Flood Warning and Inundation Mapping

This fact sheet describes how flood warning systems, flood alerts, and flood inundation products convey flood risk information. It also describes how flood warning systems can improve flood awareness and public safety, and reduce impacts from flooding.

How Do Flood Warning and Mapping Systems Improve Flood Awareness and Reduce Risk?

Flood warning and mapping systems are useful to provide situational awareness for key questions before and during flood events:

- How high might the floodwater rise?
- When might floodwater be deepest?
- Where will the water go?
- What property and people are in the areas where flooding is predicted?
- What advice and information will help people at risk of flooding respond effectively?
- How can we best give at-risk people that information?

The benefits associated with flood forecasting and warning are linked with methods used to disseminate warnings and the response actions taken by the public and supporting agencies (both voluntary and official). Depending on several variables, the benefits include reduced physical damage and losses – and improved public safety – compared with what might occur if warnings are not issued.

Physical flood damage, also called direct losses, includes the cost to repair damage caused when floodwater contacts property. Buildings may be damaged, vehicles destroyed, and building contents and personal belongings saturated and contaminated.

Losses that are more difficult to measure are called indirect losses. The most significant indirect losses are loss of life and injury. Examples of other indirect losses include loss of income when businesses must shut down to repair damage and replace equipment and inventory, and when residents must pay for alternative housing while repairs

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are made. Communities experience indirect losses when tax income is reduced and when state and federal disaster assistance requires local matching funds.

Advanced knowledge provided by flood warning systems can give people more time to act and reduce losses. The more lead-time available, the more effective these actions will be.

- Warning those who live and work in low-lying areas to evacuate
- Emphasizing the urgency of evacuating basements
- Moving vehicles to higher ground
- Pre-event maintenance of stormwater systems, such as cleaning gutters and inlets
- Installing flood fighting measures (e.g., sandbags, property flood barriers)
- Moving building contents to somewhere above the estimated flood level or out of floodprone areas
- Shutting down equipment that serves buildings
- Shutting off electric and gas service to minimize the potential for fires and explosions
- Providing evacuation assistance to facilities that serve people with mobility limitations, including hospitals and nursing homes
- Pre-positioning fire and rescue services near known problem areas
- Establishing traffic controls to facilitate evacuation and prevent inadvertent travel into hazardous areas
- Scheduling closure of schools and transporting students out of floodprone areas
- Deploying components of dry floodproofing systems designed to minimize building damage
- Timely operation of flood control structures (e.g., gates, temporary flood defenses) to prevent inundation of property and land

Why Are Flood Warning and Inundation Mapping Effective?

The **National Weather Service (NWS)**, an agency of the National Oceanic and Atmospheric Administration (NOAA), produces generalized weather and flooding information. Communities can use NWS forecasting products to establish local flood warning programs. Timely collection of more detailed information on local rainfall and stream levels may allow communities to develop more accurate and reliable predictions of floods than those available from the NWS.

Many communities develop local warning systems or participate in regional systems, while others rely on forecasts issued by the NWS and mapping products available from the U.S. Geological Survey (USGS). Local officials in communities that experience flooding should learn how using available flood warning products and inundation mapping may be an effective way to reduce flood damage and address safety risks. State emergency management agencies, water resources departments, and local NWS offices may provide technical support.

The NWS reports that floods are the main cause of weather-related deaths in the United States, with flash floods causing many of the deaths. The U.S. has averaged more than 85 flood deaths each year over the past 30 years, with that number increasing to more than 100 deaths a year since 2015. Of these, an average of 37 are attributed to flash floods. Flash floods can occur with little advance notice.

Weather researchers, meteorologists, and hydrologists have greatly increased their ability to estimate weather and flooding events over time. However, research indicates there is a knowledge gap between these professionals and the general public, specifically with regard to flood risk and flood awareness. With advances in internet mapping technology, state and local officials who are responsible for issuing flood alerts and warnings have increasingly turned to flood inundation mapping to provide geographic context to real-time flooding and predicted flood events.

What Are Flood Warning Systems and Flood Inundation Mapping?

