Examples of End-to-End Flash Flood Early Warning Systems (EWS)

Previous chapters have provided information on the various systems that comprise a flash flood EWS. As depicted in Figure 1.3, an EWS typically has a monitoring network for collecting environmental data upon which to base warnings. In the case of flash floods, this environmental data includes rainfall and sometimes stream flow information. The rainfall information may come from in situ precipitation gauges, radar measurements, satellite estimates, or via some combination of these three sampling techniques. An EWS also requires an IT infrastructure that allows for the collection and analysis of environmental network data, warning preparation, and communication channels for distributing warning and other information to constituents. If a preparedness plan is in place and if the population is aware of the flash flood hazard and is prepared to take appropriate actions when a warning is received, then the end-to-end warning system will be successful and losses mitigated.

What Is in This Chapter?

This chapter will present, in the context of early warning systems, a few flash flood forecasting subsystems, of which the first two were briefly discussed at the end of Chapter 5. The chapter will provide more in-depth information about the systems. It should be read by persons who need detailed information about some of the different types of flash flood early warning systems currently in existence or planned by various countries. The systems discussed include:

- **USA:** A typical system composed of national hydrometeorological guidance, local hydrometeorological expertise, and constituent-operated gauge networks.
- **Central America:** Central American Flash Flood Guidance System, based primarily on satellite data.
- **Italy:** Piedmont region multi-disciplinary hydrometeorological ALERT and Real-time Flood Forecasting System
- **Colombia:** Aburrá Valley Natural Hazard Early Warning System, currently in the planning stages.
Typical United States Flash Flood EWS

Earth Data Observations

As noted in Chapter 5, there are numerous locally operated ALERT networks but no national flash flood rain gauge/stream flow network in the United States. At the national level, precipitation monitoring is primarily accomplished via a network of weather radars deployed by the National Weather Service in cooperation with the Federal Aviation Administration and the Department of Defense. Figure 8.1 depicts the network of WSR-88D (Weather Surveillance Radar – 1988 Doppler) radars in the USA.

The WSR-88D reflectivity data is converted to high resolution precipitation estimates and mapped to individual basins across the country by NWS computer software called Flash Flood Monitoring and Prediction (FFMP), as discussed in Chapter 5. Local forecasters are alerted by FFMP when the observed rainfall or rainfall rate exceeds a basin’s Flash Flood Guidance (FFG). In some regions FFMP is augmented by GIS information about each basin’s physiographic characteristics through the Flash Flood Potential Index (FFPI) program discussed in Appendix D.

Also at the national level, the WSR-88D data provided to the local forecaster is augmented by satellite precipitation estimates produced by the National Weather Service’s sister NOAA agency, the National Environmental Satellite Data Information Service (NESDIS). These
estimates are provided directly to forecasters via text bulletins. A website ([http://www.star.nesdis.noaa.gov/star/index.php](http://www.star.nesdis.noaa.gov/star/index.php)) also provides forecasters with several experimental products. The current real-time satellite precipitation estimation products available at the above URL are:

- **The Hydro-Estimator (H-E)**, which produces estimates based on GOES IR window brightness temperatures and modifies them using numerical weather model data. The H-E has been the operational algorithm at NESDIS since 2002. It is produced operationally (24/7 support) over the Contiguous United States (CONUS) and experimentally (8/5 support) for the rest of the world.

- **The GOES Multispectral Rainfall Algorithm (GMSRA)**, which uses four of the GOES Imager bands and also uses numerical weather model data, though to a lesser extent than the H-E. It is produced experimentally over the CONUS.

- **The Self-Calibrating Multivariate Precipitation Retrieval (SCaMPR)**, which uses data from multiple GOES imager bands and updates its calibration in real time against microwave rainfall rates. It is produced experimentally over the CONUS.

- **The Hydro-Nowcaster** produces forecasts of rainfall out to 3 hours lead time based on rain rates from the Hydro-Estimator.

- **The Product Validation** page provides current and recent validation of 6-hour and 24-hour satellite rainfall estimates compared to rain gauges and the radar/rain gauge field.

The end purpose of radar and satellite precipitation estimates is to detect when flash flood producing rainfall is occurring so that forecasters can issue warnings with sufficient lead time for actions to be taken to protect lives and property. The radar and satellite data are invaluable, especially in areas where on-the-ground observational data are sparse or completely lacking. Greatest warning success is achieved, however, when the NWS is able to partner with local agencies and groups that deploy ALERT networks. ALERT data is generally the most accurate, and is used in real time, but also retrospectively to calibrate radar and satellite algorithms.

