BEYOND FLOOD DETECTION: ALTERNATIVE APPLICATIONS OF REAL-TIME DATA

EVE GRUNTFEST
Department of Geography and Environmental Studies
University of Colorado
Colorado Springs, Colorado USA

1. Abstract

This paper examines the rapidly evolving applications of real-time data for flash flood mitigation and for other purposes in the United States. Thousands of integrated stream gage and rain gage networks have been installed over the past 20 years. Emerging trends in reduced costs for equipment and increased speed of information transfer lead toward revolutionary opportunities for the applications of real-time data.

2. Trends

2.1. EVOLUTION OF THE ALERT CONCEPT

ALERT stands for Automated Local Evaluation in Real-Time. The classical ALERT station is composed of a stream gage, a rain gage, a temperature sensor, a wind speed sensor, and a wind direction sensor. Networks of ALERT stations have definite but limited possibilities in alternative uses and peripheral benefits. Most alternative uses and peripheral benefits of flood warning systems are made possible when such systems are upgraded to include other sensors, such as those for relative humidity, soil moisture content, solar radiation, and air and water quality.

Primary uses of ALERT systems, such as early flood warning, are essential to emergency management. Real-time rain and stream gage data are invaluable for flood forecasting. These integrated networks of data save lives and property. A great deal of ALERT real-time data remains unused during regular non-flood situations. More agencies are recognizing the value of the data for multiple uses in normal as well as flood situations.

Many users now refer to an ALERT network as a network composed of a combination of rain gages, stream gages, and full-weather stations. There are excellent examples of alternative benefits of real-time data collection integration. In the California Central Valley Project, the U.S. Bureau of Reclamation (Reclamation) integrates with a program run by the California Department of Water Resources. The program is called the California Data Exchange Center (CDEC). This program centralizes most of the real-time information systems associated with water resources run in California into a common database and an Internet database interface. CDEC also provides statewide transportation information such as road conditions.

By encouraging alternative applications, other public and private organizations are stimulated to cooperate by funding equipment and assisting in maintenance operations. A growing number of real-time data collection networks are being developed or upgraded to provide alternative uses. This is particularly true in the arid Southwestern U.S. where the systems are being used for a variety of water conservation and fire protection efforts, providing large savings in resources and staff hours.

2.2. MULTI-PURPOSE APPLICATIONS

As networks become more integrated and begin to serve multiple functions, the distinctions fade between primary uses and alternative uses. A primary use for one may be an alternative use for another. An alternative use may also take over what was initially a primary one. Overall, systems designed primarily for flood warning are increasingly used, on a daily basis, for other purposes in addition to their emergency management functions.

2.3. INCREASED USE OF THE INTERNET

The evolution of fast and reliable data dissemination is one reason behind the expansion of real-time data collection networks. Many agencies and organizations broadcast weather and stream information on the Internet. Although a disclaimer always accompanies the information, vast quantities of gage data are directly available to anyone with a connection to the Internet.

Sometimes data are displayed in raw format, not easily understood by the novice. Sites increasingly aim to convert them into readable information with graphs, maps or both. The broadcast of real-time data on the Internet makes such data available to a wide range of uses. In severe weather or flood, the communication lines to an Internet site can become saturated, therefore reducing the effectiveness. The saturation problem shows that the data are actually being used in case of emergencies. More attention to mirror sites and options for routing Internet traffic should reduce the vulnerability of the systems during emergencies. The relay of the information is often still reliant on telephone lines. The vulnerability of telephone lines limits the reliability of totally Internet based systems for emergency communication.

A major feature of the Internet sites is the possibility to link to other sites providing related or complementary information. The American Whitewater Association offers real-time gage data for its constituents by linking directly to National Oceanic and Atmospheric Administration (NOAA) and U.S. Geological Survey (USGS) Web sites.

2.4. MORE SOPHISTICATED GRAPHICAL DISPLAYS

Most sites still rely on tabular data. There is a trend toward plotted charts, graphical representations, and maps. The new graphical representations give the viewer much more information "at a glance." More and more agencies use these products, such as the Integrated Flood Observing and Warning System (IFLOWS), that use color-coded maps of the United States to instantly display states experiencing severe weather. IFLOWS Internet site also includes animated regional maps showing rainfall over different periods of time.