Flood warning system programs managed by communities or regional authorities can be effective at providing customized products, including scalable solutions and alerts, such as reverse 911 notifications. Those now in use have been credited with saving scores of lives and preventing millions of dollars of damage. In situations when flash flooding occurs very quickly following heavy rains, warning systems provide lifesaving evacuation notices and notify authorities to close low-lying roads and bridges. Even with advanced warning, people in areas prone to flash flooding may not have enough lead time to protect their property and still evacuate safely.

FLOOD WARNING SYSTEMS

Flood warning systems provide information to allow individuals and decision-makers to make informed decisions about whether to take emergency action before a flood event (e.g., evacuation, closing roads). Some flood warning systems provide real-time data on flood conditions, while others use real-time data to estimate future flood conditions several hours or days in advance.

Flood alert components of warning systems are designed to notify residents, businesses, and decision-makers when pre-defined actions should be taken. These alerts are targeted to specific locations and are pushed out, rather than requiring people to monitor a website or news reports. A flood alert that is driven by a flood warning system with estimates of anticipated flooding may be able to give people enough time to evacuate or move possessions out of harm's way. Alerts and warnings can be distributed through text, email, social media, websites, warning signs and signals, or through radio, television, and news outlets.

FLOOD INUNDATION MAPPING SYSTEMS

Flood inundation mapping systems are used to display the anticipated extent of flooding based on real-time or estimated flood levels. The flood extents are overlaid on other mapping layers, such as road networks, aerial photography, and building maps to provide recipients enough information on which to act, including evacuation or protecting property.

Where Can You Find Flood Warnings and Inundation Mapping?

NOAA NATIONAL WEATHER SERVICE

Forecasters in local NWS offices use the Advanced Weather Interactive Processing System (AWIPS) to display and forecast weather and to create and distribute weather warnings. Issued warnings can be delivered via multiple avenues including:

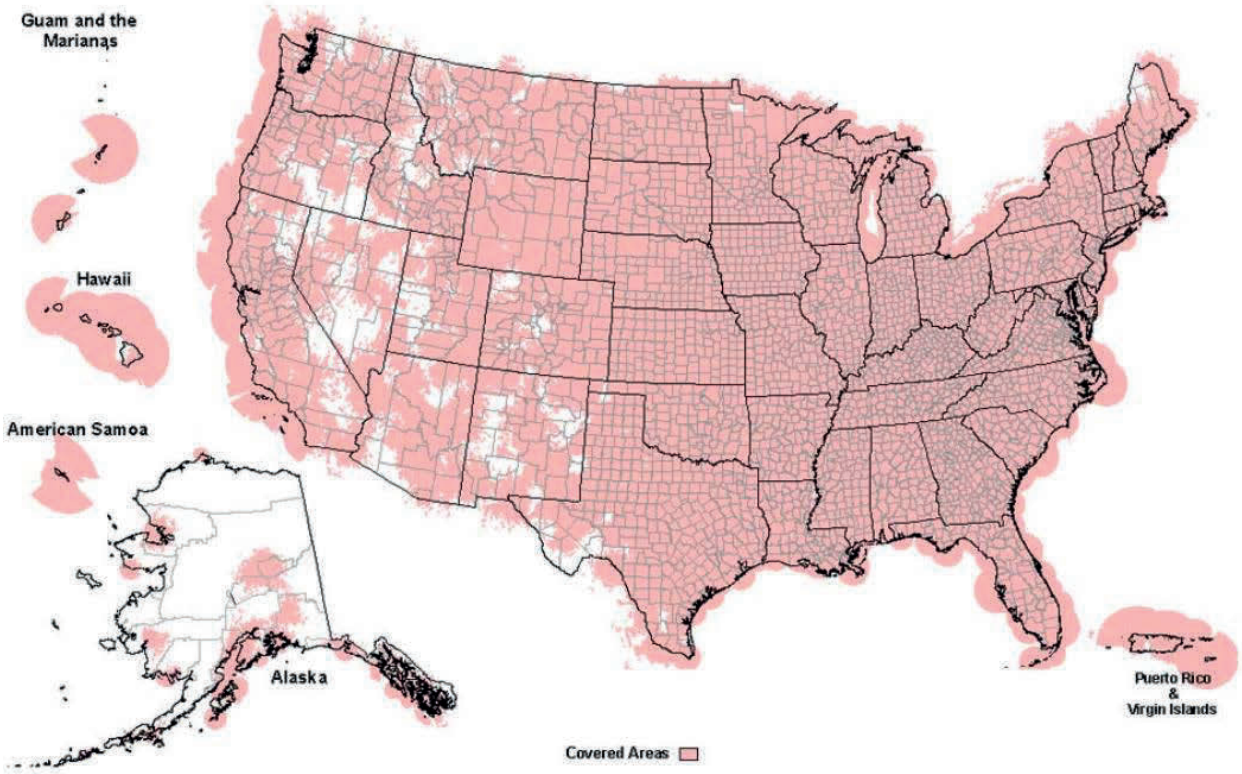
- Wireless Emergency Alerts on mobile phones
- NOAA Weather Radio (described below)
- Emergency Alert System (described below)
- Integrated Public Alert and Warning System
- NOAA Weather Wire Service
- Emergency Managers Weather Information Network
- Interactive Weather Information Network
- NOAAPORT