**Forecasting Subsystem**

Figure 8.2 illustrates the flow of information for a typical NWS-ALERT Operator partnership, in this case the Maricopa County, Arizona, Flood Control District (FCDMC). The diagram shows that satellite (SATL), RADAR, and ALERT data flow to the local NWS Weather Forecast Office (WFO). The local officials (FCDMC) also have access to this real-time information. The WFO utilizes the information to produce a Quantitative Precipitation Estimate (QPE), which is compared to FFG in the Flash Flood Monitoring Program (FFMP) to produce products that go to the local officials and the general public. If the estimated or projected rainfall equals or exceeds the flash flood guidance for an area, graphical display options assist the forecaster with rapidly identifying these locations via color coding and other methods. The forecaster may issue a flash flood warning for the flood-prone area represented by the program. Graphical display options allow the forecaster to use colors and tables to highlight areas that may be nearing flash flood guidance values or that may be experiencing high rainfall rates even though the accumulation is below flash flood guidance.
For some basins, pre-computed Flash Flood Potential Indices (FFPI), Enhanced Gridded Flash Flood Guidance (GFFG), Forced Flash Flood Guidance, or some other techniques may also be incorporated into decision making (indicated by FFPI and dashed arrows in Figure 8.2). During rapidly developing, very short-fused situations, the local officials monitor the ALERT data and may have to issue statements directly to the public.

Lack of forecast system skill makes it very difficult to issue flash flood warnings several hours in advance based on Quantitative Precipitation Forecasts (QPF). However, flash flood watches—products that give constituents a heads up to the potential for flash flooding—can be issued based upon QPFs and then later modified as necessary based on observed rainfall (QPE).

In the United States, the numerical weather prediction (NWP) model forecasts and derived Model Output Statistics (MOS) for the nation are generated at the National Center for Environmental Prediction (NCEP). The NWP and MOS information is provided to the local WFO forecasters and also to national forecasters at NCEP’s Hydrometeorological Prediction Center.
(HPC). Per NWS Instruction 10-901 (September 13, 2007), HPC produces the forecaster-developed QPF and probabilistic QPF (PQPF) products for all types of weather systems, including tropical systems. These QPF products are used as guidance to River Forecast Center (RFC) forecasters, and after possible editing to account for local hydrometeorological conditions, serve as input to river forecasting models. The HPC provides gridded QPFs to WFOs, which serve as a starting point for production of QPFs for local use. The HPC also produces other products which assimilate hydrometeorological information on a national basis, including a flood outlook product and a flash flood hazards product.

The local (WFO) forecaster’s QPF can be compared to FFMP guidance to get an indication of the chances for flash flooding in the forecaster’s area of responsibility several hours in advance. The forecaster can then coordinate with ALERT user groups to ensure that observation networks are operational and sufficient staff is available to handle a developing situation. In some situations a flash flood watch issued early in the morning can be an invaluable heads-up to outdoor enthusiasts who may later in the day find themselves in recreation areas where terrain features block the radio reception of flash flood warnings.

Dissemination

As outlined in a Maricopa County Flood Control District publication, *Guidelines for Developing a Comprehensive Flood Warning Program* (1997), a successful flood warning program must include coordination between federal, state, and local government agencies and private sector organizations. As the system is used and tested, continual update and improvement of the flood warning plan is vital to maintaining an effective flood warning program. Major components which must be addressed when planning and operating a comprehensive flood warning program include:

- Flood threat recognition
- Warning dissemination
- Emergency response
- Other response efforts
- Critical facilities planning
- Cost components
- Maintenance
- Permits and licenses

The 1997 booklet is organized in accordance with the credit evaluation criteria for Activity 610, Flood Warning, under the National Flood Insurance Program’s Community Rating System (CRS), and goes into each of the above bullets in detail. For brevity these activities are not depicted in Figure 8.2, but they are crucial to a successful warning program.
Similarly FCDMC has an online interactive product catalog that makes the following information categories available to constituents and others:

- Map of ALERT station locations
- Single sensor data report generator
- Rainfall data and products
- Water-level data and products
- Weather station data and products
- Custom products and reports
- Publications – annual and storm reports
- Station description files
- Data and product disclaimer

**Central America Flash Flood Guidance System (CAFFG)**

Following the catastrophic flooding of Hurricane Mitch in 1998 in Central America, the United States Agency for International Development (USAID) provided funding for the reconstruction of damaged infrastructure. The National Oceanic and Atmospheric Administration’s (NOAA) National Weather Service (NWS) provided technology transfer, training, and technical assistance to the meteorological and hydrologic services in the countries hardest hit (Honduras, Nicaragua, El Salvador, and Guatemala). The USAID/Office of Foreign Disaster Assistance (OFDA) also initiated a supplemental project in 2000 (known as the Central America Mitigation Initiative, CAMI) to have NWS coordinate the implementation of an early warning system for flash floods in the region. NWS worked with the Hydrologic Research Center (HRC), a public-benefit non-profit research, technology transfer, and training corporation in San Diego, California, to implement the HRC-developed Flash Flood Guidance system for the region.