There is growing integration between data sources and types of data. Former chasms between private and public data sources are virtually invisible to Internet data users. Data from a wide variety of sources may appear on one screen. In many cases, satellite data, radar, and gage data can all be accessed from one Internet address.

A Geographic Information System (GIS) is a software tool allowing graphical display of spatial data and its attributes through the use of interactive maps. A map of a region can be displayed on-screen to show the various sites in a data-collection network. Each site is labeled with a choice of real-time parameters that can be displayed in different increments. Maps can also be animated to display the dynamics of parameters over a period of time. A GIS can instantly show the values of certain parameters across a region.

A GIS is a good tool for analyzing data at a base station as well as an ideal partner to the Internet. More integrated GIS/real-time data networks should be available shortly. When local topography and other features are integrated with real-time data, these systems will experience another revolution in the levels of usefulness.

The Danish Hydraulic Institute leads the integration of GIS with real-time data. Its work in Bangladesh, India, Germany, the U.S., and many Central American countries is setting the standard for the use of graphical displays and advanced modeling capabilities [1].

A few representative sites are included in the report. All others can be directly accessed through the electronic version of a more expanded copy of this paper (co-authored with Philippe Waterincks) at the following URL:
http://web.uccs.edu/geogenvs/work/Eve/Beyond%20Flood%20Detection%20Final.html
All Internet addresses listed in this material were tested and were operational between 09/24/98 and 09/28/98.

3. Problems

3.1. STAFF REQUIREMENTS

Real-time data systems do not run by themselves. They require an assortment of hydrologists, hydrographers, meteorologists, computer technicians, and electronic technicians to operate and maintain complex data-collection network and to process and analyze the massive amount of data generated. Some agencies hire consultants to handle these tasks. In some cases new computer workstations are being installed at 24-hour operations to be sure that the data are monitored even when most offices are closed. In theory these new workstations provide 24-hour coverage. In practice, the staff who is supposed to monitor them sometimes already has full-time responsibilities and may not welcome or even have the time to keep track of developing flood forecasts. This is also a problem in dispatch offices where local law enforcement may purchase new technology but no additional staff is authorized or trained to handle the new system. Finally, the staff might resent the new equipment and it may not be used effectively.

3.2. DATA AND EQUIPMENT RELIABILITY

The enormous benefits gained by publishing data on the Internet are tainted by the fact that the accuracy of the data is not always guaranteed. Real-time data published on the Internet, generally, are accompanied by a disclaimer.

The main problems encountered with the use of real-time data collection platforms are those of reliability of the network or data. This unreliability is mainly due to the nature of the data collection. Gages, sensors, and transmission equipment suffer from mechanical and electronic failures. Some users say that aging equipment is more complex to install, operate, calibrate, and maintain. Hardware failures causing an absence or incorrect readings are commonplace. Newer equipment can be better tuned to the needs of the users and the requirements of applications, but it is often more expensive to maintain and can also be more finicky in terms of calibration or vulnerability to changes in field conditions.

Specific comments from survey participants on problems are paraphrased here:

- The main problem has been rain gage and lake level information not coming in. Radio interference or low batteries were the causes. Most troubling is a repeater that has been having interference problems with a nearby antenna.

- Part of operating an ALERT network is making sure it is properly maintained. The benefits are so huge that the maintenance overhead should be seen as only a small problem which should be dealt with as a matter of routine.

- The most significant problem encountered is that this region was an early pioneer in much of this technology. Therefore, a lot of the hardware was early generation electronic equipment. In recent years the reliability of the hardware has become an issue, and therefore significant expense to upgrade to today's hardware technologies is being performed to increase the reliability of the networks.

- Virtual reality has replaced reality and factual information to the extent that the virtual information is reported as fact rather than what is really happening. Vendors have been required to provide virtual products rather than the real world information needed to make accurate decisions.

3.3. VENDOR COOPERATION

The lack of vendor hardware and software support continues to be a major concern for several network operators. Companies go out of business or shift to new software versions. Smaller communities with smaller budgets may not be able to afford the new equipment or upgrades. In some cases, newer equipment is not as resilient to severe weather conditions and is more expensive to maintain. Some vendors, one user said, "are too involved in bigger, faster, better to be reliable…, too often we see stable environment equipment traded for so called state of the art failure plagued equipment."