NOAA Weather Radio: NOAA Weather Radio (NWR) is a nationwide network of 1,025 radio stations covering all 50 states, adjacent coastal waters, Puerto Rico, U.S. Virgin Islands, and the U.S. Pacific Territories (see map). NWR broadcasts continuous weather information directly from NWS offices to areas served by those offices. Broadcasts include NWS warnings, watches, forecasts, and other hazard information. Working with the Emergency Alert System, NWR is an "All Hazards" radio network that broadcasts warnings and post-event information for all types of hazards, including natural hazards (e.g., earthquakes, avalanches), environmental hazards (e.g., chemical releases, oil spills), and public safety messages (e.g., AMBER alerts, 911 telephone outages).

Many retail outlets such as electronics, department, sporting goods, and boat and marine accessory stores and their online catalogs carry NOAA weather radio receivers. NWR broadcasts are found in the VHF public service band at these seven frequencies (MHz): 162.400, 162.425, 162.450, 162.475, 162.500, 162.525, and 162.550.

NOAA Emergency Alert System: The Emergency Alert System (EAS) is the Nation's public warning system. Broadcasters, cable television systems, wireless cable systems, satellite digital audio radio service providers, and direct broadcast satellite providers are required to provide communications capability for the President to address the American public during national emergencies. FEMA is responsible for national-level activation of the system, including tests and exercises.

The EAS is activated most frequently for imminent and dangerous weather conditions. The system is also activated to enable state and local authorities to communicate important non-weather emergency messages, such as AMBER alerts and Civil Emergency Messages. With the exception of national-level activation, it is voluntary for participating radio and television stations to relay the messages.



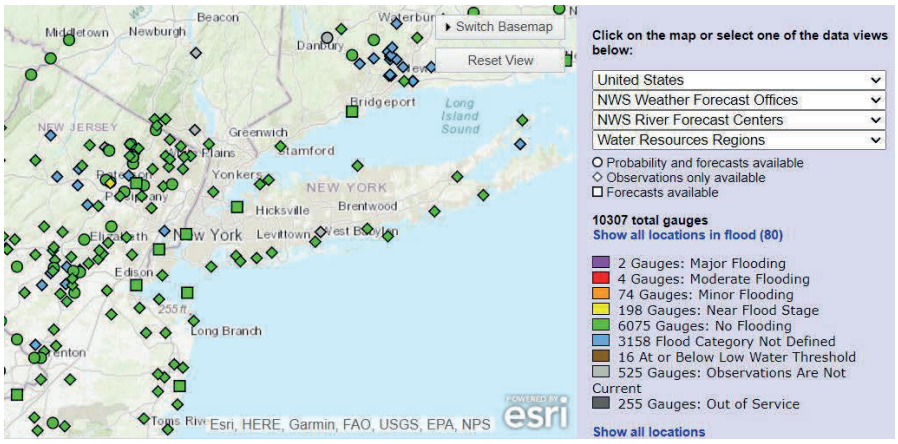
NOAA Weather Radio Covered Areas

NOAA ADVANCED HYDROLOGIC PREDICTION SERVICE

The Advanced Hydrologic Prediction Service (AHPS) is an essential component of the NOAA climate, water, and weather services. AHPS is a web-based suite of accurate and information-rich forecast products that display the magnitude and uncertainty of occurrence of floods or droughts, from hours to days and months in advance of occurrence. The graphical products have useful information used by many economic and emergency managers. These products enable government agencies, private institutions, and individuals to make more informed decisions about risk-based policies and actions to mitigate the dangers posed by floods and droughts.

