OKLAHOMA TRANSPORTATION CENTER

ECONOMIC ENHANCEMENT THROUGH INFRASTRUCTURE STEWARDSHIP

DECISION SUPPORT SYSTEM FOR ROAD CLOSURES IN FLASH FLOOD EMERGENCIES

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16. ABSTRACT

Among all the natural hazards, flash flood ranks as the No. 1 weather-related killer in U.S. More than half of the deaths in flash flood are due to drowning victims in a traffic environment. So road closure is critical to save lives from flash floods. Unfortunately, the current static roadside TADD (Turn Around Don't Drown) signs simply could not draw enough attention from travelers.

In this project, we develop a novel decision support system (DSS) to predict the roads in threats, remotely turn on TADD Red flash lights to close the roads to dangerous sections in flash flood emergencies. The DSS will help Oklahoma Department of Transportation (ODOT) and Oklahoma Department of Emergency Management (OEM) to make prompt and effective decisions to mitigate the risk of flash flood.

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SI (METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units

Symbol	When you know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	25.40	millimeters	mm
ft	feet	0.3048	meters	m
yd	yards	0.9144	meters	m
mi	miles	1.609	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm
ft^2	square feet	0.0929	square meters	m^2
yd^2	square yards	0.8361	square meters	m^2
ac	acres	0.4047	hectares	ha
mi^2	square miles	2.590	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0283	cubic meters	m^3
yd^3	cubic yards	0.7645	cubic meters	m^3
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.4536	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	degrees Fahrenheit	(°F-32)/1.8	degrees Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.448	Newtons	N
lbf/in^2	poundforce per square inch	6.895	kilopascals	kPa

Approximate Conversions from SI Units

Symbol	When you know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.0394	inches	in
m	meters	3.281	feet	ft
m	meters	1.094	yards	yd
km	kilometers	0.6214	miles	mi
		AREA		
mm^2	square millimeters	0.00155	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.196	square yards	yd^2
ha	hectares	2.471	acres	ac
km^2	square kilometers	0.3861	square miles	mi^2
		VOLUME		
mL	milliliters	0.0338	fluid ounces	fl oz
L	liters	0.2642	gallons	gal
m^3	cubic meters	35.315	cubic feet	ft^3
m^3	cubic meters	1.308	cubic yards	yd^3
		MASS		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.1023	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	degrees Celsius	9/5+32	degrees Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	Newtons	0.2248	poundforce	lbf
kPa	kilopascals	0.1450	poundforce per square inch	lbf/in^2

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DECISION SUPPORT SYSTEMS FOR ROAD CLOSURES IN FLASH FLOOD EMERGENCIES

Final Report

June 30, 2013

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Among all the natural hazards, flash flood ranks as the No. 1 weather-related killer in U.S. According to a recent National Weather Service Report, based on a national 30-year average (1977-2006), more people were killed yearly by floods (99 on average) than by lightning (61), tornadoes (54), or hurricanes (49).[2] The southwestern U.S. (including Oklahoma) is especially dangerous for both people and vehicles encountering the sudden onslaught of water from isolated thunderstorms.

Road closure is critical to save lives from flash floods. More than half of the deaths in flash flood are due to drowning victims in a traffic environment. People tend to underestimate the danger (depth and speed) of flash flood compared with other natural hazards (e.g. hurricanes, tornados, and wild fires). If moving swiftly, water of six-inches deep can sweep people off their feet, and as little as two feet of water can be enough to carry away most SUV-sized vehicles [1]. Unfortunately, not everyone truly understands the threats until it is too late. Most flash flood victims are swept away while entrapped in a vehicle or outside the vehicle seeking safety from flood waters.

Unfortunately, the current static roadside TADD (Turn Around Don't Drown) signs simply could not draw enough attention from travelers, as this roadside signage is permanently fixed at potential flood zones. These static signs are hardly visible at night, when flash floods become even more dangerous. So, even though some people are aware of the severe consequences of floods, it might be too late for them to response due to the lack of instant road signals or road closure.

Flash floods provide a very short time window for authorities to respond the threats. Flash flood happens 3 to 6 hours after the prediction is issued. In such a short period, emergency management resources are stretched to the limit to evacuate affected communities and close roads to dangerous areas. Even though today's emergency management officers have access to real-time weather data through OK-FIRST (http://okfirst.mesonet.org/about.php) and GR2Analyst (http://www.grlevelx.com/gr2analyst/), the decision making process is still manual and heavily dependent on the officer's own experience. Such valuable experience may take a relatively long time for new officers to accumulate. With many current officers getting close to retirement age, a computer system that provides a quick response and effective decision support system has the potential to save many lives in flash flood emergencies. Unfortunately, such a support system is not currently available in the United States.