To minimize these types of problems, some users hire consultants to manage the acquisition, installation, and maintenance of the hardware and software, or even to manage the data collection, manipulation, and distribution components.

3.4. GETTING THE DATA TO THE PUBLIC

Flood warning systems are useless in the absence of an efficient communication system that allows for reaching an endangered community in time. While many communities have invested considerably in real-time data collection networks, the warning and response are often inadequately addressed and funded, or totally ignored. Developing an efficient communication channel between the data acquisition base station and the public is often the most difficult aspect of installing a real-data collection network.

The involvement of local government officials and emergency response personnel in flood warning systems development and the education of the public to recognize flood threats both help in developing such communication channels. One danger of the shift of emphasis to a wide range of applications beyond flood warning is that it may divert attention from inadequacies in the emergency management communication channels. Agencies must also recognize that not all of the population-at-risk has access to real-time data. The gap between the haves- and have-nots may narrow but it will remain a serious issue to keep in mind.

Direct public access to real-time data can be a two-edged sword. Some National Weather Service (NWS) and U.S. Army Corps of Engineers officials report that individuals who monitor the gage networks consider themselves "experts." The officials find they spend a great deal of time talking with individuals whom, especially on busy days, try giving them advice on gate or reservoir operations. This prompted one official to question whether real-time data should be available to the public. Intranets with password protection help reduce this problem.

3.5. INTERNET CONGESTION

As the Internet is increasingly used to make products and real-time information available to agencies, and public and private interests, the occurrence of an emergency event can cause the system to become severely overloaded with requests. To help prevent such situations, the California Data Exchange Center (CDEC), for example, is devising creative ways to prioritize access to this information.

3.6. GAP BETWEEN POTENTIAL AND ACTUAL REAL-TIME DATA USES

There is a gap between potential uses of real-time data and actual use. Most agencies are developing their Internet pages and alternative uses in a vacuum. The ALERT user groups provide a useful network and valuable feedback. However, many systems are being developed independently without the benefit of learning from earlier experiences elsewhere.

3.7. MEASURING BENEFITS

Benefits from alternative uses, or even from primary uses, are difficult to estimate. While there are extensive costs associated with the purchase, installation, and maintenance of real-time data collection systems, a well-maintained and reliable system pays back its cost many times during even one flood event. Experiences with past flood events have proved the usefulness of flood warning systems to prevent significant property damage, loss of lives, and to increase the efficiency of emergency operations. Such paybacks can, however, only be considered in the long-term.

Because of the general infrequency of floods at any one location, justifying the on-going cost of flood warning systems is often difficult. But as more people and programs rely on the multiple applications of real-time data collection systems, increased support is generated for those systems and additional funding sources become available.

Although alternative uses are definitely perceived as providing various types and degrees of payoffs, assessment of exact tangible benefits in dollar amounts are unavailable. With the exception of the Oklahoma Mesonet, the benefits documented in this report are assessed in terms of safety, awareness, quality of life, data accuracy, efficiency of operations, and staff hours, rather than in economic values. Anecdotal evidence was most helpful.

4. Research Methodology

Our two-month long project identified secondary uses that have developed during operations of existing flood detection and warning systems. Secondary functions include, but are not be limited to uses for agriculture, recreation, weather monitoring, and regulatory compliance. Information collection for the investigation was conducted via the Internet, telephone, personal interviews, literature reviews, and survey mailings.

4.1. SOURCES

This report is drawn from the following information sources: facilities and departments of the U.S. Bureau of Reclamation; federal, state, county, and municipal agencies; universities and research institutes; private organizations and non-profit organizations; vendors of real-time hydrological and meteorological systems; weather and water resources consultants and, partnerships between any of the above.

The research was focused on agencies in the United States. However, through our Internet survey, excellent feedback was received from Australia and Denmark.

4.2. DATA COLLECTION METHODS

An on-line survey was developed and published on the Internet. Field specialists were asked to submit an on-line reply form. This method facilitated inexpensive and rapid interaction. An extensive survey of Internet sources was also performed to document real-time data uses and publications. Our sources included the Bureau of Reclamation, previously published material, ALERT Internet sites, and real-time data sites on the Internet.