The NWS AWIPS (described above) uses sophisticated computer models and large amounts of data from many sources such as automated gages, Geostationary Operational Environmental Satellites (GOES), Doppler Radar, and weather observation stations. The system produces hydrologic forecasts for almost 4,000 locations across the U.S. These forecasts are developed by NWS River Forecast Centers and widely distributed.

The current set of AHPS products covers forecast periods ranging from hours to months. AHPS yields valuable information about the chances of flood or drought that is presented through user-friendly graphical products. Flood forecasts, including how high a river may rise and when it is likely to reach its peak or crest, are shown through hydrographs. A hydrograph illustrates how water elevations rise and fall over time. Other information produced includes the probability of a river exceeding minor, moderate, or major flood levels; the chance of a river exceeding certain level, volume, and flow of water at specific points on the river during 90-day periods; and a map of areas surrounding the forecast point that provides information about major roads, railways, landmarks, and other features that are likely to be flooded, along with levels of past floods.



Example of stream gage location map showing real-time conditions.

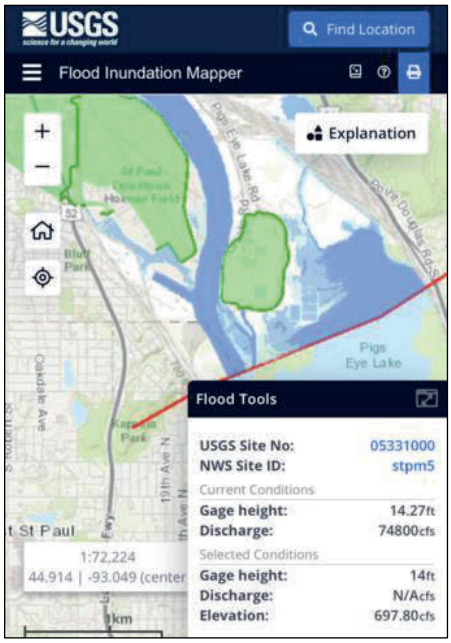
UNITED STATES GEOLOGICAL SURVEY

The **USGS Flood Inundation Mapper (FIM) Program** helps communities protect lives and property by providing tools and information to help them understand their local flood risks and make cost-effective mitigation decisions. The program focuses on partnering with communities to develop flood inundation libraries and provide online access to flood inundation maps along with streamflow data, flood forecasts, and potential loss estimates.

The flood inundation libraries can be used for:

- Preparedness through development of "what-if" flooding scenarios
- Timely disaster response
- Aiding in damage assessments during flood recovery
- Input data for risk assessments for flood planning and mitigation
- Displaying flood extents based on real-time and forecast information

For more information on the USGS FIM Program, visit: https://www.usgs.gov/mission-areas/water-resources/science/flood-inundation-mapping-fim-program#overview.



USGS Flood Inundation Mapper during Minor Flooding Level in St. Paul, Minnesota (April 7, 2020).

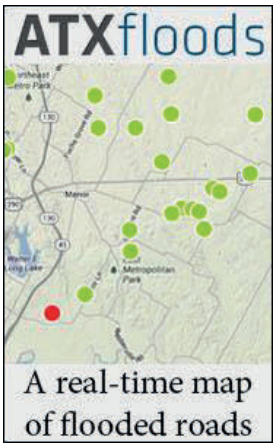
STATE AND LOCAL GOVERNMENTS

Increasingly, state and local government agencies are developing networks of flood gages and inundation mapping programs to augment the NWS and USGS products. These programs use NWS forecasts, gage data, and locally available data to produce flood warnings, alerts, and web-based inundation mapping. Five local programs are described below.

