IDEA

Innovations Deserving
Exploratory Analysis Programs

Intelligent Transportation Systems Program

ROADWAY FLASH FLOODING WARNING DEVICESFEASIBILITY STUDY

Final Report for ITS-IDEA Project 79

S. Edward Boselly, Weather Solutions Group, Chesterfield, MO

November 2001

TRANSPORTATION RESEARCH BOARD • NATIONAL RESEARCH COUNCIL

INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS MANAGED BY THE TRANSPORTATION RESEARCH BOARD (TRB)

This investigation by Weather Solutions Group, Chesterfield, MO was completed as part of the Intelligent Transportation Systems (ITS) IDEA program which fosters innovations in development and deployment of intelligent transportation systems. The ITS-IDEA program is one of the five IDEA programs managed by the Transportation Research Board (TRB). The other four IDEA program areas are: Transit-IDEA, which focuses on transit practice in support of the Transit Cooperative Research Program (TCRP), NCHRP-IDEA which focuses on highway systems in support of National Cooperative Highway Research Program, High Speed Rail-IDEA (HSR), which focuses on high speed rail practice, in support of the Federal Railroad Administration, and Transportation Safety Technology (TST), which focuses on motor carrier safety practice, in support of the Federal Motor Carrier Safety Administration and Federal Railroad Administration. The five IDEA program areas are integrated to promote the development and testing of nontraditional and innovative concepts, methods, and technologies for surface transportation systems.

For information on the IDEA Program contact IDEA Program, (phone: 202/334-3310, fax: 202/334-3471, http://www4.nationalacademies.org/trb/dive-idea.nsf)

TABLE OF CONTENTS **Page**

EXECUTIVE SUMMARY

The purpose of this project was to investigate the potential use of active systems that would automatically warn motorists of hazardous conditions through the use of variable message signs and that could actually close roads with physical barriers similar to rail crossing gates. More people are killed each year in the United States by flash floods than by any other weather-related phenomenon. The majority of these fatalities occur on roadways.

Few motorists understand the potential or real danger of entering a location where water is over the road. When high water is combined with frequently fast currents, vehicles can be swept away and their occupants placed in extreme danger of drowning either in their vehicles or while trying to escape. Currently there are passive and active warning devices used to warn motorists of potential danger. None of these systems prevents motorists from entering a hazardous area.

Emergency crews and highway maintenance personnel can also place barricades across a road when the water depth over the road is too high. This takes time during which motorists are at risk. Motorists are also known to ignore such barricades or move them out of the way and drive on, sometimes making a fatal mistake in so doing.

Following the submission of the original IDEA proposal, the Transportation Research Board recommended that an initial feasibility study be conducted. Questions to be addressed included:

- Investigating existing flood sensing technology;
- Describing the continuum of water-over-the-road scenarios;
- Investigating methods for detecting water over-the-road;
- Determining costs of sensing options;
- Defining monitoring system configurations;
- Investigating traffic control options by determining control options currently being used;
- Assessing the effectiveness of these methods, and defining potential new traffic control options;
- Investigating legal risks involved in flood sensing and road closure;
- Understanding the liabilities with detecting and warning;
- Describing follow-on work needed to develop flood warning systems to the point of field tests;
- Finding potential partners for testing;
- Investigating the integration of weather information to improve reliability of flood warning by incorporating weather prediction; and
- Preparing reports and outreach materials as required.

This project, in conjunction with a panel of experts, addressed each of the above issues. It is indeed feasible to develop a system that will automatically warn motorists and control traffic with devices such as railroad crossing gates. Some systems currently exist but none provides the capability to automatically close roads. In addition, there is concern over the durability and cost of existing systems. Therefore, certain issues require further investigation, such as the

development of a low-cost, reliable, accurate, and robust system that will withstand the rigors of the flash flood environment.

The project team developed a proposed system design that will provide the durability, data accessibility, alerting, warning and traffic control functions required and at a reasonable cost. The proposed system would contain the following components:

- Sensing subsystem, comprised of durable, accurate, reliable water level sensors;
- Data processing subsystem, for formatting data for monitoring and alerting;
- Data dissemination subsystem, for data logging, storing, and transmission;
- Alerting subsystem for notifying emergency personnel;
- Monitoring subsystem, a web-based graphical user interface for site-based information;
- Motorist warning subsystem, for activating message signs;
- Traffic control subsystem for activating barricades or traffic signal preemption; and
- Power subsystem for providing the power required by all components.

It is recommended that the proposed system be developed for laboratory testing and subsequent field demonstration. It is also recommended that any field testing include all subsystems except the warning and traffic control subsystems to ensure the other subsystems properly before activating signs or barricades.

INTRODUCTION

The purpose of this project was to investigate the potential use of active systems that would automatically warn motorists of hazardous conditions through the use of variable message signs and that could actually close roads with physical barriers similar to rail crossing gates.

More people are killed each year in the United States by flash floods than by any other weather-related phenomenon. The majority of these fatalities occur on roadways. Although the National Weather Service has embarked on a modernization effort to improve hydrological forecasting in an attempt to provide better warning service for flash flooding, few people actually using the roads ever hear a flash flood warning. Even if they do, human nature says, "it won't happen to me." Frequently, the hazardous condition is on such a local scale that it is unforecastable.

A related issue is that few motorists understand the potential or real danger of entering a location where water is over the road. Studies indicate that about one foot of water will float approximately 1,500 pounds of vehicle. Combined with frequently fast currents, vehicles can be swept away and their occupants placed in extreme danger of drowning either in their vehicles or while trying to escape.

There are specific locations that flooding occurs. These locations are known to highway agencies and to the local traveling public, but unknown to non-local road users. In addition, even if the location is a known potential hazard, there is frequently no way of knowing whether the condition is or is not at a given moment in time a hazard. Motorists therefore enter a situation that they can't determine is hazardous. Similarly, a situation that doesn't look hazardous and can cause the motorist to venture onward, only to be trapped.

Currently there are passive and active warning devices used to warn motorists of potential danger. The passive warnings involve warning signs that indicate a location on the road may flood or that there might be standing water during heavy rains. Active devices require a sensor to determine water is over a road and typically flashing lights on signs are activated to warn motorists.

In addition, if time permits, emergency crews and highway maintenance personnel can also place barricades across a road when the water depth over the road is too high. This takes time during which motorists are at risk. Motorists are also known to ignore such barricades or move them out of the way and drive on, sometimes making a fatal mistake in so doing. Highway maintenance personnel indicate motorists driving four-wheel drive vehicles with winches on the front have even been known to move concrete barriers that are blocking roads.

Following the submission of the original IDEA proposal, the Transportation Research Board recommended that an initial feasibility study be conducted. Questions to be addressed included:

- Investigating existing flood sensing technology;
- Describing the continuum of water-over-the-road scenarios;
- Investigating methods for detecting water over-the-road;
- Determining costs of sensing options;

- Defining monitoring system configurations;
- Investigating traffic control options by determining control options currently being used;
- Assessing the effectiveness of these methods, and defining potential new traffic control options;
- Investigating legal risks involved in flood sensing and road closure;
- Understanding the liabilities with detecting and warning;
- Describing follow-on work needed to develop flood warning systems to the point of field tests;
- Finding potential partners for testing;
- Investigating the integration of weather information to improve reliability of flood warning by incorporating weather prediction; and
- Preparing reports and outreach materials as required.