An Internet site was designed and intended to be the main data collection tool. It included an outline of the research objectives, a survey questionnaire with an electronic reply form, and examples of alternative uses of real-time data.

The survey asked about the nature of their system (ALERT, IFLOWS, other); the nature of organization/agency (federal, local, other); the nature and number of data collection sites; primary uses of system; secondary uses of system; and benefits of their system.

The Internet site was then publicized by phone, e-mail, and the online Disaster Research newsletter of the Natural Hazards Research and Applications Information Center. The Internet page was located at the following URL: *www.uccs.edu/~geogenvs/alert.htm*. A hard copy of the survey was also available upon request.

The contacts were made in a variety of ways:

Internet research: The Internet was researched extensively to identify possible sources of information. The information collected fell in three categories: names of organizations or persons to contact for the survey; published information on alternative uses; and, examples of uses of real-time weather data.

Telephone: Representatives from public and private sources were contacted by telephone and were asked to participate in the electronic survey. Some participants elected to answer the survey questions on the phone.

Electronic mail: Many of the telephone contacts were also contacted by e-mail. The outgoing e-mail outlined the scope of research, asked the recipient to participate in our Internet survey, and requested suggestions of other people who might also know of alternative uses.

Personal interviews: Several interviews were conducted in-person with users, consultants, or vendors. The interviews proved to be very productive.

4.3. CRITIQUE OF METHODOLOGY

The bulk of the information came from research on the Internet. More than 50 sites were extremely useful.

Unfortunately, only eight reply forms were sent on-line. One reason for the low response rate was technical. Only Netscape Navigator browser users were successful in submitting the reply form. Internet Explorer users were unable to electronically participate using a survey form on-line. The short time frame for the project did not allow enough time to fix this technical problem and re-publicize the survey. To compensate for the low return rate, extra attention was paid to phone calls, E-mail contacts, and Internet sites.

A second factor for the low response rate may have been the nature of the questions. Many agencies use real-time data for multiple purposes and cannot specify the primary or alternative uses/benefits with any precision.

5. Case Studies of Real-Time Data Usage

A few examples are briefly discussed below. Two excellent case studies are the Oklahoma Mesonet and the Urban Drainage and Flood Control District. These cases are discussed in other chapters of this book by Ken Crawford and Kevin Stewart, respectively.

5.1. US GEOLOGICAL SURVEY WATER RESOURCES – A FEDERAL CASE [*http://water.usgs.gov/public/data.html*]

The USGS provides real-time water data from over 3,000 data collection platforms throughout the U.S. Real-time data are available for each of their stream gages in the country. The streamflow data for real-time stations throughout the United States are available to the public via the Internet. Data are updated at 15-60 minute intervals.

5.1.1. *Puerto Rico 1998 example*

Because Puerto Rico is so often in the path of destructive hurricanes, USGS hydrologists have developed contingency operations to ensure that information on the effect of hurricane rains on local rivers would be available to those who need it. The streamflow gaging stations in Puerto Rico have been outfitted with satellite-linked data collection platforms that transmit streamflow in real-time to the main computer in the USGS Puerto Rico office in San Juan. The entire computer and data relay system in Puerto Rico is backed up with a diesel-powered generator to ensure that information would continue to flow even in the event of power failures.

In September 1998, Hurricane Georges passed over the island. Data were received into USGS computers from the backup system so that data were provided on a continuous basis to key cooperators. For more information, check out the URL: *http://www.usgs.gov/public/press/public_affairs/press_releases/pr636m.html.*

The 123 stream gages in place in Puerto Rico have permitted real-time streamflow data to flow to reservoir operators, emergency officials, and others who needed crucial streamflow information after the passage of the hurricane.

5.2. AUTOMATED LOCAL EVALUATION IN REAL-TIME (ALERT) NON-PROFIT ASSOCIATION [*http://www.alertsystems.org*]

This Internet site provides an overview of ALERT systems. It has excellent links to the user groups in the U.S. ALERT is a method of using remote sensors in the field to transmit environmental data to a central computer in real-time. This standard was developed in the 1970's by the National Weather Service (NWS) and has been used by the NWS, the USGS, the U.S. Army Corps of Engineers, the Reclamation, numerous state and local agencies, and international organizations.

