automated flood gages along river and at low water crossings prone to flooding and tied into IPAWS for phone alerts
- Prioritizes protection of human life (1 response)
  - No loss of life from flooding
- Functions consistently and understood by the community (1 response)
  - One that works consistently and that residents are aware of
- Local infrastructure data are reflected in forecasting tools (1 response)
  - Technical Connectivity: Assistance with "check-in/check-out" procedures for dynamic living models to ensure the local data (e.g., new culverts or bridge elevations) reflects in the regional forecast

Types of resources that would most improve flood warning (main bullet represents a summarized response, while the sub-bullets are verbatim responses):

- Staffing, coordination, and institutional support (3 responses)
    - Dedicated staff time and technical capacity
    - Fostering interactions and data exchange between municipal, county, and local agency staff
    - Sustainable Funding
- Monitoring infrastructure and sensor coverage (3 responses)
    - Funding for automated flood gages along river and at low water crossings prone to flooding and tied into IPAWS for phone alerts
    - More local sensors in the right places
    - Hyper-local sensors and 2D mapping are essential for accurate detection and evacuation planning
- Data, analytics, and decision support (2 responses)
    - Predictive Analytics & Decision Triggers
    - Interoperable Data & Dashboards
- Accurate hydrology and mapping (2 responses)
    - Funding for updated hydrology would be first on the list so that we can have a better idea where flooding of crossings or neighborhoods might occur. This new data could then be used to determine what type of flood warning system is needed until the city can address the flooding issue, if possible.
    - Updated flood inundation maps for all high-hazard dams in jurisdiction.
- Effective communication and public notification (2 responses)
    - Both tech and non-tech warning communications
    - More information on the systems, training, funding, best ways to notify the public, should we use redundant systems
- Training and capacity building (2 responses)
    - Training of employees and interested citizen groups
    - Training and exercises focused on flood decision-making
- Immediate risk reduction at roadways (1 response)

  - Automated flashers remain the most critical resource for preventing immediate vehicle-related drownings during flash flood events.
- Practical, usable tools (1 response)
  - Practical tools

Geographical scale most useful for flood warning information (from an operational standpoint):

- Watershed-based (7 responses)
- County-based (4 responses)
- Multi-county/regional (2 responses)
- Jurisdiction-specific only (2 responses)

Knowledge of and needs met for NCTCOG's Flood Warning System cooperative purchase:

- NA/no/not familiar with (6 responses)
- Needs improving (2 responses)
  - Needs to be easy for employer to use
  - 1. Inclusion of "Emerging" Low-Cost Tech. The Issue: Many established contracts favor traditional, high-end USGS-style gages ($15k–$25k+). The Improvement: Expanding the contract to include more "Alternative FEWS" vendors—those offering $2,000 IoT (Internet of Things) sensors. This would allow city to deploy sensors at 50 locations for the price of 5, which is essential for neighborhood-level coverage. 2. Direct Transportation Integration (The "T" in TSI). The Issue: The current focus is heavily on hydrological data (how high is the water?). The Improvement: Adding specific line items for ITS (Intelligent Transportation Systems) integration. This includes software APIs that automatically push flood data to Waze, Google Maps, or city traffic management centers to trigger digital message boards without manual intervention. 3. Maintenance and "Life-Cycle" Bundling. The Issue: Purchasing the hardware is easy through TXShare, but many communities struggle to find funds or labor for the twice-yearly sensor cleaning and calibration. The Improvement: Creating a specific "Regional Maintenance Tier" within the contract where a vendor can be hired to maintain sensors across multiple small cities simultaneously, reducing the per-city cost of keeping the system operational. 4. Data Sharing and "Public

API" Standards. The Issue: Some software vendors under these contracts charge extra fees to "export" data to third-party apps or neighboring cities. The Improvement: Standardizing a "Data Openness" requirement in the contract, ensuring that any software purchased through TXShare must provide a free, standardized data feed to the NCTCOG regional dashboard.