INVESTIGATION

The following sections describe the results of the investigation for each of the topic areas listed above. Information was gathered through literature searches and vendor contacts. Literature searches were conducted via the Internet and at the Missouri Department of Transportation's (MoDOT) Research Library. In addition, the Office of Chief Counsel for MoDOT provided copies of National Cooperative Research Program Legal Research Digests for review.

Vendor contact was made and information was gathered at vendor displays at two conferences. The Principal Investigator (PI) attended the American Meteorological Society's Annual Meeting that has a very large vendor show. In addition, the PI attended the Air & Waste Management's Annual Meeting & Exhibition. In each case, vendors of weather and water monitoring equipment were present. Discussions were held regarding available technology.

Contacts were also made with agencies currently using some form of water-level-monitoring technology. These included:

- City of Scottsdale, AZ street department;
- City of San Antonio Department of Public Works, Street and Drainage Section;
- Kansas City, MO Department of Public Works, Storm Water Utility;
- U.S. Army Corps of Engineers, St. Louis Region;
- Metropolitan St. Louis Sewer District (MSD), MO;
- U.S. Geological Survey personnel, Rolla, MO;
- Horner & Schifrin, Inc., a watershed management engineering firm serving MSD; and
- The City of Carrollton, TX Department of Transportation.

The Chesterfield Fire Protection District also acquired information from other agencies via e-mail queries.

INVESTIGATE THE TECHNOLOGY

Although research had been conducted into flash flood warning technology in order to prepare the original proposal, additional research during this project provided more insight into existing technology, its implementation, and its problems.

In general, a great deal of technology exists to monitor and report on the environment, including water level. Vendors indicate a preference to ultrasonic sensors, although pressure transducers are also used. Agencies with sensors in-place indicated the pressure transducer sensors, when protected properly, can be more durable. These sensors are used primarily where water is continuously above the sensor. Ultrasonic sensors can be mounted above an area where water exists or is expected to exist and can determine the height of water below the sensor. Data loggers are very common items and are available from a number of sources.

In May, the PI made a presentation to the ITS IDEA Committee at the National Academy of Sciences facility in Washington, DC. Considerable insight was gained through discussions during and after the presentation. A report of the results of the presentation is provided in Appendix A.

In June, the PI attended an ITS-45 IDEA Project Meeting in Wyoming. ITS-45 dealt with the development and trial deployment of a warning system for avalanche hazards in the highway environment. The purpose of attending this meeting was to get information on lessons learned from a similar project. This project involved sensing, data collection and dissemination, motorist warning and road closing technologies and ideas. This project had developed a motorist warning capability, and tested the deployment of a barricade system using a railroad-type crossing gate. The system did work until an avalanche destroyed it. However, the drawings for the Wyoming DOT-developed gate have been obtained for potential future use. A wider test of the road closure system was not attempted due to the lack of a vehicle identification and tracking system.

In July, the PI convened a Project Panel meeting. A list of panel members is shown in Appendix B. The results of the discussion at this meeting are documented in Appendix C.

Potential problems exist with current technology. Off-the-shelf sensors probably would not fare well in the environment associated with flash flooding. During any rain events where water will be coursing through the streambed, debris can impact or build up on anything in the bed, including sensors. Even sensors some distance above a bed could be subject to damage from debris in a flash flood. Nearly all of the sensors in-place in San Antonio, TX were destroyed in flooding in October of 1998.

Another concern is the potential cost of a standard monitoring installation. A typical road weather information system installation can cost tens of thousands of dollars. This is a result of the combination of sensors, data loggers, communications equipment, and the infrastructure required to contain and protect the suite of equipment. Further cost is associated with communications to and from a site.

CONTINUUM OF OVER-THE-WATER SCENARIOS

The spectrum of possible flash-flooding scenarios discussed ranges from:

- Tremendous flooding situations such as the Big Thompson Canyon flood in Colorado some 20 years ago and the more recent tragic flash flooding in the Grand Canyon;
- Sudden surges or rising of water over a road in a local watershed drainage basin; to
- Gradual rise of water over the road.

In the Big Thompson Canyon flood, 139 are known to have died that night, and 88 people were injured. Seven victims have never been located. The flood destroyed 316 homes, 45 mobile homes, and 52 businesses. 73 mobile homes suffered major damage. The Big Thompson-type flash flood can involve walls of water tens of feet deep; the gradual rising of water over the road can take place over a period of hours. In an incident at Ladue Road and State Highway 141 in St. Louis County, Missouri in August of 1996, the area for which the original proposal was submitted, the water reportedly rose 18 in. in 10 min. Other cases of deaths have involved vehicles floating away downstream or people who got out of vehicles being swept away in relatively benign-looking environments.

The problem for the motorist is knowing the depth of the water over the road and whither or not the water is moving swiftly. Unless there is signage that can point to the water depth, the motorist has to decide whether or not the road is passable. Even then, few people understand the forces involved and that a small amount of water over the road can mean trouble, whether from hydroplaning or from actually floating. Project panel members indicated the extreme importance of closing roads in certain urban environs when water is flowing over the road.

METHODS FOR DETECTING WATER OVER-THE-ROAD

There are two main types of sensors used for detecting water level. These are either pressure transducers or ultrasonic devices. The pressure transducer type is commonly used in hydrological ALERT systems and in US Geological Survey (USGS) stream monitoring sites. These sensors rest on streambeds in some form of closed pipe system. The pressure transducer systems are calibrated to determine the level of liquid above the sensor. Ultrasonic sensors are generally mounted above the level of a surface and measure the distance to the surface. Both can be used to determine the height (depth) of water as well as the rate of rise.

A third type of sensor is the type being used in Carrollton, Texas. They use a beam of light that reflects off water when the water level reaches a specified height. The sensing system has been in place since 1984.

Other methods for determining water level include an in-pavement sensor and video cameras. The in-pavement sensor is potentially desirable because the key element to know is water-over-the-road. A problem with an in-pavement sensor, however, could be determining the depth of water over-the-road. A sensor would probably have to be higher than the surrounding pavement. Placing such a sensor on the shoulder of the road could minimize this problem.

Video has obvious advantages for not only determining if water is over-the-road, but for providing verification for human intervention. Unfortunately video has drawbacks due to its need for ambient lighting, although infrared video is becoming available.

Regardless the type of sensor used, there is concern over the environment in which flash flood warning sensors may need to exist.

- Sensors may need to be protected from mud and debris associated with flash flooding. This will require some form of shroud, or a vertical French Drain, which is a pipe with holes or slits in it for water to enter but not debris.
- The sensor may need to operate in a location that is dry 99 percent of the time and then operate flawlessly when needed during a flooding incident.
- The sensor must also be "immune" to vandalism and damage from humans and animals. (It was learned in conversation with a Corps of Engineer person on July 7 that one type of ultrasonic sensor, which is protected by a shroud similar to that described above, has significant problems with mud daubers building their mud nests in the pipe and rendering the sensor useless.)
- Sensors in the waterbed need to survive freeze damage during the winter.

The key with any sensor is to monitor water over-the-road and to use the system to buy time for emergency services or maintenance personnel to arrive at a location.

COST OF SENSING OPTIONS

A standard figure for a stand-alone site configured to measure water depth and precipitation and report these data, usually via radio modem, is about $10,000. The USGS stream gauge, if mounted on a stream bank, is approximately $5,000, but this is for a data logging and not real-time reporting system.