The system implemented, Central America Flash Flood Guidance (CAFFG), provides operational meteorological and hydrological services in seven Central American countries (Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua,

![Figure 8.3 Countries served by CAFFG](Image)
and Panama) with timely guidance for those NMHSs to issue effective flash flood warnings for small river basins. Unique characteristics of the CAFFG system include:

- The world’s first regional flash flood guidance system – operational dissemination of both regional and small scale products for all countries throughout Central America
- Fully automated real-time operation – data acquisition, ingest, quality control, model processing, output publication, and data management are all automated
- A regional center at the National Meteorological Institute in San Jose, Costa Rica, for the centralized acquisition, standardization, and archiving of a variety of real-time data products throughout the entire region
- All products are disseminated to each country via the internet, requiring the countries to acquire and maintain only a PC and internet connection

**Figure 8.4** CAFFG organizational structure

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**Earth Data Observations**

CAFFG became operational in August 2004. The flash flood warning system uses the NOAA/NESDIS HydroEstimator product for estimating precipitation. Flash Flood guidance, which is the rainfall required to produce flash flooding, is calculated every six hours for stream basins from 100 km$^2$ to 300 km$^2$. A physically-based hydrologic model is run every six hours...
to simulate soil moisture for the region and to determine flash flood guidance. Graphical and text rainfall, soil moisture, flash flood guidance and flash flood threat products are created and posted to the internet for access by the NMHSs for analysis and dissemination to disaster preparedness response agencies in the seven Central American countries.

### Forecasting Subsystem

Figure 8.5 depicts a programmatic flow diagram for the CAFFG subsystem. CAFFG is designed to accommodate the existing global digital spatial databases for Central America and also the real-time remotely-sensed, on-site precipitation and temperature databases. The flow chart illustrates the flow of information through the system models from the input hydrometeorological data to the computation of flash flood guidance. The real-time rainfall data pass through a quality control model, as depicted in Figure 8.6, which identifies data with impossible values and adjusts for biases in the remotely sensed data on the basis of real-time and daily on-site rain gauge information. The result of this model is a merged hourly rainfall product, estimated as a mean areal rainfall value over the small watersheds that cover the Central America region (areas of 100-300 km²).

A “potential ET” processor uses daily temperature and climate information on evapotranspiration (ET) to provide daily potential ET input to the soil moisture model. The soil moisture model runs on a 6 hourly basis and determines the real-time soil moisture conditions to

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Figure 8.5 Programmatic flow diagram of the CAFFG system
allow estimation of rainfall abstractions (such as actual ET and deep groundwater flow) and of the volume of surface runoff. Parametric databases for this model are computed from digital spatial data of 1-kilometer resolution terrain (TERRAIN), streams from global databases (STREAMS), land–use and land-cover data (LULC), and soil texture (SOILS). Threshold runoff is computed on the basis of geomorphologic theory from watershed and land characteristics. Soil moisture deficits and threshold runoff estimates are used in the flash flood guidance model to produce the volume of rainfall of a given duration that is necessary to initiate flooding (bankfull flow) in the small watersheds, that is, FFG.

Threshold runoff is defined as the volume of effective rainfall of a given duration over the watershed of a small stream that is just enough to cause bankfull flow at the watershed outlet. The term “effective” is used to denote the rainfall volume that remains after evapotranspiration and deep percolation abstractions, and which appears as surface runoff through the stream network. Threshold runoff provides an estimate of the potential for excessive surface runoff of the small basins under soil saturation or land-surface impervious conditions. It is computed through geomorphologic theory and with the use of global digital terrain elevation, soils, and land use/land cover data (1-km resolution), along with regional stream data. Given these spatial databases in CAFFG, threshold runoff is produced for small watersheds on the order of 100-300 km².
Spatial Data

Digital elevation data with 30-arcsecond resolution (approximately 1-kilometer) for the Central American region is obtained from the United States Geological Survey’s GTOPO30 database (a public domain global database). This data is used to delineate stream networks and watershed boundaries through GIS processing. The elevation data is shown in Figure 8.7 for regions of Honduras, El Salvador, and Nicaragua, in which the black lines represent the delineated stream networks and the blue polygon shapes represent the watershed boundaries.