- Meets needs (1 response)

Education and outreach efforts currently in use to communicate flood risk and flood warning systems and biggest challenges (main bullet represents a summarized response, while the sub-bullets are verbatim responses):

- Multi-channel, layered outreach (2 responses)
    - From in-person at neighborhood meetings and with kids groups and in ISDs, curriculums and signage, direct mail messaging, signage in high risk areas, to online and social media messaging, print messaging, emails, Next Door posts, event engagement, promotional giveaways w/messaging, installed HWWS flashers and associated real-time warning website, provide NOAA WX radios to elderly or disabled in higher flood risk areas to give as much notification via a low digital method for residents who are low tech (elderly), etc.
    - Training and community engagement
- Use of existing regulatory and planning frameworks (1 response)
    - Our Floodplain Management regulations, FEMA maps, and a local Flood Planning Study
- Digital outreach under staffing/budget constraints (1 response)
    - Social media and newsletters; best way with limited staff and budget
- Place-based risk emphasis (1 response)
    - Residential areas in flood spill ways.
- Partner engagement and interagency discussion (1 response)
    - Discussions with local resource agencies
- Recurring direct communications and on-site materials (1 response)
    - Yearly letters to those residents that are near past/present substantially damage homes; flyers at library and City Hall; sometimes a city booth at events; early flyer in utility bill.
- Behavioral and communication challenges (1 response)

  - "Flood Fatigue" and Normalization in North Texas, heavy thunderstorms are frequent. Many residents become desensitized to "Flash Flood Warnings" on their phones. The Challenge: Differentiating between a "typical" heavy rain and a life-threatening event. When people see a warning every week, they stop changing their behavior (like choosing a different driving route).
  - The "Last Mile" of Information. We might know a creek is rising, but getting that specific data to a driver 500 feet away from the crossing is difficult. The Challenge: There is often a gap between the data (a sensor reading) and the action (a driver stopping). Outreach hasn't yet fully solved how to provide "hyper-local" warnings that feel personal and immediate.
  - Language and Economic Barriers. Our city is highly diverse with a large population of non-native English speakers and residents who may not have consistent access to high-speed internet or smartphones. The Challenge: Traditional digital-only outreach can miss vulnerable communities. Ensuring that flood risk education is multilingual and available through non-digital channels (radio, community centers, physical signage) is a constant struggle.
  - Renters vs. Homeowners Outreach is often targeted at property owners via tax records or mailers. The Challenge: A significant portion of residents are renters who may not realize they live in a flood-prone apartment complex or park their cars in a low-lying lot until an event occurs.
- Reliance on free, established information tools (1 response)
  - Use of free online tools from USGS, NOAA, OneRain, etc.

Support needed to help continue or strengthen conversations with public officials about investing in flood warning systems (main bullet represents a summarized response, while the sub-bullets are verbatim responses):

- Training and outreach (4 responses)
  - Broader reach; joint developed and funded ad campaign and psa's that includes advertising in: tv, radio, print, outdoor, transit, online and social media
  - Pamphlet or video that can be provided to officials
- Case studies (3 responses)

- Presentations from entities that have FWS that include discussions on equipment costs, software costs, maintenance costs, and replacement periods and costs
- Case studies or tools that calculate the Benefit-Cost Ratio (BCR). For example, "Every $1 spent on FEWS in a similar city saved $6 in emergency response, vehicle damage, and infrastructure repair." Impact: This transforms FEWS from a "cost" into an "investment" that protects the city's general fund.
- Seeing flooding and its impact on the community

- Simple solutions (1 response)
  - Many local representatives are part-time, retired, or otherwise time-limited and do not have the resources to learn complicated systems. It needs to be simple, or afford access to a simplified dashboard that can be customized to display the information they need.
- Continued funding and historical data (1 response)

Creative or non-traditional partnerships that could help implement or expand local flood warning systems, e.g., schools, universities, local businesses, community organizations (main bullet represents a summarized response, while the sub-bullets are verbatim responses):

- Schools/universities (3 responses)
  - Educational and Academic Partnerships: Partnering with local universities allows the city to use "Living Labs." Students can help develop machine learning models to predict floods or build low-cost sensor prototypes as part of senior design projects.
  - Local ISD (STEM Programs): Placing mini-weather stations or sensors at local schools turns campuses into data nodes. This provides the city with hyper-local rainfall data while offering students real-world STEM curriculum opportunities.
- Others (2 responses)
  - Meteorologists/broadcasters/regional weather services
  - Media and Technology Partnerships Navigation App Partnerships (Waze/Google): Rather than just an API, a formal partnership with "Connected Citizens Programs" ensures that flood alerts are prioritized in the algorithm, rerouting drivers before they reach a high-water crossing. Local News "Weather Watcher" Networks: Partnering with local news

  - stations to integrate city sensor data into their broadcast apps creates a massive, ready-made audience for early warnings.