The $10,000 cost estimate includes sensors, a solar cell to keep a battery charged, and a transmitter or data logger. Additional costs are incurred if standard weather measuring equipment, such as wind and temperature/dew point instruments, are included.

DEFINE MONITORING SYSTEM CONFIGURATIONS

Many configurations for monitoring water level can be described. Figure 1 provides a block diagram of a proposed system. The basic configuration would include the following subsystems:

- Sensing subsystem, composed of one or more, perhaps up to four sensors in a test mode;
- Data processing subsystem, composed of a data logger that processes sensor output and sensor status data as well as status information from other subsystems the power subsystem;
- Power subsystem, which would include batteries for powering subsystem components and solar panels to keep batteries charged.

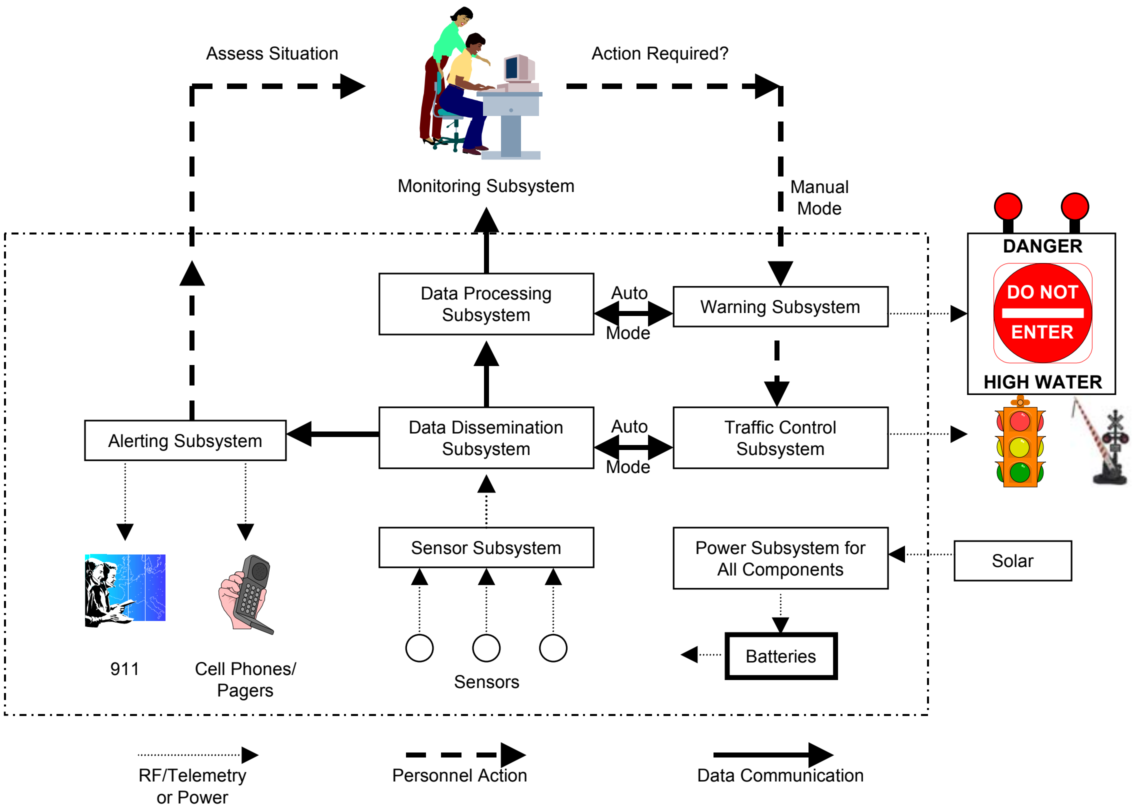

Figure 1. Proposed Flash Flood Warning System Design

- Data dissemination subsystem, preferably not hardwired, but a radio-signal-based subsystem connecting the sensing subsystem to the data processing subsystem and to the alerting subsystem; and an
- Alerting subsystem, the purpose of which is to alert via pager or telephone emergency response personnel to the fact that something is occurring at a site. Alerts would be provided for water-over-the-road, high water, and rate or rising water, with all parameters site selectable. Agency personnel can then respond as is appropriate.

Additional subsystems can be added depending on the functionality desired. Upgrades to the basic system could include:

- Monitoring subsystem, a web-based site where agency personnel, researcher team members, and others if deemed desirable, can view sensor output, sensor status, variable message sign (if used) status and messages, barricade (if used) status, and video (if used) of a site. For a demonstration, the web site could simulate a variable message sign and automated barricades, simulating;
- Warning subsystem, which would include, but not be limited to, an appropriate sign with flashing lights (not to be installed in the next stage); and a

- Traffic Control subsystem, comprised of signs, signal preemption where possible, and crossing gates when appropriate (none to be installed in the next stage).

TRAFFIC CONTROL OPTIONS

Traffic control options can be very simple and inexpensive or very complicated and expensive. At the simple and inexpensive end of the option spectrum are motorized signs that fold over or unfold to reveal a message such as "DO NOT ENTER" in the appropriate Manual for Uniform Traffic Control Devices (MUTCD) compliant format with additional information such as "HIGH WATER" [1]. The sign will typically have a flashing red beacon [2]. The intent of the sign is to stop traffic from entering a dangerous area. Variable message signs can also be used, but they may be used more for warning of problems at some distance from the flood problem. These warning signs could be used to divert traffic to alternate routes.

In addition to signing, in locations where there are traffic signals, the monitoring, alerting, or data dissemination subsystems can be used to preempt normal signalization at intersections in or near the flooded site. Traffic can be halted at some distance away and decisions can be made to take alternate routes. Flashing red lights would be the preferred tactic to alter traffic.

The ultimate traffic control would involve the use of railroad crossing gates. In many locations barricades are in place but have to be manually closed. This process takes too long to prevent incursion into a flooded area. Ideally, railroad-crossing gates could be activated automatically by the data dissemination, alerting, or monitoring subsystems. Such barricades would have to be of the quad-gate type, blocking both inbound and outbound lanes. Gates have been developed in the ITS IDEA project ITS-45 for avalanche-related traffic control. The gates could be activated manually on-site but again, this takes too long. A system can be designed that will allow the gates to be activated remotely from the monitoring subsystem, or automatically by the data dissemination or alerting subsystems. This traffic control subsystem component would also require traffic detection to keep gates from falling on cars and to let any outbound vehicles out of the blocked area.

LEGAL RISKS

Based on discussions with the MoDOT District 6 Chief Counsel in the St. Louis area, little legal risk is associated with a well-planned and successfully demonstrated technology. There are two basic questions that must be asked:

1. What is the present condition that is being corrected, and
2. What is the condition being created?

Action being taken to correct a dangerous or hazardous condition must be viewed as a positive step. As long as the technology being implemented doesn't create an additional or different hazard or danger, then there is no legal risk.

In fact, there may be some legal risk for not implementing a technology that could reduce a hazard. As long as the agency or agencies involved has or have constructive knowledge of a hazard or danger and take no action to correct it, then there may be a legal risk [3].

There is also an issue of whether or not an agency is at risk if best available technology or best engineering practices are not employed.