City of New York, NY, FloodNet: FloodNet is a cooperative of communities, researchers, and New York City government agencies working to better understand the frequency, severity, and impacts of flooding in the city. The data and knowledge gained can be used by local residents, researchers, city agencies, and others to advocate around and work to reduce flood risk. FloodNet brings together innovative sources of information on street flooding impacts in neighborhoods that are vulnerable to high tides, storm surge, and stormwater runoff. Real-time flood sensors were developed by the FloodSense project at New York University and the CUNY Advanced Science Research Center. The sensors provide information on the presence, frequency, and depth of hyperlocal street-level flood events to a range of stakeholders, including policymakers, government agencies, citizens, emergency response teams, community advocacy groups, and researchers.

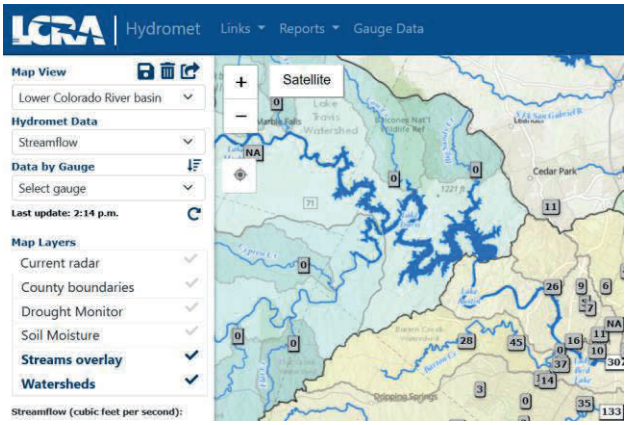
New York City maintains web sites to provide information to residents, property owners, and businesses. FloodHelpNY is a primary source for information about flood risks, flood retrofits, stormwater flooding, and flood insurance. In addition to explaining actions the city takes to plan and prepare for urban flooding, Rainfall Ready NYC is where people can sign up to receive alerts about emergencies, including weather events.

For information about NYC initiatives, visit: https://www.floodnet.nyc/, https://www.floodhelpny.org, https://www.nyc.gov/site/dep/whats-new/rainfall-ready-nyc.page



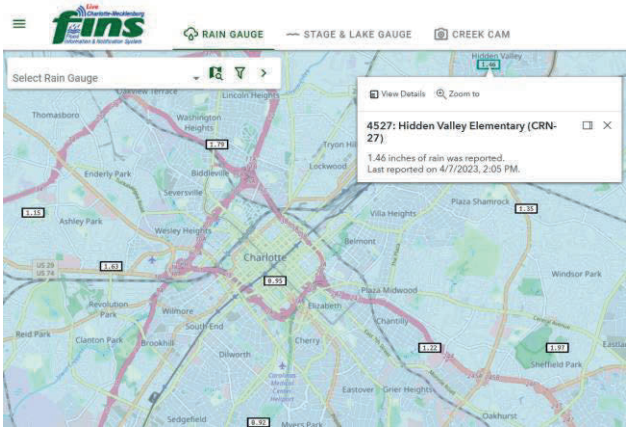
City of Austin, TX, Flood Early Warning System (ATXfloods): ATXfloods, established in 1985, is maintained by the City of Austin Flood Early Warning System team. It was built in large part to monitor flooded roadways in Austin and the eight surrounding counties. The system uses 130 gages and cameras to monitor water levels in creeks and at low-water crossings. Individuals can sign up online to receive flood alerts via email, text message, or phone call. In addition, Austin has placed flashing lights and automated barricades at 15 low-water crossings to prevent motorists from driving into high water.