- Government or special districts (1 response)
  - TRWD
  - USGS
  - NCTCOG
- Associations (1 response)
- Local businesses (1 response)
  - Private Sector and Infrastructure Partnerships Delivery & Logistics Companies (Amazon/UPS/FedEx): Since these companies have large fleets constantly moving through the city, they have a vested interest in avoiding flooded roads. Partnerships could involve sharing real-time "road condition" data from driver apps or mounting sensors on delivery hubs located near flood-prone industrial zones.
  - Real Estate Developers: For new large-scale developments (like those in the Design District or near the Trinity), the city could incentivize or require the installation of "private-public" sensors. The developer pays for the hardware as part of their drainage plan, but the data feeds directly into the municipal FEWS.  Data Centers: The city is a major hub for data centers. These facilities require massive cooling and are highly sensitive to weather. They could provide the "cloud" hosting or backup power for FEWS telemetry in exchange for high-priority risk data.
- Community organizations (1 response)
  - Community and Civic Partnerships HOAs and Neighborhood Associations: Affluent HOAs often have the funds and the desire to protect their property. The city could provide the "technical specs" for sensors that the HOAs purchase and maintain, expanding the city's network at zero capital cost to the taxpayer.
  - Local Watershed "Friends" Groups: Organizations can act as "Citizen Scientists." They can be trained to perform basic sensor maintenance (like clearing debris) or provide ground-truth photos during events to verify sensor data.

Methods to best engage local community in understanding and using flood warning information, e.g., public dashboards, test or app alerts, roadway signage, public awareness campaigns:

- Examples provided (public dashboards, test or app alerts, roadway signage, public awareness campaigns), specifically (7 responses):
    - Websites
    - From in-person at neighborhood meetings and with kids groups and in ISDs, curriculums and signage, direct mail messaging, signage in high risk areas, to online and social media messaging, print messaging, emails, Next Door posts, event engagement, promotional giveaways w/messaging, installed HWWS flashers and associated real-time warning website, provide NOAA WX radios to elderly or disabled in higher flood risk areas to give as much notification via a low digital method for residents who are low tech (elderly), etc.
    - Our community is more senior now, so a public awareness campaign, text, or app alerts might be best. A program at senior centers might be good.
- Most NRCS Flood Prevention Sites (aka NRCS/SCS ponds, PL566 ponds) are gaged. These could be monitored (and perhaps instrumented) for more localized flood response info. (1 response)
- To effectively engage a large and diverse community, engagement must move beyond static information and become interactive, localized, and integrated into daily life. The following methods are considered "best-in-class" for bridging the gap between technical flood data and public action (1 response):
    - Hyper-Local "Micro-Dashboards" While a city-wide map is useful for emergency managers, residents care most about their own street. The Method: Develop a mobile-friendly dashboard that allows users to save "favorite" crossings or routes. The Engagement: Use color-coded risk levels (Green/Yellow/Red) rather than technical "gage heights." If a resident sees their "Commute to Work" is "Red," they are far more likely to engage with the data than if they read that "Coombs Creek is at 14 feet."
    - Automated "Push" Notifications with Rerouting Passive information (like a website) requires the user to seek it out; active information finds the user. The Method: SMS/Text alerts are standard, but the "next level" is GPS Integration. The Engagement: Partnering with apps like Waze or Google Maps to push "Flood Ahead" alerts directly to a driver’s dashboard in real-time. This turns a "warning" into a "service" that helps the community avoid traffic.
    - Physical "Visual Cues" at the Source Digital tools fail if cell towers are overloaded or if a driver isn't looking at their phone. The Method: Dynamic, sensor-triggered roadway signage and depth gages. The Engagement: Installing high-visibility "depth rulers" on bridge pilings and automated

flashing beacons. These provide an immediate "gut check" for drivers that reinforces the "Turn Around, Don't Drown" message with physical evidence.

- Gamified Public Awareness and "Citizen Science" To combat "flood fatigue," engagement needs to be community-driven rather than just government-issued. The Method: A "High Water Mark" campaign or a photo-sharing portal. The Engagement: Encouraging residents to upload geo-tagged photos of street flooding to a city portal. This makes the community feel like "partners" in the FEWS and provides the city with valuable "ground-truth" data to calibrate their sensors. 5. Multilingual & Multi-Channel Outreach, a "one size fits all" approach misses thousands of residents. The Method: Targeted campaigns in Spanish, Vietnamese, and Amharic, delivered via trusted community hubs (churches, neighborhood centers, and local radio). The Engagement: Using non-digital methods like "High-Water Door Hangers" in vulnerable neighborhoods before the spring rainy season to ensure those without consistent smartphone access are informed.