LIABILITIES ASSOCIATED WITH DETECTING AND WARNING

Other than the liabilities discussed above, the liability concern centers on developing and implementing a technology that works. If a sensor or other component of a system fails to operate properly such that no alert or warning is issued and a motorist is put in harms way, then there is an obvious liability. Although there is a liability for the public agencies on this issue, there is also a commercial liability for the developer of such a system. Liability insurance and coverage for errors and omissions will be a key component of any proposed development activity. System reliability and redundancy are major factors in reducing the liability associated with the development.

Liabilities also exist with the use of automated barricades. One instance would be if automated barricades hit a vehicle when activated. Another instance would be barricades being activated with a vehicle trapped in the hazard area between entrance and exit locations. In each instance, additional technology can be added to a traffic control subsystem that will not allow barricades to fall on vehicles in an entrance or exit location or may open as a vehicle approaches an exit region. And, if barricades or signs in-place don't function properly, the liability is obvious.

DESCRIBE FOLLOW-ON WORK

The next phase of this investigation will demonstrate both in a laboratory environment and then in an actual flash flood environment new innovative technology that will be developed to address the issues raised in this feasibility investigation.

The research team believes it can successfully develop and field a low-cost, reliable, robust and accurate flash flood warning system that can function either as a basic or enhanced system. The system will either employ new sensor technology or modified existing technology to withstand the rigors of the environment and provide the accuracy and reliability needed. The system would also be designed to employ new communication technology to increase flexibility and pare costs. Finally, the system would provide emergency managers real-time information in a format that improves response and ultimately will protect motorists.

FIND POTENTIAL PARTNERS FOR TESTING

During the development of the original proposal for this project, agencies were contacted to discuss participation. Subsequent discussions, including the project panel meeting, prompted discussions with additional agencies. The following public agencies have expressed interest in participating in a demonstration phase of this development:

Missouri Department of Transportation
St. Louis County Department of Highways and Traffic
Jefferson County Department of Public Works
City of Chesterfield, MO Department of Public Works
Chesterfield Fire Protection District

INVESTIGATE INCORPORATING WEATHER PREDICTION

The potential exists for emergency managers to become more aware and responsive to flash flood situations. National Weather Service WSR-88D Doppler weather radar data can provide estimates of precipitation over large areas. According to NWS hydrologists, there are limits to the usefulness of the data. Near the radar site and at long range, the ability of the system is limited to measure accurately the radar reflectivity required for the precipitation algorithms. Nonetheless, the proposed system will be designed to provide up-to-date weather radar and other weather information at the monitoring subsystem.

Also according to NWS hydrologists, real-time-reporting precipitation gauges are critical to being able to monitor and predict precipitation amounts in watershed scale areas. Typically, the hydrology forecasts are on a macro scale. Flash flooding occurs on a very local scale. Unless a network of precipitation gauges is in place, there is no ground truth for initiating and updating forecasts. Many flood-prone areas have no gauges in place or, as in the case of the St. Louis, Missouri area, have gauges in place for study and modeling efforts, but are not real-time reporting gauges. In addition to gauge input, emergency managers may on occasion provide inputs of precipitation amounts from their facilities. These reports are sporadic and undependable.

A public domain storm water model may offer an opportunity to provide forecasts of flash flood potential on the watershed level. The Environmental Protection Agency (EPA) Storm Water Management Model (SWMM) uses historical data from networks of stream gauges and precipitation gauges to calibrate model output. It may be possible for EPA SWMM, or one of its commercial variants, to use real-time data, especially when combined with WSR-88D radar data, to produce forecasts for specific watersheds and local flash flood problem areas. Hydrology forecasters from two NWS hydrology offices were unaware of research in this area. Such an effort would be worthy of a separately funded research project.

PREPARE REPORTS AND OUTREACH MATERIALS

At the request of TRB, the project team developed a Product Report describing the investigation and the innovation expected to emerge as a result of this project. The Product Report was provided to the ITS IDEA program manager for use with other outreach material.

CONCEPT AND INNOVATION

Although water-over-the-road warning systems exist, these systems don't always work properly when needed. The primary problems center on sensor failures and damage to sensors during flooding. The ambient environment for sensors is particularly harsh in areas prone to flash flooding. In addition, reliable sensors tend to be expensive. Innovation requires the development of a sensor system that is reliable, robust, and durable with extremely high operational availability.

In addition to a robust sensor system, alerting, monitoring and warning capabilities need to be fail-safe. Another product of the research will be a web-based monitoring system for use by emergency and highway maintenance managers. These personnel will be alerted via cellular phone or pager directly from the site(s) when critical thresholds of water levels or rates of water-level rise are exceeded. The managers can then check the web page to determine from water level sensor output and video from the site (if available) what measures need to be taken. These managers will have the capability to activate signs and barricades manually through the web page and then will be able to determine that signs and barricades have been activated properly. The system will also have the capability to automatically activate message signs and barricades. The managers can then dispatch emergency crews to attend to the area and ensure the site is returned to a safe condition before allowing motorists into the flooded area(s). The sensor and warning subsystems will have built-in diagnostics to verify proper operation and to warn of malfunctions of components. Key weather information, such as radar data, will also be available to managers through the web page.

IDEA PRODUCT

The product that will result from this project is a modular system that will improve the ability of emergency response and highway maintenance personnel to respond to flash flooding problems. More importantly, the system will have the capability to reduce the risk to motorists of being trapped and possibly killed in flash flood situations. The modularity allows for the deployment of relatively inexpensive and efficient or highly effective and possibly expensive systems depending on an agency's needs and desires. An example of an inexpensive system would be a set of sensors and an alerting capability (see subsystem descriptions). One or more signs could be added to warn motorists. An obviously expensive system would involve the installation of crossing gates.

PROPOSED SYSTEM DESIGN

A modular design is suggested for the flash flood warning system. Such a design allows for flexibility in implementing the technology. An agency could specify any or all of the components based on its needs.

Sensor Subsystem

The sensor subsystem should be comprised of devices that can sense the level of water in various types of locations. These locations should include streambeds, bridges, and road surfaces. These locations will require various levels of water to be detected. The road sensor will require completely different packaging requirements. Both sensor assemblies should have the capabilities to be secured firmly, but not permanent in place. Each of these locations will require the sensor to combat varying challenges to adverse conditions. The sensor must be able to function under the coverage of debris and sediment, muddy or heavy media saturated water, forces which would cause shock or vibration to sensor and assembly, annually changing environmental conditions, sun light and ultraviolet radiation and finally, lightning.

It is advantageous to place multiple sensors in a location. Multiple sensors will allow more data to be taken during a flooding event. The most critical aspect of deploying multiple sensors is to allow redundancy in providing an early warning alarm response. As a result, the sensor must be cost effective. To achieve this requirement, the sensor should be simple in overall construction with few parts. In addition, the means to transmit the water level information must be performed with a minimal amount of connections. Because most sensor subsystems will not have direct access to continuous line power, the sensor must not consume a large amount of power.

Data Dissemination Subsystem

A minimal amount of data logging and storage capability should be placed on-site with the sensors. The only equipment necessary would be to establish a communications link with an Internet Service Provider (ISP). This connection can be via hard wire or radio frequency. The Internet connection can then allow data to be transferred to a personal computer (PC) where all the data logging, analysis and control can be performed. Placing equipment on-site only causes the equipment requirements to be more robust to the environmental conditions present. Power consumption increase and adequate means must be implemented to sustain these demands. In all, the cost increases. The goal is to have a high-performance, cost-effective system that would allow the flow of data to redundant PCs in different locations. The redundant locations are to protect against one system going down. All data are shared and are set-up to be the same on both computers. Software on the computer system can then store and analyze the data. Based on the analysis performed the software can then communicate with the Alerting, Warning, Traffic Control, and Data Processing subsystems.