There are many manufacturers of ALERT hardware and software, but they are all designed to meet a common set of communications criteria. Because of this, most equipment and programs are interchangeable, which has allowed for competition to improve performance and reduce cost. ALERT systems have become a standard in real-time environmental data collection because of their accuracy, reliability, and low cost.

5.3. CALIFORNIA DATA EXCHANGE CENTER (CDEC) – STATEWIDE SYSTEM [*http://cdec.water.ca.gov*]

CDEC integrates real-time data from various sources in California and makes them available on the Internet. They provide real-time information in the following 10 areas:
river and tide forecasts, weather forecasts, reservoir data and reports, water supply, river stages and flows, precipitation and snow, snowpack status, satellite images, station information (current and historical data), and, test reports.

5.4. AMERICAN WHITEWATER AFFILIATION (AWA) [*http://www.awa.org/awa/online/gages.html*] (NON-GOVERNMENTAL CASE)

The AWA Internet site is a good example of an intelligent and appealing use of the Web for the dissemination of river flow data. It provides information useful to whitewater recreation by linking to the USGS streamflow data for almost every state, to the NOAA netcast's weather and water information, to the NOAA Interactive Weather Information Network (IWIN), by giving river flow information by state, and to other Internet sites providing river flow information. It also gives a list of dial-up bulletin boards (BBS) giving river level updates, and a list of dial-up phone gages where river level information is given by either a live person or a recorded message.

5.5. FLOOD CONTROL DISTRICT OF MARICOPA COUNTY, ARIZONA (FCDMC) [*http://156.42.96.70/alert*] (LOCAL GOVERNMENT CASE)

This system is used for weather conditions, flood control, stormwater runoff, floodplain studies, hydrologic modeling, fire weather, air quality, forensic evidence, engineering projects, research, education, and planning. The Flood Control District of Maricopa County operates an ALERT network of 232 real-time data collection platforms including 222 rain gages, 100 stream gages (96 pressure transducer, 3 bubbler, 1 infra-red), and 15 weather stations. The system was originally designed and funded to measure flows on the major rivers in the County and to monitor dams and flood channels. The network continues to grow at a rate of approximately 10 sites per year.

Real-time data are transmitted by VHF radio to a central base station and the information provided is also received by the NWS and is used in conjunction with other data to issue flash flood warnings and other weather advisories.

The precipitation data are also published on the Internet in tabular and graphical format in 1-, 6-, and 24-hours increments. Other information includes historical weather and stream data, weather conditions, and trends. Maps display site locations and current as well as trends for each.

Additional services provided include daily precipitation reports, daily surface water reports, rainfall maps, current information at flood control district structures (stage, discharge, storage, and, percentage full), and road closure maps. The benefits are hard to quantify, but the data have saved millions of dollars in lawsuits against the County since 1993.

5.6. VENTURA COUNTY FLOOD CONTROL DISTRICT, CALIFORNIA [*http://www.ventura.org*]

Ventura is a leader in alternative uses. They developed many alternatives during drought years, to keep funding for the gage system. The uses include flood warning, runoff monitoring, irrigation management, power demand, quantitative precipitation forecasts, dam breach detection, inflow modeling, fire weather, monitoring, weather data, hand glider forecasts, lawyer requests, and water quality sampling.

Ventura County operates a network of rain and stream gages and full weather station with radio transmission over a reserved frequency to a central base station.

The data are distributed to a number of users including city governments: the U.S. Navy, the National Weather Service, the Ventura County Sheriff and the Office of Emergency Management, Fox Weather (private forecaster), the Casitas Municipal Water District, the United Water Conservation District, the USGS, the Ventura County Fire Department, and the Corps of Engineers - Los Angeles District.

The Grounds Department turns off automatic sprinklers if forecast winds would blow spray onto cars near the median. The County also uses it for scheduling the road department striping program; setting irrigation demands for crop fields; wind rose calculation; historic reservoir levels and variation throughout the year; correlation studies to nearby canyons with no gages; and to provide data in remote areas where no observers are present.