For more information about ATXfloods, visit: https://www.austintexas.gov/department/flood-early-warning-system



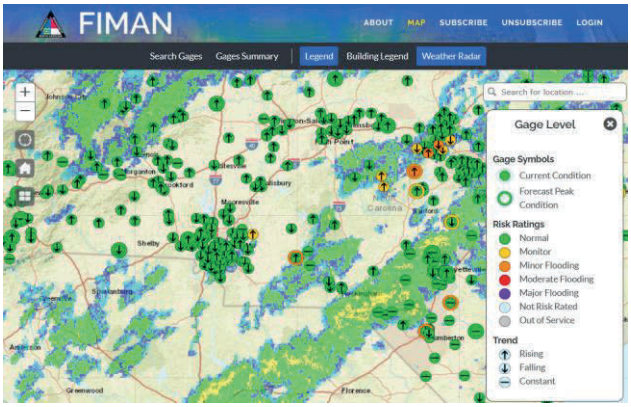
Lower Colorado River Authority Flood Operations Notification Service (LCRA FONS): Because releases from flood control dams on Highland Lakes and Bastrop Dam in Central Texas can cause flash flooding, the Lower Colorado River Authority operates a flood alert system to warn residents living below Lake Austin when flood releases are occurring. Individuals can sign up online to receive flood alerts via email, text message, or phone call when flood operations begin. The notification service supplements NWS warnings. It prompts individuals and businesses to take mitigative action in advance of flooding and to evacuate.

For more information about LCRA FONS, visit: https://www.lcra.org/water/floods/floodgate-operations-notification-system



City of Charlotte, NC, Flood Information and Notification System (FINS): FINS is a partnership involving the City of Charlotte, Mecklenburg County, and the USGS. FINS Live continually monitors real-time rain and stream gage levels along creeks throughout the area. Emergency responders and the public are notified when there is a potential or actual flooding concern.

For more information about FINS, visit: https://finslive.mecklenburgcountync.gov/?gauge=rain&period=PT24H



North Carolina Flood Inundation Mapping and Alert Network (FIMAN): The FIMAN website contains inundation maps for selected sites across North Carolina, as well as along some entire river basins. Flood risk information is provided for areas with inundation maps. For each incremental rise in floodwater, Geographic Information System libraries display pre-developed flood mapping extents. Buildings, roads, and infrastructure that could be impacted are identified. Information on water depth at each affected building is displayed, along with estimated damage costs.

For more information about FIMAN, visit: https://fiman.nc.gov/

How Are Federal Flood Warnings and Inundation Maps Developed?

The NWS is the primary source of water and climate data, and weather forecasts and warnings in the U.S. With 122 Weather Forecast Offices, 13 River Forecast Centers, nine National Centers, and other support offices, the NWS collects and analyzes more than 6.3 billion observations per day, and releases about 1.5 million forecasts and 50,000 warnings each year. Forecasters build their datasets and resulting forecasts with observations from surface stations, weather balloon readings, and satellite data to input to numerical weather, water, and climate models. Forecasters communicate this information and potential impacts to the public, emergency managers, and other key stakeholders to help them make decisions that save lives and protect property.

For more information on NWS forecasts and services, visit: https://www.weather.gov/about/forecastsandservice.

FLOOD WARNINGS

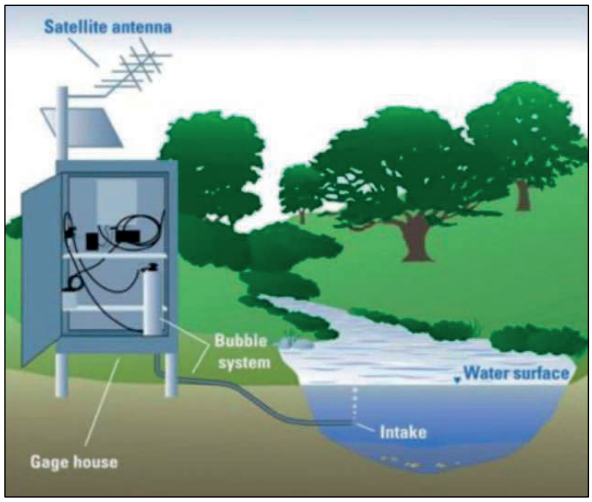
Flood warning systems have three components: data collection, computer modeling using the data, and establishing flooding thresholds for dissemination of flood watches and warnings. Each component is described in more detail below.

Data Collection

The NWS collects weather data from rain gages, stream gages, and remote-sensing sources. A large network of cooperative observers also collects and reports data to NWS.

Rain Gages: Rain gages operated by NWS are usually located at manned sites where local observers check readings daily and perform regular maintenance. The USGS collects precipitation data at about 3,400 locations around the country. About one quarter of the rain gages are co-located with stream gages.