Data Processing Subsystem

Data processing can take place on the same computer in which the Data Dissemination takes place. As data are retrieved, they are stored in a database. The database will take into account all locations. A Graphic User Interface (GUI) will be developed to present the data and location information in real-time or historical format at the central location. This will be tailored to the needs of the Monitoring Subsystem. Information and data should be made available to any and all external sources who wish to obtain the information via the world wide web (WWW) to be delivered in Hyper Text Mark Language (HTML) format. This will allow anyone with web browser software (e.g., Netscape, Explorer) to view the information without having custom software. In addition, disseminating upgrade software would not be required. Information would also processed for automatic response modes to allow for warning and alerting of adverse conditions before operator intervention can take place. Capabilities should also include a means to automatically contact the proper authorities and responsible personnel to provide the same warning and alerting response. Communication with the proper authorities and personnel could be achieved through pager, phone, and/or e-mail contact by the computer performing the monitoring.

Alerting Subsystem

The alerting subsystem will provide automated alerts to emergency response personnel. The actual alerting should take place directly from the data processing subsystem. The notification capabilities would include telephone, cellular phone, paging, or e-mail alerts depending on the structure and capabilities of the responsible agencies. Telephone and cellular phone alerts would be comprised of a set of voice messages generated based on the data received and processed. Alerting would be virtually immediate. The personnel alerted would be directed to the monitoring subsystem or to the site itself, as required. Pager and e-mail notification would contain the same information as voice alerts unless the pager capabilities do not allow messaging. In that case, a specially coded number would be transmitted to the pager(s) and personnel would respond based on prearranged response to the codes.

Monitoring Subsystem

The monitoring subsystem will be a web site database that receives data from the fielded subsystems and provides readily accessible and useable information to emergency managers. The information will be presented on a base map in an format that alerts viewers or personnel in the area with both audible and visual alerts. For example, the sensor data could be shown in a graphical user interface (GUI) using a color-coded box with green (everything is OK), yellow (initial alert), or red (warning time) colors displayed for immediate recognition. The GUI would also provide alerts for subsystem status problems. For the demonstration, only real-time data would be displayed.

In addition, the GUI would provide access to weather information. Near-real-time (free) or real-time (for a fee) WSR-88D Doppler radar data would be immediately accessible. Data from standard weather reporting stations and any local networks of weather stations would be available.

The monitoring subsystem would also provide access to the warning and traffic control subsystems described below. Current variable message sign displays would be displayed and could be updated through access to this web site (with appropriate security in place). The status of any traffic control measures capable of being activated would be available.

Finally, video from field sites could be provided. The video would provide verification of conditions and the status of a location for use by managers in making emergency management decisions.

Motorist Warning Subsystem

A serious problem exists when using warning devices for sporadic events such as fog on the road, avalanches, flooding, or even deaf children playing. Motorists tend to simply disregard such devices that are in view 100 percent of the time but report a one percent event occurrence. When the time to obey such a warning is called for, they have already developed a habit of disregarding the warning.

Because of this, the most effective warning devices are event driven - Watch for Fog When Flashing is an example of this interactive sign. However, even these devices are disregarded due to built up apathy or, as in the case of many of the potential flooding conditions a self-determination by the motorists that the situation is safe when, in fact, it is not.

"The MUTCD provides for a uniform approach to traffic signing to..." provide such guidance and warnings as are needed to insure the safe and informed operation of individual elements of the traffic stream." According to the MUTCD, a traffic control device needs to meet the following requirements:

1. Fulfill a need;
2. Command attention;
3. Convey a clear, simple meaning;
4. Command respect of road users; and
5. Give adequate time for proper response.

To develop a warning device for flooding, each of these areas must be considered. However, key is developing a warning system that not only conveys a clear message, but also commands attention and the respect of road users.

For this application, this likely means creating a sign that is not obtrusive during periods of inactivity, but comes alive only when needed (such as a flip sign). This warning system needs to conform to the MUTCD while, at the time, be specific to the flood peril.

Motorist warning could be automatedly or manually activated. Output from the Data Processing Subsystem could trigger variable message or fixed message signs based on the occurrence of water level or rate of rise crossing certain thresholds. In addition, signs could be activated manually based on review by emergency personnel of output to the Monitoring Subsystem. A detailed description of this Subsystem will be left for future work. However, the signage discussed above in Traffic Control Options in the INVESTIGATION section will be a likely candidate.

The Project Panel recommended that during the demonstration phase of the product, the system should not initially provide information or warnings to the traveling public. Upon meeting warning thresholds, data would be provided to the Monitoring Subsystem for review by project and emergency personnel. In addition, the alerting subsystem would be activated when thresholds are exceeded.

Traffic Control Subsystem

Traffic control could also be automatedly or manually activated. Traffic control could include traffic signal preemption at signalized intersections where traffic can be diverted or held out of harms way. In addition, rail-crossing gates could be used to physically barricade the roadway. A quad-gate system should be used to prevent motorists from entering a dangerous situation by going around barricades on the exit side of a roadway. Such a system would include special traffic monitoring sensors for raising the exit side gate upon the approach of a vehicle from the flooded or flooding area and for prohibiting a gate from impacting a vehicle. It is recommended that signals and barricades would remain in place until emergency response personnel can assure the traveling public that the roadway is once again safe for travel.

The Project Panel also recommended that during the demonstration phase of the product, this system should not initially be activated. Emergency personnel would respond to the site(s) based on the Alerting and Monitoring Subsystems to close the roads.

Power Subsystem

The power subsystem will provide the electrical requirements for all the site-based subsystems. Each site will be stand-alone.

Batteries charged by solar cells will generally always provide power. This is necessary because most flash flooding occurs as a result of thunderstorms. The power is most likely to go out in an area where there is heavy thunderstorm activity. This is when the flash flood warning system is most needed and power must be available. In the event stable power is available, solar power and batteries would be used as a backup.

PROPOSED DEMONSTRATION AND DEPLOYMENTS

The proposed next phase of this investigation will involve two separate actions. First, the research team will conduct a laboratory demonstration of the sensor subsystem developed in this project. The laboratory phase will provide proof-of-concept and accuracy information.

Following the successful demonstration in the laboratory, a field demonstration of all the components except the warning and traffic control subsystems will be conducted. The data dissemination and alerting subsystems for the demonstration will employ the least-cost communications from the selected site for the purposes of the demonstration. However, the system will be designed to allow the use of various communication technologies.

The project panel recommended that all subsystems except warning and traffic control be fully tested before actually activating message signs or traffic control devices.

Field demonstrations requiring weather events of infrequent occurrence should have multiple test locations. Therefore, it is likely that at least three installations will be made in order to assure that some field data will be acquired.