Digital hydrographic features (including locations of streams, lakes and reservoirs) can also be obtained from the Digital Chart of the World (DCW). The data is useful for verification of the GIS delineation processing.

A global land cover dataset with 1-kilometer resolution, publicly available through the University of Maryland’s Global Land Cover Facility, is also used. Primary land covers for the region are woodland or wooded grasslands (along the western portions of the region), evergreen forest (primarily along the eastern portions of the region), and a large region of deciduous forest in the northern regions of Guatemala. Characterization of the land cover is necessary in the soil moisture analysis to aid in estimation of evapotranspiration.

Figure 8.7  Elevation data, streams, and watershed boundaries for CAFFG
The Food and Agriculture Organization (FAO) of the United Nations has produced a digital database of soils and terrain properties. The data was obtained for the Central American region, which included geo-spatial and relational databases for soil and terrain characteristics. The soil characteristics can be related to soil texture classifications and used to subsequently obtain derivative soil hydraulic properties and their variation across the region. The variation of hydraulic conductivity (the ease with which water can move through pore spaces or fractures) is significant, with large regions of low hydraulic conductivity (< 0.006 m/hr), and localized areas with relatively high hydraulic conductivity (> 0.03 m/hr). Figure 8.8 depicts an example of a soil field capacity mapping.

**CAFFG System Hardware**

The CAFFG system is composed of two servers installed at the Instituto Meteorológico Nacional (IMN) in San Jose, Costa Rica.

- **CAFFG Processing Server (CPS)**
  - Red Hat Enterprise Linux WS v4.5
  - Collects and standardizes numerous real-time data products, evokes various models to produce FFG and publishes output to the dissemination server (CDS)

- **CAFFG Dissemination Server (CDS)**
  - Red Hat Enterprise Linux WS v4.5
  - Provides login-restricted, secure internet and SCP (secure and encrypted data transfers) access to various national data products for all CAFFG-participating National Meteorological and Hydrological Services (NMHS)
    - The CDS is designed for dissemination purposes only
    - A graphical user interface (GUI) facilitates user review of available data products and streamlines remote data acquisition, including national data, regional data products, static ArcView resources, and system monitoring resources.
Chapter 8: Examples of End-to-End Flash Flood Early Warning Systems (EWS)

Dissemination

CAFFG System products are developed at the regional center in Costa Rica and disseminated to the national meteorological and hydrological services (NMHSs) and response agencies as appropriate. Dissemination paths of system products, updated hourly (precipitation products) or every 6 hours (remaining products), are depicted in Figure 8.9. Various levels of detail are available as appropriate for user agencies. Extensive user training on the CAFFG system is available on-line at: http://www.hrc-lab.org/caffg_training/en/index.html

![Figure 8.9 Possible dissemination paths to CAFFG response agencies](image)

Italy: Piedmont Region Hydrometeorological ALERT and Real-Time Flood Forecasting System

The Piedmont is the second largest of Italy’s twenty regions (Fig. 8.10). The river Po, with headwaters in the Alps in the west of the region, is Italy’s largest river. The upper Po consists of many fast responding tributaries while the middle Po is moderately flat and has a much longer flood response time (Rabuffetti and Barbero, 2003).

The Po River Authority, a government inter-agency group, developed a strategic plan for operating a flood/flash flood/landslide EWS for the Piedmont. Authorities created a map of relative flood risk within the plain that incorporates topography and land use. They did so in order to identify the areas in the drainage basins that are vulnerable to floods, flash floods, and land slides and assign them a relative risk category. Figure 8.11 depicts the 3 levels of possible hydrological hazard along a river. The C area indicates the 500-
year flood plain. Within, the B area indicates the 200-year flood plain, and takes into account levees and reservoirs. The A area includes the main stream flow and areas subject to frequent small floods. In the A area, no building is permitted. Within the B area, human activities are permitted only in accordance with the defined objectives of the area. The C area is land inhabited and built on by people. The region is characterized by numerous levees but the plan focuses on enhancing safety through non-structural activities like building/zoning codes, preparedness plans, and a warning system.

Records that date to 1800 show that the region floods significantly with either flash floods or lowland river floods about every other year, usually in either spring or autumn. In recognition of the risks posed by these floods, the Po River Authority established an inter-agency flood forecasting team and early warning system (EWS).