In this project, we develop a novel decision support system (DSS) to predict the roads in threats, remotely turn on TADD Red flash lights to close the roads to dangerous sections in flash flood emergencies. The DSS will help Oklahoma Department of Transportation (ODOT) and Oklahoma Department of Emergency Management (OEM) make prompt and effective decisions to mitigate the risk of flash flood.

CHAPTER 1 INTRODUCTION

1.1 Threats of Flash Floods

Floods are among the most common and widespread natural disasters. According to US/National Weather Service 30-year statistics, 127 people lose their lives in floods annually, with more than $2 billion property damage averaging (NCDC 2008). As the No. 1 weather-related killer in USA, flash floods usually result from intense storms within a brief period with little or no warning. Flash floods occur in all 50 states, especially the southwestern and Southern U.S. (including Oklahoma) due to their high frequency of thunderstorms and hurricanes.

In Oklahoma, flash floods are listed as the second worst hazard after tornado due to its dominate clay soil type and hilly topography in eastern Oklahoma. Cities and residential areas are even more vulnerable with paved or concrete surfaces. Here we list four severe historical floods in Oklahoma:

- May 26-27, 1984, rainfall of over 15 inches pounded the Tulsa city overnight, resulted in 14 deaths, arguably the most significant urban flash flood in Oklahoma history.
- May 8, 1993, Oklahoma City, Flash Floods on Twin, Brock, and Lighting Creeks claimed 4 deaths and over 2,700 homes were damaged.
- August 19, 2007, the heavy rainfall brought by the Tropic Storm Erin caused widespread flash floods in central Oklahoma with 9 fatalities. Most of the fatalities were directly involved with transportations. Two drivers drowned in Fort Cobb and Kingfisher, and three others were found dead after a flood-related automobile accident near Carnegie. Another automobile accident fatality took place in Okmulgee County, when a car became stranded on an section of highway as the road beneath it washed away.
- June 13, 2010, severe thunderstorms ripped through Oklahoma and dumped 10” of rain across the Oklahoma City area within 5 hours, triggering vicious flash floods that caused 136 people injured, roads and cars submerged, numerous homes and business buildings destroyed. A state of emergency has been declared in 59 of Oklahoma's 77 counties. Of the 200 destroyed homes, only a handful carried government flood insurance, because only 2% of the homes were located in areas classified as federal flood zones.

Statistically, more than half of all flash flood fatalities involve vehicles according to US/National Weather Service. Flash floods pose severe threats to traffic, due to the following facts:

- Many flash floods occur at night when flooded roads are more difficult to see;
- Flood waters can erode roadbed creating unsafe driving conditions;
- Driving through water causes vehicles to hydroplane and lose contact with road surface;
- Just 2 feet of flooding water can float most vehicles;
- Six inches deep fast-moving flooding water can knock down pedestrians.

1.2 Existing DSS for Flash Floods

Maaten et al. (2007) provided a review of existing decision support systems (DSSs) for flood event management. They concluded that despite the wide experience of using DSSs for long-term flood risk management, there is still a lack of experience with using DSSs for flood event management, especially for the flash flood events.

In Europe, a DSS for flood warning was proposed and to be implemented in three pilot areas located in the United Kingdom, Netherland, and France (FLOODSite, 2010). This DSS aimed to provide the relevant authorities with support in deciding on the evacuation procedure to follow. Another DSS has been scheduled for installation in the Liguria Region in Italy and the Greater Athens catchment in Greece (Abebe and Price, 2010).

In Asia, a DSS for flash flood risk management was implemented by three provinces in Thailand. The decision support environment allowed a number of "what-if" type questions to be asked and answered, thus, multiple decisions can be tried without having to deal with the different real life consequences (Kanbua1 and Khetchaturat, 2008).

In U.S., a DSS prototype was implemented to identify impacts that flooding would have on local communities and surrounding land use activities in the Missouri River Basin (Fulcher 1995). In Canada, a flood risk management DSS was implemented in the Red River Basin (Simonovic 2003).