The district has a tool to capture real-time rain history for past 1- 6- 12- 24- and 36-hours. Fox Weather provided a similar tool for forecasted rain. Each of those files is transferred to a GIS system containing 222 watersheds in Ventura County. These are then routed and junctioned to produce models of each watershed. All of the other GIS information available can also be used to identify points of estimated critical flow from aerial photos to quad sheets with the National Climatic Data Center (NCDC), the Regional Climate Centers (RCC's) and State Climate Offices.

6. Conclusions

6.1. MULTIPURPOSE FUNCTIONS OF REAL-TIME DATA COLLECTION

Although flash flood warning systems have proven to be an important service, they are used relatively infrequently while they need on-going maintenance and require the dedication of permanent personnel. Equipment and personnel can therefore be made available for alternative applications that take place on a more frequent basis.

Alternative applications seem a natural development of flood warning systems that can be applied to any disaster requiring real-time, alarming capable systems. The upgrade of flood warning data-collection platforms to various degrees of full weather stations and the design of networks that integrate multiple functionality allow for a considerable number of alternative applications in addition to flood warning.

Alternative uses of real-time data collection systems, especially on the statewide scale, seem to be the key economic factors in justifying and maintaining long-term funding. Users are increasingly using alternative uses to justify the existence of their systems.

6.2. ALTERNATIVE USES SUMMARY

The following list summarizes the 29 alternative uses suggested by this study:

1. Air and water quality
2. Agriculture
3. Calibration of hydrologic models
4. Community development/growth determination
5. Dam and reservoir operations
6. Dam safety
7. Database archiving
8. Engineering projects (roads, stormwater channels)
9. EPA compliance (NPDES)
10. Fire prediction and protection
11. Groundwater recharge monitoring
12. Hazardous materials
13. Highway safety
14. Irrigation management
15. Landslide prediction
16. Legal and liability issues
17. Marine fisheries forecast
18. Media use
19. Recreation
20. Riparian habitat monitoring
21. Seismic detection
22. Storm runoff diversion to storage facilities
23. Stormwater quality
24. Tide monitoring
25. Toxic spill monitoring
26. Utility demand forecasting
27. Water conservation
28. Waste water/effluent impact on watersheds
29. Weather forecasting

6.3. BENEFITS

Some studies have determined the benefit/cost ratios of flood warning systems. The U.S. Army Corps of Engineers studied the need for automated flood warning systems in

Massachusetts (1990). An economic evaluation was performed by James A. Montgomery Consulting Engineers for the Flood Control District of Maricopa County in Arizona (1992) [7].

However, although integrating flood detection networks with other programs seems to prove efficient and cost effective by allowing agencies to share the cost and the utility of the data collected, there is little evidence of quantitative benefits arising from alternative uses.

One study reported the financial benefits of the Oklahoma Mesonet on a state-wide scale [6]. The other sources that were contacted in this survey did not quantify the benefits in dollar terms. Many benefits are non-quantifiable. The benefits are more intangible and are considered added-value to community services, increased awareness of environmental parameters, better understanding of natural hydrologic and meteorological processes, increased efficiency of emergency operations, conservation of natural resources, and better protection of hydraulic structures.

7. The Next Steps

The results of this two-month long project indicate exciting, emerging trends in the applications of real-time data. Literally every day new Internet sites are available, showing the range of opportunities for collection and display of integrated data. Clearly the implications of these integrated real-time data sets extend beyond flood warning.

This report provides an inventory of the types of alternative uses. Further work should focus in more depth on the range of uses, users, and precise calculations of actual economic and social benefits of alternative uses. The multi-purpose uses should be more fully explored for modeling and archiving.

Recommended future research includes the following efforts:

1. There should be in-depth studies of the best case studies with emphasis on the benefits and tradeoffs of alternative uses. The follow-up studies should evaluate whether the promise of "reduced overtime" and other benefits are being realized.

2. There should be in-depth studies of alternative uses for particular types of uses. For example, how can the Bureau of Reclamation best maximize multi-uses for ALERT data when the primary function of the data is for dam safety?

3. The conclusions could be incorporated into guidelines for agencies and communities considering alternative uses. The guidelines would allow future efforts to learn from previous experiences.

As current trends accelerate the prospects for improving effectiveness and payoffs of real-time data for flood warning, many other purposes will also increase. The day-to-day benefits of the alternative uses will provide excellent return on investments for the purchase and maintenance of the monitoring equipment.

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