RESULTS AND CONCLUSIONS

The results of the feasibility investigation can be categorized rather simply. The development of a flash flood warning system to automatically close roadways is feasible. There are a few obstacles to over come and they are listed in the conclusions that follow:

- Technology exists and is in use to warn motorists of water over highways;

- In general, the technology in use for monitoring water level is too expensive for widespread use in flash flood prone areas;
- The sensors used are not durable enough to survive in flash flood situations and environments;
- There are few legal impediments to developing and implementing an automated road closure system for flash flooding;
- Liability is an issue and a reliable, accurate and durable system needs to be developed; this includes all subsystems. Commercial insurance coverage cost will be an issue in the development of any warning and control system; and
- The ready access to data and their usability are key to the development of a successful system. The graphical user interface will be an important part of a demonstration test.

REFERENCES

1. *Manual on Uniform Traffic control Devices*, Federal Highway Administration, US Department Of Transportation, Washington, DC. 1989
2. *Supplemental Advance Warning Devices*, NCHRP Synthesis 186, Transportation Research Board, National Research Council, Washington, DC. 1993
3. *Risk Management for Transportation Programs Employing Written guidelines as Design and Performance Standards*, NCHRP Legal Research Digest 38, Transportation Research Board, National Research Council, Washington, DC. August 1997

APPENDIX A – Results of the ITS IDEA Committee Meeting Presentation

ITS - 79

Report of Project Presentation

to the

ITS IDEA Committee

May 26, 1999

Introduction

The ITS IDEA Committee of the Transportation Research Board, National Academy of Sciences, met in formal session May 26, 1999, at the National Academy of Sciences, Washington, DC. The meeting agenda is shown in Appendix A. The purpose of this report is to document the presentation of project ITS-79 to the Committee and to record the comments from the committee members and the direction suggested for the project.

Mr. S. Edward Boselly, Principal Investigator for project ITS-79 made a formal presentation to the committee of the status of the project. Although the project was just slightly over a month old, Mr. Boselly documented the progress that had been made and the current status of the project. The actual presentation is shown in Appendix B.

Comments

This section documents questions and comments from committee members. No formal minutes of the meeting were taken. Mr. Boselly recorded these questions and comments immediately following the meeting. They are based solely on his best recollection. The name shown with a comment is also based on his best recollection. Following each comment or question is the essence of a response from Mr. Boselly or a proposed action to be taken in the project.

1.a. Sensor reliability is an issue with respect to the use of gates (comment from Mr. German).

We agree and believe that multiple sensors will be needed at each installation to assure reliability

1.b. Sensors will be the biggest problem. Ultrasonic sensors didn't work in October in Texas (comment from Mr. German).

Same comment as above. However, a "vertical French drain" can protect ultrasonic sensors with the sensor(s) surrounded by a PVC pipe with holes in it.

3. I suggest you interface with the Corp of Engineers to find out their capabilities in this area (comment from Mr. Rifkin).

   We will contact them.

4. I suggest you contact railroad people who have had a lot of experience with forecasts of precipitation events (comment from Mr. McCown).

   We will contact them.

5. I suggest you get a copy of the bridge inspection report I sent Keith Gates (comment from Mr. McCown).

   Copy was obtained from Keith Gates on 5/26/99.

6. I suggest you have Paul Pisano [FHWA] on your expert panel (comment from Mr. Felser?).

   Budget was set for panel meetings in Missouri (Boselly)
   FHWA will pay travel expenses (Felser?)
   We will ask him to help us (Boselly).

7. Are you going to conduct a reliability assessment (question from unknown member)?

   We need to do that. Reliability is an issue. Redundant sensing, data processing, and video inputs should all help improve system reliability.

8. Have you or will you look into forecasting capabilities to pinpoint flash flood problems (question from Dr. Wallace prior to the meeting)?

   Yes, that is one of the subtasks (also see comment above from Mr. McCown).

9. Are you going to conduct a benefit-cost analysis of the costs of potentially costly installations versus the numbers of installations needed (question from Mr. McCown?)?

   We will certainly look at the issue. It is expected that there will be more inclination for expensive installations in urban areas rather than rural. We know Missouri is interested from the huge number of rural problems they have and could certainly not support expensive installations at all locations. In addition, many of the problems are also county jurisdictions and they certainly can't afford expensive installations.

10. The budget for Stage 2 appears to be too small (comment from unknown member but may have been associated with the question at item 8, above).

These are obviously first cut numbers after only one month into the project. A more refined budget will be provided at the completion of this Stage.

11. You will need to submit a proposal for follow-on work for Stage 2.

We will submit a formal proposal that will meet the next ITS IDEA cycle time lines.

Conclusion

The presentation by Mr. Boselly generated constructive comments and ideas for the project. The general consensus seemed to be that this is a worthwhile project that has nationwideapplicability. Further input will be sought from committee members who volunteered their assistance, especially Messrs. German and McCown.

APPENDIX B – IDEA Project ITS-79 Panel Members

Name	Title	Agency	Phone	E-Mail
Larry Frevert	Deputy Director, Dept of Public Works	Kansas City, MO	816-274-2364	larry_frevert@kcmo.org
William Koehrer	Highway Engineer	Jefferson CO, MO	636-797-5340 Fax: 797-5565	
Bill Stone	Rural ITS Coordinator	Missouri DOT	573-526-0122	stoneb@mail.modot.state.mo.us
Teresa Krenning	ITS Project Manager	Missouri DOT	314-340-4317 Fax: 340-4509	krennt@mail.modot.state.mo.us
Keith Gates	IDEA Project Manager	TRB	202-334-3724	kgates@nas.edu
Mike Geisel	Director, Dept of Public Works	Chesterfield, MO	636-537-4738	mgeisel@chesterfield.mo.us
Richard Gans	Director	Chesterfield, MO Fire Protection District	314-514-0900 Fax: 514-0696	rickgans@mindspring.com
Dennis Bice	Director, Community Relations	St. Louis County; Missouri	314-615-5000	dennisbice@co.st-louis.mo.us
Paul Pisano	Weather Projects Coordinator	Federal Highway Administration	202-366-1301	paul.pisano@fhwa.dot.gov
Les Crews	Asst. Chief	Chesterfield, MO Fire Protection District	314-514-0900, ext 317	

APPENDIX C – Report of ITS-79 Project Panel Meeting

July 1, 1999
Jefferson City, Missouri

INTRODUCTION

The ITS – 79 Expert Panel met on July 1, 1999, in Jefferson City, Missouri, at a Missouri Department of Transportation (MoDOT) facility. A list of panel members is shown in Appendix C-1; the meeting agenda is shown in Appendix C-2.

The purpose of this report is to:

- Record the comments from the panel members; and
- Document the direction suggested for the project.

Ed Boselly, Principal Investigator for project ITS-79, chaired the meeting. Following introductions of the attendees, Mr. Boselly provided a brief overview on the history of the project from its inception, through the submission of the IDEA proposal, to the contract award, and finally the subsequent efforts undertaken to date.

Keith Gates of the Transportation Research Board provided ITS IDEA comments, especially from the ITS IDEA Committee perspective. The committee and the IDEA Program are interested in innovation. From the original proposal perspective, gates to barricade a roadway are not innovative. There needs to be innovative technology explored. A special concern relative to the technology is that the development must consider false alarms. The goal is no false alarms. Such innovation might involve the use of radar information to determine the null case, i.e., no precipitation is occurring. Finally, he advised that the purpose of the project is the development of technology, not the resolution of institutional issues.