To the best of our knowledge, most of the existing DSSs have been designed for long-term flood risk management, but not for real-time emergency management. We are not aware of any existing flood management DSSs that were built on the GIS, and were for automatic road closures when facing flood emergencies. This project is the first GIS-based DSS to assist with road closure decisions facing flood emergencies.

1.3 GIS and Emergency Management

Many problems that arise in emergency management are inherently spatial (Cova, 1999). As a computer-based system specifically designed to handle spatial data, Geographic Information System (GIS) has a natural fit to support emergency management. A GIS includes a wide range of functions to support the collection, maintenance, storage, analysis, output, and distribution of spatial data and information. These functions can support various tasks in all four steps of emergency management, including mitigation, preparedness, response, and recovery (Cova, 1999). Below is just a short list of GIS functions that can facilitate flash flood emergency management:

- **Visualization** allows emergency management officers to view both the spatial and non-spatial characteristics of a flash flooding event conveniently in a digital map format. Like pictures, maps can much more efficiently convey information than words and therefore offer a powerful means for officers to comprehend the complex situations of a flood.

- **Interactive map viewing** can help emergency management officers examine a flash flooding event at different scales and from different angles, which will allow them to quickly capture the characteristics of the spatial distribution of a disaster and evaluate its potential impacts.
- **Geocoding** can help officers easily pinpoint a location with its civil address or geographic coordinates.
- **Digital elevation model (DEM***)* supports a three-dimensional (3D) perspective view of the terrain of a region and can be used to evaluate the situations of a flooded area.
- **Overlay** analysis can be used to combine a predicted flooding zone with a road network layer and pinpoint specific road segments that will be influenced by the flood.

GIS recently has been adopted in a number of emergency management agencies to store, manage, analyze, and distribute disaster related information. For instance, the Federal Emergency Management Agency (FEMA) houses a Mapping and Analysis Center (MAC) which provides national level GIS support and coordination to the Agency and produces various mapping products related to disasters (see http://www.gismaps.fema.gov/).

In this project, we use GIS as a platform to integrate the outcomes from the flash flood predication module and information from a road network database of Oklahoma, and develop a prototype decision support system for making effective road closure decisions to prevent potential unnecessary life losses under the flash flood emergencies in Oklahoma.

1.4 Summary of Project Deliverables

The Decision Support Systems (DSS) developed in this project has four major components: Oklahoma Flash Flood Database, GIS-based Database, GIS-based User Interface, and Road Closure Control Module. Figure 1.1 shows the structural design of the DSS.

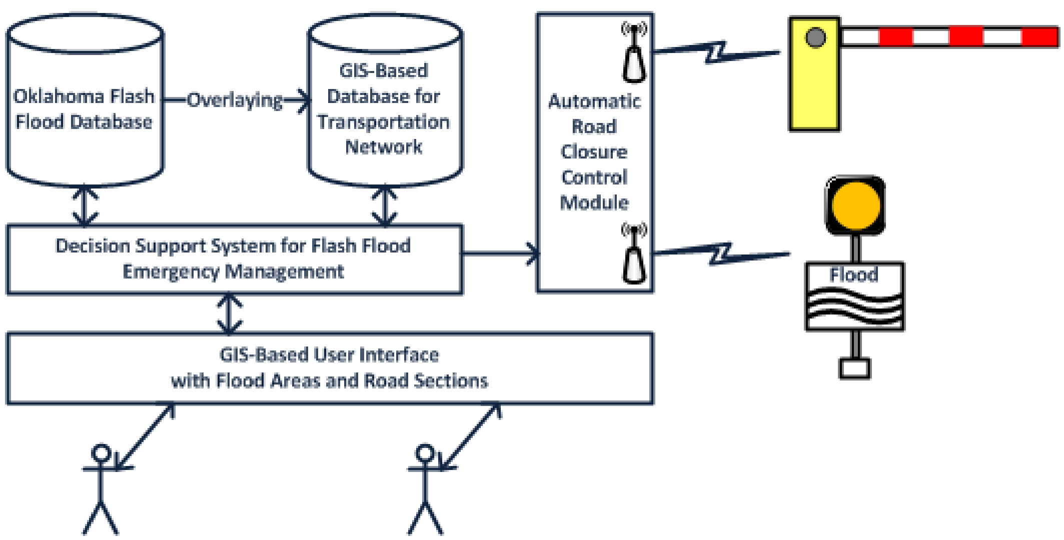

Figure 1.1: Structure of the Decision Support System

Oklahoma Flash Flood Database: In this project, we establish a user-friendly and research-quality database of flash floods for Oklahoma based the existing flash flood database by utilizing remote sensing images and leveraging a new SHAVE initiative (Severe Hazards Analysis and Verification Experiment). By utilizing remote sensing images and the SHAVE approaches, we aim to expand the flash flood databases from the existing United States Geological Survey (USGS) streamflow measurements and National Weather Service (NWS) observer reports. A comprehensive flash flood dataset in Oklahoma will improve our understanding of the spatiotemporal distribution of flash floods, better characterize the environments susceptible to extreme rainfall-producing storms, and ultimately refine tools to accurately detect and predict the occurrence of flash floods.