**Forecasting Subsystem**

Formed in 1978, the Regional Technical Preventive Service Administration established a 24/7 operations center, the Natural Hazard Situation Room (SSRN), tasked with forecasting dangerous floods in the region. At the center, teams of experts work in operational groups dedicated to geology, meteorology, hydrology, and snow to study the potential for floods and take action based on any predicted threats. The SSRN produces a daily report of the observed and expected meteorological situation, paying particular attention to the precipitation forecast. These evaluations are then distributed to agencies tasked with protecting and warning the public. Individual communities participate with the following actions:

- Creating a local flood emergency plan
- Studying local flood and hill slope dynamics. Such local studies improve response and forecasting of dangerous floods and are forwarded to the regional and national level for evaluation and synthesis
- Executing the planned emergency response during floods using volunteers and exchanging updates and advice with national and regional authorities

The EWS phases—*Survey, Warning, Alarm*, and *Emergency*—are activated successively when conditions warrant. Those conditions include major river flooding, flash floods, and small landslides in mountain catchments. Each assessment is coded by risk: 1 for no danger, 2 for low
danger, and 3 for high danger. Officials decide between categories 2 and 3 based on the land area potentially affected and the expected number of floods. This formal scheme helps reduce subjectivity.

To execute this process, the NMHS and regional forecast centers continuously survey conditions. When they declare a *Warning*, the activation of local operations centers is triggered but no products are relayed to the general public. Once flooding has commenced and is judged to be imminently dangerous, an *Alarm* is broadcast to the public. Since this system keeps mid-level warnings restricted to local authorities and only warns the public when a dangerous event is nearly certain to occur, it minimizes public false alarms.

The Piedmont alert system assesses and issues warnings for the following situations:

- Flood risk due to prolonged heavy rainfall on large floodplains (area >400 km²) endangering towns and infrastructure in river valleys and lowlands
- Local hydro-geological flood risk due to short, intense storms on small areas (area <400 km²), that is, flash floods, small landslides, and failure of drainage systems in cities and suburbs
- Road closures and other transportation difficulties caused by heavy snowstorms

The alert system divides the Piedmont into drainage basins or areas that have similar watersheds, rainfall patterns, and flooding properties. The system also incorporates practical considerations related to emergency management and political boundaries and is thus a compromise between environmental and human factors. Figure 8.12 depicts these “homogeneous areas”.

![Figure 8.12 Homogeneous forecast areas in the Piedmont Alert System](image-url)
The Operational Structure of the SSRN

The SSRN is a 24/7 operations center with two main tasks: (1) hydrometeorological survey, whereby technicians ensure the system is operational and continuously reporting data, and (2) forecasting by meteorologists, hydrologists, geologists and snow scientists of hydrometeorological events. This cadre of experts issues forecast and warning bulletins and works to verify and improve the forecast and warning system. The following information systems are in use at SSRN:

- An automatic observing network for meteorological and hydrometric monitoring
- Meteorological radar (currently there are two)
- Automatic upper air soundings of the atmosphere, performed twice daily
- Numerical modeling for meteorological forecasting on global and local scales
- Numerical modeling for flood forecasting on the main river network

The SSRN meteorology group produces a daily 48-hour quantitative precipitation forecast (QPF) and temperature forecast for each of the 11 regional alert areas shown in Figure 8.12. This allows hydrologists and geologists to evaluate the expected effects of the meteorological situation.

There are two different methods for assessing risk level (as depicted in Figure 8.13). The first involves comparing the QPF with predefined rainfall thresholds (Flash Flood Guidance).

![Figure 8.13 Structure of the Piedmont hydrometeorological forecasting group](image)
Chapter 8: Examples of End-to-End Flash Flood Early Warning Systems (EWS)

derived from studies and numerical model simulations of past events (off-line activities). The second uses real-time numerical simulations (on-line procedures).

- **Forecast Mode** uses quantitative precipitation forecasts, is linked to the hydrology module, and allows for very early warning. Since QPF includes significant uncertainty, meteorologists only qualitatively use this for long-term (1-2 day) forecasting. This system generates frequent false alarms, but because in the majority of cases they are only shared with local authorities, the public sees few of them.

- **Management Mode** uses the hydrodynamic module and real-time hydrometeorological observations as depicted in Figure 8.14. The system produces short-term (6-12 hour) reasonably skillful peak discharge and arrival time forecasts, and can thus be used quantitatively. Emergency management officials have found this real-time information very useful. But these short-term warnings are most effective when preceded by a prior medium-range “heads-up” to local authorities.