TOPICS OF DISCUSSION

This section documents the discussion and comments from committee members. The following list of topics was extracted from the National Academy of Sciences contract for ITS-79. A list of these topics and subtopics was provided to panel members and meeting attendees prior to the meeting. Any additional topics discussed are included in the "Other Items Discussed" section. Although the topics are listed in the specific order presented in the contract, the discussions frequently moved from one topic to another. The information related to one topic is shown there regardless of its sequence in the meeting.

Investigate Flood Sensing Technology

Panel members indicated that some water level sensing is occurring in various areas. In Kansas City, for example, 20 sensors are in place along Brush Creek. This is a critical area because nine people were lost in Kansas City on Oct 4, 1998. The sensors are manually monitored.

Most warning systems currently located in urban areas. Discussion pointed to the problem being an urban issue rather than a rural issue. In rural areas, local residents know when they should not or can traverse locations where water is over-the-road.

Much of the technology currently in place for flood sensing is also for more generic flooding issues such as large flood plains in this area associated with the Mississippi and Missouri rivers and their tributaries. It was suggested to contact the Municipal Sewer District (MSD) and the Corps of Engineers to determine the locations of and applicability of in-place monitoring systems. It is important to find out about stream monitoring, gauges, and sensing water levels and flow velocity. MSD has systems in place at Olive Street Road and Creve Coeur Mill Road, Ladue Road, and Conway road in the drainage stream basin that is part of the problem area for which the original proposal was based. MSD may also have a monitoring system in the River Des Peres, another flooding problem area. It was suggested that the National Weather Service Missouri Basin River Forecast Center in Pleasant Hill, MO, be contacted in this regard.

Similarly, it was suggested the research team contact the city of Los Angeles which has a monitoring system already installed. Maricopa County in Arizona is another agency with a large monitoring system. (Based on the ITS IDEA Committee meeting, Ed Boselly will also contact San Antonio, TX, which has a flash flood system. Ed has subsequently recalled that there is a large flood management system in place in the Denver area and will make contact through the meteorology firm that provides support to both the Denver area and Maricopa County.)

Describe the Continuum of Water-Over-the-Road Scenarios

The discussion related to this topic was relatively brief. However, the spectrum of possible flash-flooding scenarios discussed ranges from:

- Tremendous flooding situations such as the Big Thompson Canyon flood in Colorado a number of years ago and the more recent tragic flash flooding in the Grand Canyon;
- Sudden surges or rising of water over a road in a drainage basin, to
- Gradual rise of water over the road.

The Big Thompson-type flash flood can involve walls of water tens of feet deep; the gradual rising of water over the road can take place over a period of hours. In the incident at Ladue Road and State Highway 141 in August of 1996, the area for which the original proposal was submitted, the water reportedly rose 18 in. in 10 min.

The problem for the motorist is knowing the depth of the water over the road. Unless there is signage that can point to the water depth, the motorist has to decide whether or not the road is passable. In addition, few people understand the forces involved and that a small amount of water over the road can mean trouble, whether from hydroplaning or from actually floating. The consensus from the meeting was that people, both emergency services personnel, agencies responsible for maintenance or response, and motorists need to be warned when water is over-the-road.

Investigate Methods for Detecting Water Over-the-Road

Discussion centered on the two main types of sensors used for detecting water level. These are either pressure transducers or ultrasonic devices. The attendees also discussed concerns for sensor reliability and the environment in which such sensors may be required to operate.

- Sensors may need to be protected from mud and debris associated with flash flooding. This will require some form of shroud, or as was mentioned in the meeting, a vertical French Drain, which is a pipe with holes in it for water to enter but not debris.
- The sensor may need to operate in a location that is dry 99 percent of the time and them operate flawlessly when needed during a flooding incident.
- The sensor must also be "immune" to vandalism and damage from humans and animals. (It was learned in conversation with a Corps of Engineer person on July 7 that one type of ultrasonic sensor, which is protected by a shroud similar to that described above, has significant problems with mud daubers building their mud nests in the pipe and rendering the sensor useless.)

Other methods potentially useable include in in-pavement sensor and video cameras. The in-pavement sensor is potentially desirable because the key element to know is water-over-the-road. A problem with a pavement sensor could be determining the depth of water over-the-road.

Video has obvious advantages for not only determining if water is over-the-road, but for providing verification for human intervention. Unfortunately video has drawbacks due to its need for ambient lighting.

The key guidance from the panel was to focus on monitoring water over-the-road and to use the system to buy time for emergency services or maintenance personnel to arrive at a location.

Concern was expressed as to the ability of off-the-shelf sensors to operate properly in the weather environment to which they may be subjected. This includes heavy rain that is probably responsible for the flash flooding event. Sensors must work in this environment. In addition, they may have to operate properly in freezing weather and in snow events.

Determine Costs of Sensing Options

The cost of sensing options needs to be a major consideration. It is almost necessary that the sensing portion of a system to be developed be as inexpensive as possible, given the reliability, redundancy and operational availability considerations, because the warning and road closing options can be very expensive. (It was suggested that Ed Boselly contact the Rail IDEA

Program Manager, Chuck Taylor, at the Transportation Research Board for crossing gate cost information.

Since the potential cost for a single installation may be too high to have such devices and controls in many locations, it will be important to develop criteria for installing them. Suggested criteria included, besides a probability or propensity for flash flooding, moderate traffic volume and a critical roadway, perhaps based on roadway classification or use by emergency services and school buses, for example.

Define Monitoring System Configurations

Because of a lack of detail available at this meeting, little discussion took place on a formal system configuration. However, the following components were discussed in general and form the basis for a system configuration:

- Sensing subsystem, composed of one or more, perhaps up to four sensors in a test mode;
- Data processing subsystem, composed of a data logger that processes and displays sensor output and sensor status data as well as status information from other subsystems such as confirmation that gates are closed, signals are preempted, signs are activated and lights are flashing, etc. Data would be supplied to the monitoring subsystem for access;
- Monitoring subsystem, a web-based site where agency personnel, researcher team members, and others if deemed desirable, can view sensor output, sensor status, variable message sign (if used) status and messages, barricade (if used) status, and video (if used) of a site. The web site, for the purposes of the demonstration, would function as the variable message sign and barricades, simulating their activation;
- Alerting subsystem, the purpose of which is to alert via pager or telephone emergency response personnel to the fact that something is occurring at a site. Alerts would be provided for water-over-the-road, high water, and rate or rising water, with all parameters site selectable. Agency personnel can then check the monitoring subsystem for actual conditions;
- Data dissemination subsystem, preferably not hardwired, but a radio-telemetry-based (spread spectrum radios likely) subsystem connecting the sensing subsystem to the data processing subsystem and to the alerting subsystem;
- Warning subsystem, which would include, but not be limited to an appropriate sign with flashing lights (not to be installed in the next stage);
- Traffic Control subsystem, comprised of signal preemption, where possible, and crossing gates, when appropriate (not to be installed in the next stage); and
- Power subsystem, which will probably include batteries for powering subsystem components and solar panels to keep batteries charged.

Investigate Traffic Control Options

Traffic control options discussed included the following possibilities, which are listed in order from most likely to control traffic to least likely.

- Locking cattle-type gates;
- Concrete barriers (people will move these, especially with 4wd and power winches)
- Railroad crossing gates (quad gates);
- Railroad crossing gates (dual gates – people will go around on the on-coming traffic side);
- Moveable barricades (can be moved easily);
- Active warning signs with flashing red lights;
- Variable message signs;
- Signal preemption (assumes a signalized intersection). Signals should be changed to flashing red, not steady;
- Passive warning signs with water level indicators

The consensus seemed to be that railroad crossing gates (quad) provided the best option and should be closed as soon as water is over the road. Both lanes should be barricaded. Signage alone is probably not enough of a deterrent.