Stream Gages: The USGS collects data from more than 10,000 stream gages nationwide. A stream gage is a structure installed beside a stream or river that contains equipment to measure and record water levels (called gage height or stage) of the stream. Streamflow volume (also called discharge) is computed from measured water levels using a site-specific relationship (called a stage-discharge rating curve) developed from onsite water level and streamflow measurements made by USGS hydrographers.



Typical USGS stream gage installation
Credit: L.S. Coplin, USGS

Remote Sensing Data: In addition to actual measurements taken by rain gages and stream gages, data are collected from national and local Doppler Radar systems and GOES satellite data. These data provide large-scale weather information such as precipitation total estimates and forecasted precipitation.

For more information about USGS water data, visit: https://waterdata.usgs.gov/nwis/rt

Computer Modeling

NOAA uses complex computer models and large amounts of data from a wide variety of sources, including automated gages, satellites, Doppler Radar, weather observation stations, and the computer and communications system called AWIPS. The NWS provides hydrologic forecasts for almost 4,000 locations across the U.S. The forecasts are developed by the NWS River Forecast Centers and distributed by NWS field offices to a range of customers. The computer models provide several products to aid forecasters, including anticipated precipitation (timing and amounts), river and stream hydrograph forecasts (water levels over time), weekly chance of exceeding certain stage and flow levels, and graphical probabilistic forecast guidance.

Communicating Flood Risks to the Public

The NWS uses four flooding thresholds of increasing risk to communicate predicted conditions to the public. The NWS also uses known information at specific locations on certain streams and rivers to signal flood levels and potential impacts to define the level of flooding expected. The levels of flooding are:

- **Bankfull Stage:** When streams and rivers begin to overflow their banks.
- **Action Stage:** When the NWS and others begin monitoring flood levels and begin mitigative actions.
- **Flood Stage:** When flooding begins to pose risks to life, property, and commerce.
- **Minor Flood Level:** When flooding is occurring, but there is no anticipated building damage or more than minor overtopping of roads.
- **Moderate Flood Level:** When floodwater is inundating buildings and roads near the stream or river and evacuation and moving property to higher ground may be needed. When this level is reached, the NWS issues Flood Warnings.
- **Major Flood Level:** When flooding is causing extensive inundation of buildings and roads. Significant evacuations and emergency actions may be needed.

1 FLOOD WATCHES

Issued when conditions are favorable for flooding to occur.

2 FLOOD ADVISORIES

Issued when flooding is expected, and caution is needed to avoid threats to life and property.

3 FLOOD WARNINGS

Issued when flooding is imminent or already occurring.