The real time simulations are carried out via FloodWatch, a decision support system for real-time flow forecasting. FloodWatch combines an advanced database with the Danish Hydraulic Institute (DHI) MIKE 11 hydrological and hydrodynamic modeling and real-time forecasting system (DHI, 2006), all packaged with the ArcView GIS environment. This combination is a very powerful tool for real-time streamflow forecasting and flood warning. FloodWatch can run automatically with a built-in task scheduler, or can be manually operated by a technician. Figure 8.14 outlines the data flow of this system.

![Figure 8.14 Schematic of the Piedmont FloodWatch System](image-url)

Flash Flood Early Warning System Reference Guide
Dissemination

FloodWatch produces several outputs. ArcView’s graphical displays automatically display and update real-time status and forecast conditions. The system also makes text products and graphs of observed and forecast water-levels and streamflows.

The FloodWatch system provides river-level and discharge forecasts for the entire river network. Hydrologists validate the forecasts by studying 40 cross sections of the main rivers. Once this is done, they are saved in HTML format for immediate display on the intranet site hosted by RUPAR (Unique netwoRk for Regional Public Authorities). These products are never seen by the public.

Finally, a team of experts produces forecast text bulletins of the expected hydrologic hazard risk (A, B or C) and corresponding danger level (1, 2 or 3) for each alert zone. After the event is over, actual flood data is entered in a database whenever damage from floods and/or landslides triggered by rainfall is reported. This provides system developers the ability to see whether rainfall and water-level thresholds used in the alert system are on target or need adjustment and to improve the flood-forecasting model. Recent developments using a distributed hydrologic model have shown that even with significant quantitative discharge forecast (QDF) errors many flood scenarios can still be successfully forecasted categorically (Rabuffetti et. al. 2009).

As noted by Rabuffetti and Barbero (2004) the Piedmont alert system can be applied to other areas experiencing a high incidence of flash floods. However, the success of the system depends on the adequacy of observation data, the capacity of information technology systems and communications systems, and the extent of interdisciplinary cooperation.

Aburrá Valley Natural Hazard Early Warning System (Colombia): An Example of Designing an EWS from the Ground Up

In 2008, NOAA was invited by a consortium of government agencies in Colombia to design an early warning system that would help to reduce the impact of flash floods in Medellín and nine other neighboring municipalities in the Aburrá Valley of the Colombian Andes.

The Aburrá Valley Natural Hazard Early Warning System (AVNHEWS) NOAA (2009) was designed using a “systems-based” approach. Systems engineering is an iterative, mission-driven design and construction process that breaks a single complex system (e.g. AVNHEWS) into a series of simpler subsystems that can be designed and developed somewhat independently with later systems integration in mind. When operational, the Aburrá Valley Natural Hazard Early Warning System (AVNHEWS) will integrate existing disaster management infrastructure with new infrastructure to create an end-to-end early warning system that will (1) reduce the loss of life and suffering caused by floods, flash floods, and debris flows within the Aburrá Valley, (2) enhance reservoir management practices in the basins surrounding the Aburrá Valley, and (3) improve local weather forecasting. AVNHEWS will also build national capacity in overall rainfall estimation and flash flood prediction throughout Colombia.
As illustrated by the AVNHEWS General System diagram (Figure 8.16), there are many subsystems that will work in combination to achieve this mission:

- The **Surface Gauge Subsystem** will draw primarily on rainfall, streamflow and other sensors already deployed throughout the region to create a real-time data stream of surface measurements with which to calibrate radar and satellite-based rainfall estimates and improve forecast models.

- The **Weather Radar Subsystem** will involve at least one weather radar station to produce high-resolution rainfall estimates over and around the Aburrá Valley. Additional surveillance (or gap-filling) radars may also be employed if improved coverage is required.

- The **Hydro-Estimator Subsystem** will employ IDEAM’s (Institute of Hydrology, Meteorology, and Environmental Studies) existing mesoscale weather observation capabilities, such as GOES satellite imagery reception, to produce a real-time, nationwide rainfall estimate.
The **Flash Flood Forecasting Subsystem** will produce real-time indices of flash flood hazard at high spatial resolution for the Aburrá Valley and at low spatial resolution for all of Colombia. The subsystem will also produce bias-corrected, real-time, radar and satellite-derived Gridded Quantitative Precipitation Estimate for use by other subsystems.

The **Hydrologic Forecasting Subsystem** will analyze flood hazard in the Aburrá Valley, and will enable reservoir operators to manage hydropower generation and flood hazard in the surrounding basins.