# Appendix C

# Gap Analysis Checklist

## C.1 Identify Flood Risk

1. Are key flood hazards and related threats identified?
    - Summarize what's known about geographical extent, magnitude, intensity, historical data, future risks.
    - What are the watershed response times at key locations of significant flood impact?
    - What flood hazard maps are available?
2. Are flood risks and vulnerabilities identified?
    - Critical facilities mapped (e.g., hospitals, water treatment, fire/police stations, etc.)
    - Impacts to critical infrastructure evaluated.
3. Are roles and responsibilities of stakeholders identified?
    - Who are the key agencies. (e.g. Host agency, NWS, NWSRFC, USGS, USACE, etc.)? Describe roles.
    - Hazard identification and risk information coordination. Who is responsible?
    - Available experts to assess quality of risk data and information. (e.g., PW Engineer, Consultant, etc.)
    - Process in place to engage rural and urban communities in risk assessment.
4. Is risk information consolidated?
    - Is there a centralized database of events, disaster, and risk information, including GIS. Where? Who is responsible?
    - Is process in place for systematic collection, sharing, and assessment of risk data?
    - Process in place for regular review and updating of risk information, including new or emerging vulnerabilities.
5. Is risk information properly incorporated into the FEWS?
    - Mapping shows flood extents, safe zones, and evacuation routes.
    - Risk information on vulnerable groups.
    - Process in place for regular review and updating of risk information, including new or emerging vulnerabilities.

## C.2 Detection, Monitoring, Analysis and Forecasting of Flooding and Possible Consequences

1. Are monitoring systems in place?
    - Describe network to monitor rainfall, stream levels, and other relevant data (e.g., wind, tide, etc.)
        - Provide network maps with GIS or KML files of gage locations.
        - What is the rain gage density (mi2/gage)?
        - What is the stream gage network?
        - Other hydrometeorological sensors? (Describe)
    - Measurement parameters and specifications documented. Rain/stream reporting resolution and frequency? Web site?
    - Data reporting protocol

Self-reporting

- ALERT
- ALERT2
- GOES
- Other (Describe)

Interrogated

- SCADA
- Microwave network
- Cell phone
- Other (Describe)

Communications medium

- VHF/UHF radio
- Microwave
- Cell phone
- Satellite other than GOES
- Other (Describe)

- Web camera network. Describe.
- Are data available via a publicly accessible website?
- Personnel trained to operate and maintain equipment.
- Monitoring data received, processed and available in an interoperable format in real time or near real time. Describe data sharing/transfer. SHEF, DSS, FTP (Push/Pull), others?
- Monitoring data and metadata routinely managed with quality controls, archived and accessible for verification, research purposes and other applications.

- Monitoring hardware and software maintenance conducted routinely. Describe.
- Operations and maintenance costs and resources budgeted to ensure long-term operation.
- Are power supplies at field sites and at the data operations center sufficient for continued operations if main power fails?
- Are there potential single points of failure? (e.g., a single radio repeater, single radio receiver/modem, single computer at data collection site, single point internet access, etc.)

1. Are there forecasting and warning services in place?
    - Describe data analysis and processing, modeling, prediction, and warning products generated. (e.g., high water alerts, streamflow forecasts etc. Are flood forecasts generated internally or by an outside agency such as the NWS.)
    - Describe information dissemination to key stakeholders and public. (e.g., high water alert displays on a website, text, emails, etc.)
    - Can new data analysis and processing, modeling, prediction, and warning products be integrated easily in the system as science and technology evolves?
    - Warning centers are always operational (24 hours/day, seven days/week) and staffed by trained personnel following appropriate national and international standards.
    - Warning messages are clear, consistent and include risk and impact information and are designed with consideration for linking threat levels to emergency preparedness and response actions.
    - Software and data analysis for the received data updated periodically and to appropriate cyber security standards
    - The state of the monitoring and data analysis systems continuously monitored for any data gaps, connection issues, or processing issues
    - Flood warnings generated and disseminated in an efficient and timely manner
    - Warning system subjected to regular system-wide tests and exercises
    - Process established to verify that warnings have reached the principal stakeholders and people at risk
    - Mechanisms in place to inform people when the threat and its impacts have ended
    - Operational processes, including data quality and warning performance, are routinely monitored and evaluated
    - Fail-safe systems in place, such as power backup, equipment redundancy, and on-call personnel systems

- Strategies developed to build credibility and trust in warnings (e.g. understanding difference between forecasts and warnings)
- False alarms minimized and improvements communicated to maintain trust in the warning system
- Warning and forecast archival processes and systems in place