4 FLASH FLOOD WARNINGS

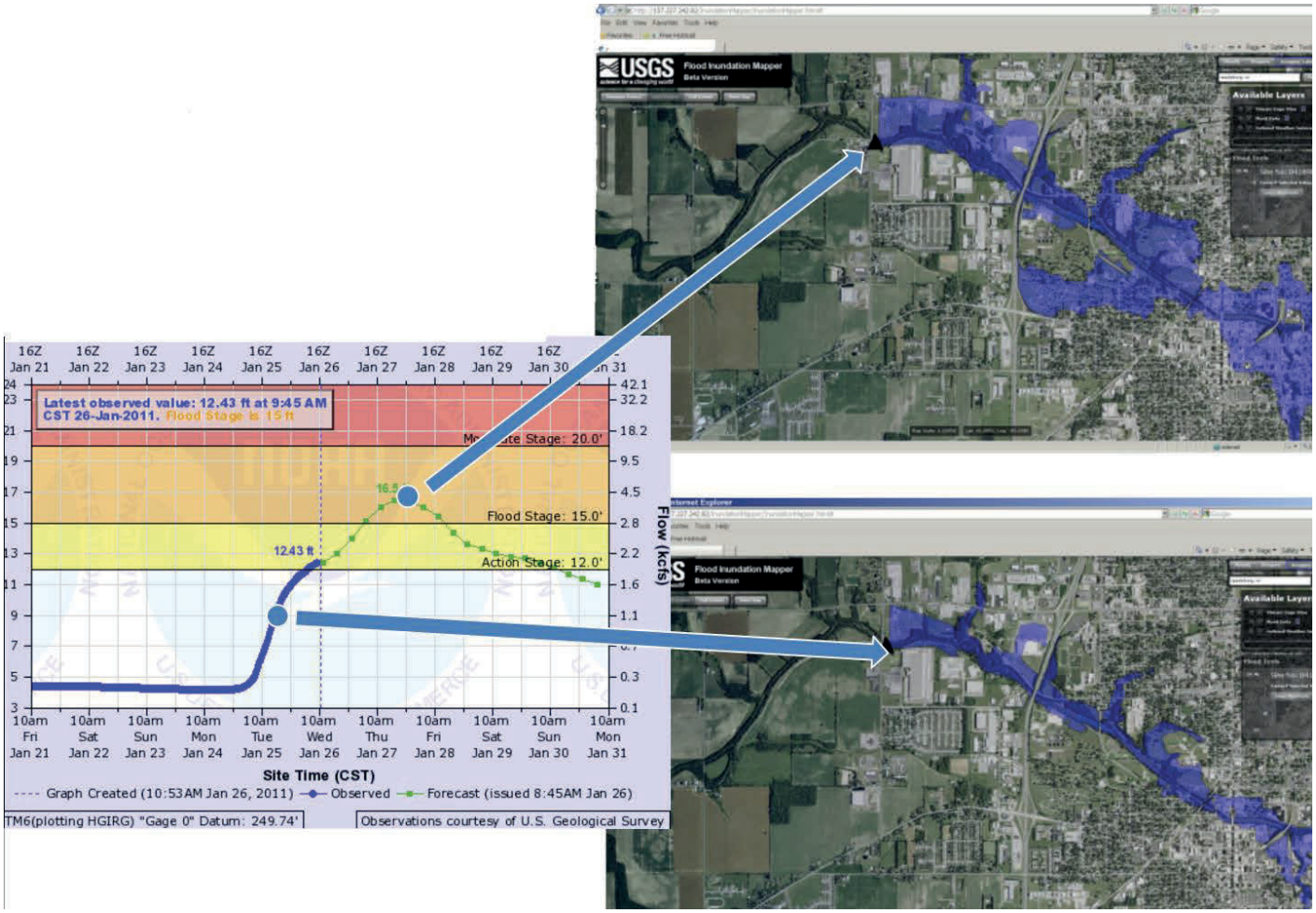
Issued when a flash flood is imminent or already occurring.

FLOOD INUNDATION MAPPING

According to the USGS, several agencies and partners develop flood inundation mapping products and systems to provide the geographic context of flooding. Flood inundation mapping systems use hydrologic and hydraulic models to map different flood levels. This is often created as a “library” of flooding extents that illustrate areas predicted to be impacted by flood levels of different severity, usually in equal increments such as every foot of water above a level established at a nearby stream gage. To allow users to easily view at-risk areas in relation to known landmarks, the maps of flooding extents are combined with other GIS layers, including aerial photography, street and road networks, building locations, and topography.

In online applications, the library of flooding extents is displayed based on input from gage readings or from flood peak forecasts. The NWS image below shows the correlation of a flood level from a USGS gage hydrograph (lower image) and a forecasted flood peak (upper image). The combination of the gage reading, flood forecast, the flood "libraries," and GIS layers allows the flooding to be depicted spatially and, as shown in the example, users can see buildings and infrastructure that are in the mapped flood extent.

For more information on USGS Stream Gage Hydrographs and Inundation Mapping, visit:
https://water.weather.gov/ahps/



USGS Stream Gage Hydrograph and Inundation Mapping

For More Information

Local officials should contact their state emergency management agency, state or regional water resources departments, and their local NWS office to learn more about flood warning and inundation mapping systems. To learn what resources may be available in your community, citizens should contact their local emergency management office or their community's floodplain administrator.

For More Information

See the FEMA Building Science Frequently Asked Questions at https://www.fema.gov/emergency-managers/risk-management/building-science/faq.

Send questions on FEMA Building Science Publications to FEMA-Buildingsciencehelp@fema.dhs.gov or call 866-927-2104.

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