The **Information Management Subsystem** (indicated by red arrows in Figure 8.16) will ingest, store, and disseminate the above data subsystems to the forecasting subsystems, enabling AVNHEWS staff to distribute meaningful information to first responders and the general public.

**Operations Center Subsystem** (the large subsystem that contains the Weather Forecasting and Hydrologic Forecasting subsystems) will house the staff and equipment associated with the awareness, forecasting, and warning process of AVNHEWS. The Operations Center will coordinate with other stakeholders including first responders, media, and the general public according to the AVNHEWS Concept of Operations (see Chapter 9).

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**Figure 8.16** AVNHEWS general system diagram
Understanding Existing Capabilities

One of the first steps in designing any EWS is to assess existing capability (and infrastructure) that could be employed by the EWS and what gaps need to be filled by new capability and infrastructure. Every early warning system (EWS) is unique and needs to be adapted to local conditions – however, each EWS needs to contain four basic components in order to be effective. As Figure 1.3 indicates in Chapter 1, the four essential components for any effective early warning system are:

1. **Awareness** – systematic assessment of hazards and vulnerabilities, and mapping of their patterns and trends
2. **Forecasting** – accurate and timely forecasting of hazards using reliable, scientific methods and technologies
3. **Warning** – clear and timely communication of warnings to all those at risk
4. **Action** – national and local capacities and knowledge to act correctly when warnings are communicated

Earth Data Observations

In the case of the Aburrá Valley, much of the required capability for the above components already existed. The weakest category of the existing disaster management infrastructure relates to forecasting. There was no appreciable capacity to predict hydrometeorological events in or around the Aburrá Valley. This was the critical gap in realizing an effective EWS.

That is not to say there is no hydrometeorological forecasting infrastructure – indeed the Colombian Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) operates a surface synoptic network of 28 stations, with 7 of them working 24/7. In addition to several upper air stations, IDEAM also operates approximately 250 automated gauges and a GOES satellite station at its Bogotá headquarters. For operative short weather forecasting, meteorologists currently use the outputs from the Global forecasting system (GFS) model from NOAA; this is then compared with IDEAM’s MM5 mesoscale model to produce forecasts (up to three days) for the main cities and for the four main geographical regions of Colombia.

The two regional hydropower generators, Empresas Publicas de Medellin (EPM) and the electric utility at Antioquia (ISAGEN), conduct gauge-based hydrologic forecasting operations throughout the region and also employ mesoscale models to improve their short-term rainfall prediction. Local research institutions such as Universidad Pontificia Bolivariana (UPB) also contribute by running mesoscale weather forecasting models including MM5 and WRF.
Without satellite and radar-based precipitation estimation and associated hydrometeorological models, the mission of AVNHEWS would be unattainable. Figure 8.16 illustrates that AVNHEWS was designed to be able to grow thematically and support applications beyond hydrologic, flash flood, and debris flow forecasting. For example, Red Aire and Red Río could use AVNHEWS to issue public health warnings whenever Medellín experiences an unsafe level of air or water pollution. Debris flow forecasting could be expanded to include other forms of mass movement, including landslides. It is also worth noting that AVNHEWS is open to any type of data that may be available. Even human observations derived from traffic camera feeds, emergency reports, and visual observations could be integrated to improve the situational awareness of AVNHEWS forecasters.

AVNHEWS was designed to be scalable geographically as well as thematically. This will allow it to connect to other early warning systems as they are established throughout the region in the future. Over time, collaboration between forecasting centers will improve the quality of their products and services. The AVNHEWS Flash Flood Forecasting Subsystem, for example, will provide radar-based flash flood threat analysis specifically for the Aburrá Valley, as well as satellite-based analysis for all of Colombia. So as the domestic weather radar network expands, so can the quality of its flash flood forecasting (since radars offer better temporal and spatial resolution than satellites).

**Forecasting Subsystem**

The primary purpose of the AVNHEWS Flash Flood Forecasting Subsystem (FFS) is to provide real-time guidance about the potential of (a) small-scale flash flooding throughout the Aburrá Valley and (b) large-scale flash flooding throughout the entire country of Colombia. The subsystem was designed to address the AVNHEWS goal of reducing suffering and the loss of life and property from the devastation caused by flash floods.