The use of barricades is to restrict access until emergency response personnel can arrive and assess the situation. Unfortunately the price of quad gates make their use, in except possibly a few locations, cost-prohibitive. Also, if crossing gates are used, variable message signs or lights need to be activated in locations upstream from the barricades to warn motorists that barricades are down. Barricades should be set back far enough to allow motorists to turn around.

Concern was expressed about using crossing gates and how to deal with vehicles inside the gates. One possible technique is to use a time delay on the outbound gate in a quad installation. Panel members indicated there is a distinct possibility that drivers would go around the inbound gate. The use of median barricade devices similar to delineator posts was suggested to prevent the drive-around, but it was mentioned that these don't work well. People will drive right over them.

It was suggested to use some form of detection to open an outbound gate for a vehicle inside the gates. A motion detector or other device could be used (it was reported that loop detectors in the pavement are not reliable enough) to open an outbound gate. A sign should be placed on or near the gate that indicates a driver should wait for the gate to open.

In addition closing roads, the system should keep the road closed until emergency response personnel have responded and checked the roads or bridges for structural damage. The barricades should not open automatically after water recedes.

Investigate Legal Risks Involved in Flood Sensing and Road Closure

Following discussions between Ed Boselly and the local MoDOT Chief Counsel, from a testing perspective, there don't seem to be pressing legal issues. More of the issues rest with liability, discussed below.

There are two legal questions: what is the condition that currently exists and what is the condition being created. Testing of the system described above is not expected to create conditions worse than what exist already. Possible concerns exist if items installed become a distraction, obstruction, or other hazard.

Understand the Liabilities Associated with the Project

There are both contractor and agency liabilities. Obvious contractor liability exists if a system is installed that doesn't work. This is partially a reason for proposing to install a test system as described above that will have no public display of output information or warning. Favorable results of a demonstration would then be considered for installing warning or traffic control devices.

Another potential liability concern is related to the implementation of technology in some locations but not in others. If was felt that the key here will be for agencies to develop well-founded criteria for putting in and not putting in such technology.

A third liability relates to how warnings and alerts are generated. In an operational system, it was felt that once water is over the road, warnings should be generated and gates (if available) should be closed. If quad gates` are in place, there needs to be a time delay (on outbound sides) to get people out of harms way.

Describe Follow-On Work Needed to Develop Flood Warning Systems to the Point of Field Tests

The consensus of the attendees was that the next stage, for which an new proposal will be submitted, should involve the testing or components and concepts for providing alerts and warnings. This should be done in two ways.

First, laboratory tests should be conducted to determine the reliability and durability of sensors. In order to ensure fail-safe operations, beyond just redundancy or measurements, sensors should be tested to subjected to conditions that will simulate life-cycle conditions. This would include, at a minimum, temperature cycling to test for system failure and for operations in harsh temperature environments. The laboratory tests would also be used for accuracy and precision determinations.

Second, the project should test one or more interim installations of components without signs, signal connections, or barricades. This installation would provide assessments of the sensing and data collection portion of the system to provide alerts and signals that would be used for emergency notification, warning through sign and/or signal activation, and road closing through barricade activation. In addition, this installation would validate the data-logging portion of the system.

The testing in the environment would include the dissemination of two levels of information. One would be for alerting; the other would be for warning. System output signals would provide:

- Alerts to emergency maintenance or other response personnel;
- Signals that would be used for warning sign activation and/or barricade closing;
- Field data related to sensor output. Minimum output would include water level, rate of water level rise, and height of water above the road;
- System health information, at a minimum to include battery strength and output, sensor health confirmation, and solar panel output.

Data transmitted from the site(s) would be sent to a special web site where the data would be presented in a format that users could use in assessing the above functionality. In addition, alert signals would be sent to the emergency response personnel who then would check or monitor the web page to determine the need to go to the site(s). (We will also investigate the potential for installing video and transmitting video to the web site. This will depend on cost and the actual locations selected for these interim tests.)

The key to successful testing will be to generate enough data to determine that such a system functions properly and to answer any possible questions related to reliability, durability, and operational availability.

In correspondence subsequent to the meeting and based on a review of a draft of this report, Paul Pisano from Federal Highway Administration suggested that a design vehicle should be developed to use as a baseline for thresholds for warning motorists and for alerting emergency response personnel.

Find Potential Partners for Testing

For the purpose of this next stage, it was suggested that a number of locations within the jurisdictions represented by panel members could be used. The partnering for this stage will essentially require right-of-way for installing sensors and the other system infrastructure that would be required. Memoranda of Understanding would be executed between the project and the agencies involved, as required.

An important part of finding partners will be to address the issue of finding locations where sufficient data can be collected to ensure a successful test.

Investigate the Integration of Weather Information to Improve Reliability of Flood Warning by Incorporating Weather Prediction

The group consensus was that predictive weather information is not the way to go. It was felt that predictions are still too inaccurate and are on such a gross spatial resolution that they would not be helpful.

This is not to say that other weather information would not be helpful. Certainly timely weather radar information could be used to indicate whether or not precipitation is likely occurring and reduce the false alarm potential. Paul Pisano also indicated, subsequent to the meeting, that weather radar information in conjunction with good short-term, fine-scale forecasting could be a valuable addition to the decision making process. The project team will contact the National

Weather Service hydrology personnel to better assess this potential. Some finer-scale resolution products are now being produced, but the hydrology focus appears to be similar to that of the Corps of Engineers.

Other Items Discussed

Consideration needs to be given, outside the scope of this project, to public service announcements related to water level indicators and any flash flood warning devices developed.

CONCLUSIONS

The panel meeting produced extremely constructive comments and ideas for the project. The general consensus seemed to be that this is a worthwhile project that has significant potential for success and certainly has nationwide applicability.

APPENDIX C-1. ITS – 79 Panel Meeting Attendees

Name	**Title**	**Agency**
Larry Frevert	Deputy Director, Dept of Public Works	City of Kansas City, MO
William Koehrer	Director of Public Works and Highway Engineer	Jefferson CO, MO
Bill Stone	Rural ITS Coordinator	Missouri DOT
Jarrod Paul	Traffic Engineer	Missouri DOT
Keith Gates	IDEA Project Manager	TRB
Mike Geisel	Director, Dept of Public Works	City of Chesterfield, MO
Dennis Bice	Director, Community Relations	St. Louis County; Missouri
Les Crews	Asst. Chief	Chesterfield, MO Fire Protection District
Ed Boselly	President	Weather Solutions Group
Craig Holan	Engineer	Crawford Bunte Brammeier
David Kniepkamp	President	Kniepkamp Engineering, Inc.

APPENDIX C-2. ITS – 79 Project Panel Meeting Agenda

9:15 – 9:30	Introductions
9:30 – 10:00	Project Overview
10:00 – 10:15	Review of Tasks
10:15 – 10:25	Break
10:25 – 12:00	Discussion of Tasks
12:00 – 1:00	Lunch
1:00 – 2:20	Discussion of Tasks
2:20-2:30	Break
2:30 – 3:00	Issues
3:00 – 3:15	Meeting Summary
3:15	Adjourn