2. Are there institutional mechanisms in place?
    - Plans and documents for monitoring networks available and agreed upon with experts and relevant authorities
    - Standardized process, and roles and responsibilities of organizations generating and issuing messaging established and mandated by legislation or other authoritative instruments (e.g. memorandum of understanding (MOU), standard operating procedures)
    - Agreements and interagency protocols established for exchange of monitoring systems data (e.g., Standard Hydrologic Exchange Format, ALERT, ALERT2, DSS, etc.)
    - Agreements and interagency protocols established to ensure consistency of warning language and communication responsibilities
    - Warning system partners, including local authorities and the media, are aware of and respect which organizations are responsible for generation and issuance of warnings
    - Cross-border exchange of warnings and observation data realized through bilateral/ multilateral agreements (e.g., IWBC)

## C.3 Preparedness and Response Capabilities

1. Are disaster preparedness measures, including response plans, developed and operational?
    - Flood preparedness, including plans or standard operating procedures, developed in a participatory manner, disseminated to the community, practiced and underpinned by legislation where appropriate
    - Flood preparedness measures, including plans and standard operating procedures, account for the needs of people with different degrees of vulnerability
    - Flood risk assessments utilized to develop and design evacuation strategies (evacuation routes, safe areas and location of temporary shelters, use of vertical evacuation if needed)
    - Community's ability to communicate in response to early warnings assessed
    - Contingency planning developed in a scenario-based manner following forecasts or likely scenarios across different timescales

- Early action and response options across time and on geographical scales are linked to the provision of funding to support them
- Strategies implemented to maintain preparedness for longer return-periods and cascading hazard events
- Protocols incorporated in the plans or standard operating procedures to reach emergency and health services that need to be ready to respond to events promptly
- Protocols established to activate and mobilize last-mile operators (e.g. local police, firefighters, volunteers, health services) who disseminate warnings to the public and decide public measures, including issuing orders for evacuation or sheltering in place
- Regular exercises undertaken to test and optimize the effectiveness of early warning dissemination processes, preparedness, and response to warnings

2. Are public awareness and education campaigns conducted?
    - Ongoing public awareness and education programs
    - Public education provided to recognize hydrometeorological and flood hazard triggers
    - People educated on how warnings will be disseminated, which sources are reliable and how to respond

## C.4 Warning Dissemination and Communication

1. Are organizational and decision-making processes in place and operational?
    - Functions, roles, and responsibilities of each partner in the warning dissemination process included in the standard operating procedures
    - Warning communication strategies at the national, state, regional and local levels in place that ensure coordination across warning issuers and dissemination channels
    - Regular coordination, planning and review meetings between the warning issuers, the media, and other stakeholders
    - Professional and volunteer networks established to receive and disseminate warnings widely
    - Feedback mechanisms in place to verify that warnings have been received and to correct potential failures in dissemination and communication
    - Mechanisms to update the information are in place and are resilient to the event
2. Are communication systems and equipment in place and operational?
    - Trust between stakeholders established

- Communication and dissemination systems tailored to the different needs of specific groups (urban and rural populations, women and men, older people and youth, people with disabilities, etc.)
- Understanding of last-mile connectivity to know which population groups can be reached by different services, including mobile-cellular, satellite and radio services
- Warning communication and dissemination systems reach the entire population, including seasonal populations and those in remote locations, through multiple communication channels (e.g. satellite and mobile-cellular networks, social media, flags, sirens, bells, public address systems, door-to-door visits, community meetings)
- Communication strategies evaluated to ensure messages are reaching the population
- Agreements developed to utilize private sector resources where appropriate (e.g. mobile-cellular, satellite, television, radio broadcasting, amateur radio, social media) to disseminate warnings
- Equipment maintained and upgraded to utilize new technologies (when appropriate) to ensure interoperability
- Backup systems and processes in place in the event of failure
- Resilience of communication channels and early warning system hardware evaluated in advance to reduce the impact of events on the infrastructure
- Coverage of communication channels and multiple-channel systems assessed to identify gaps and possible points of failure that may increase vulnerability

3. Are impact-based early warnings communicated effectively to prompt action by target groups?
    - Warning messages provide clear guidance to trigger reactions (e.g. evacuation)
    - Early warnings should take into account the different risks and needs of subpopulations, including differential vulnerabilities (urban and rural, women and men, older people and youth, people with disabilities, etc.)
    - Public and other stakeholders are aware of which authorities issue the warnings and trust their message