The FFS outputs will be made available to users as a diagnostic tool to analyze weather-related events that can initiate flash floods (like heavy rainfall or rainfall on saturated soils) and then to make a rapid evaluation of the potential for a flash flood at a location. The subsystem is designed to allow the addition of experience with local conditions, incorporate other data and information (like Numerical Weather Prediction output), and any last minute local observations (like non-traditional gauge data) to assess the threat of a local flash flood. Evaluations of the threat of flash flooding will be done at hourly to six-hour time scales for basins from 25-50 km² in size within the Aburrá Valley to 100-300 km² in size for the rest of Colombia. Radar and satellite precipitation estimates will be used together with available local and regional in-situ precipitation gauge data to obtain bias-corrected estimates of current rainfall volume over the region. These precipitation data will also be used to update soil moisture estimates through a soil moisture model in the subsystem.
An integral part of the subsystem is the Information Subsystem component. This subsystem was designed to be fully integrated into the overall design of the AVNHEWS and dependent on the data availability (including types, quantity, quality and latency) from the AVNHEWS. However, data processing within the subsystem was optimized to:

- Provide fully-automated data acquisition, ingestion, processing, modeling, product export, and publication
- Establish strategic data acquisition schedules to optimize data availability during subsystem model processing
- Establish strategic processing schedules to expedite the availability of subsystem results using sustainable processing loads

This approach, along with a carefully constructed concept of operations (see Chapter 9), should ensure that the appropriate data and information are made available to users in a timely manner for developing flash flood warnings.

**Dissemination**

The FFFSS will be implemented as two applications—one for the Aburrá Valley and one for the remainder of Colombia. The two applications will use real-time, observed rainfall from different sources and will have different output resolutions.

The subsystem aims to empower users within the Aburrá Valley and the rest of Colombia with readily accessible observed data and products and other information to produce flash flood warnings over small flash-flood-prone basins. In the context of this design, a flash flood is a small-scale flooding event that occurs in a short time (response time of 6 hours or less) after the onset of rainfall in the basin.

The FFFSS will produce two primary products which can be used in developing warnings or alerts for flash floods – **flash flood guidance** and **flash flood threat**. These are defined as follows:

**Flash Flood Guidance** is the amount of rainfall for a given duration over a small basin needed to create minor flooding (bankfull) conditions at the outlet of the basin. For flash flood occurrence, durations up to six hours are evaluated and the basin areas are of such a size to allow reasonably accurate precipitation estimates from remotely sensed data and in-situ data. Flash Flood Guidance then is an index that indicates how much rainfall is needed to cause minimal flooding in a basin.

**Flash Flood Threat** is the amount of rainfall of a given duration in excess of the corresponding Flash Flood Guidance value. The flash flood threat then is an index that provides an indication of areas where flooding is imminent or occurring and where immediate action is or will be shortly needed.
Once a warning or watch has been issued by IDEAM there are four users with priority:

- National Office for Prevention and Disaster Management (DPAD)
- Civil Defense
- Red Cross
- President of Colombia

A portion of the warning distribution system is shown in Figure 8.17. The DPAD is connected to 32 Regional Committees for Prevention and Disaster Management called CREPADs. At the same time CREPADs coordinate the warnings with local Committees for Prevention and Disaster Management called CLOPADs.

**Figure 8.17** Idealized depiction of Aburra Valley warning distribution system


Important Things to Remember about End-to-End Flash Flood Early Warning Systems

- One of the first steps in designing a EWS is to assess existing capability (and infrastructure) that could be employed by the EWS and what gaps need to be filled by new capability and infrastructure.

- Lack of forecast skill makes it very difficult to issue flash flood warnings several hours in advance based upon quantitative precipitation forecasts (QPF). However, flash flood watches can be issued based upon QPFs and then later modified as necessary based upon observed rainfall (QPE).

- The U.S. FFEWS system employs partnerships between the NMHS (NCEP), area forecast centers, and local flood and emergency management officials.

- The CAFFG system provides the NMHSs in seven Central American countries with timely centralized guidance for the issuance of effective flash flood warnings for small river basins in each country’s area of responsibility.

- The Piedmont (Italy) system is designed around a situation room where each day throughout the year, experts from various sectors, organized in specific operational teams (geology, meteorology, hydrology, and snow) analyze the current events and decide what actions, if any, are required.

- The Aburrá Valley Natural Hazard Early Warning System (AVNHEWS) is being developed from a systems engineering approach. That is, an iterative, mission-driven design and construction process that breaks a complex system into a series of simpler subsystems.
Chapter 8: Examples of End-to-End Flash Flood Early Warning Systems (EWS)

References


NOAA 2009: Design of the Aburrá Valley Natural Hazard Early Warning System (AVNHEWS- A plan to implement a state of the art Flash Flood Warning System in the Abrurra Valley, Colombia, March 2009.