GIS-based Database: The second product of this project is an integrated GIS database which contains multiple data sets that are needed for emergency management officers to make well-informed decisions on road closures under flash flood emergency scenarios. This database stores and manages both spatial and non-spatial data related to this project. For the convenience of users, spatial data in various formats, such as digital elevation model (DEM) data in raster format, road network data represented in lines, predicted flooding zones in polygons, and TADD gates/lights locations in points, can be maintained in this GIS-based database. Non-spatial data sets, such as various demographic data, can be managed in the database as well. A GIS database template is developed to efficiently manage all these data sets. This database can be readily transferred to manage a similar database for a different region.

GIS-based User Interface: A custom GIS toolset is developed to help emergency management officers efficiently and effectively comprehend various aspects of a flash flood event, evaluate its impacts on the road network and local communities, and make timely decisions of road closures to prevent potential life losses. The toolset includes two groups of tools: visual analysis tools and spatial analysis tools. The visual analysis tools allow users to interactively visualize the data by combining different map layers (e.g., drape a predicated flooding zone over a population distribution layer) or examining the progress of a flash flood event with an animation approach. These tools will help emergency management officers gain better understanding of the concerned flash flooding event. The spatial analysis tools focus on identifying the road segments that will be affected by a flash flood, predicting when it will happen, and then determining which TADD gates/lights should be engaged to warn travelers. Overlay and buffer functions are used to combine the information from multiple input layers and derive the results for road closure suggestions.

Road Closure Control Module: The Road Closure Control Module sends signals to close the TADD gates or turn on the TADD red lights to keep travelers from entering the flooding areas once flash floods are predicted and road closure decisions are made. The TADD devices receive the control signal and other information from the DSS through their embedded radio modules. In the case that electricity is not available in the region, the TADD devices will be powered by solar panels and batteries.

CHAPTER 2 ESTABLISING OKLHOMA FLASH FLOOD DATABASE

There isn't a single source of information that holistically describes flash flooding. The intention of this task is to gather and unify information about flash flooding in the US from different sources and provide the database in three different formats (i.e., comma-delimited text file, GIS shapefile, and kmz file for Google Earth™) for a variety of users who may be interested in quick-and-easy plots, detailed spatial investigations, or statistical analysis using the raw data.

The database consists of the following three datasets:

- Streamflow measurements maintained by the US Geological Survey (USGS);
- Reports of flash flooding in the National Weather Service Storm Events Database,
- Public survey responses about flash flood impacts collected during the Severe Hazards Analysis and Verification Experiment (SHAVE).

The database assembled by the three datasets contains the inherent limitations associated with each one, yet the database combines the high-resolution details from SHAVE with the broad spatial coverage and event narratives from the NWS storm reports with the automated streamflow measurements from USGS to provide a more complete depiction of flash flooding across the US.

2.1 USGS Streamflow

USGS Dataset Description:

There are a total of 10,106 gauges with records dating from Jul 1927 through Sep 2010. Of these gauges, 3,490 have defined stage heights associated to stream bankfull conditions, warning, minor, moderate, and major flood stages (see Fig. 2.1). Each NWS office defines these thresholds in coordination with the local emergency management and stakeholder community. Flood stages are determined by impacts to lives and/or property. In many cases, in the more rural areas, a bankfull stage may be significantly lower than the flood warning stage.

To generate a flash flooding database from the automated reports, we identified all events that exceeded the pre-defined warning levels for each station. In total, there were 98,668 events that exceeded warning criteria at 2,948 of the gauges in the USGS archive. For each event, we provide the following information: USGS Gauge ID, latitude (decimal degrees), longitude (decimal degrees), start time (UTC) at which the flow exceeded the warning discharge threshold, end time (UTC) when the flow dropped below the warning threshold, peakflow magnitude ($m^3 s^{-1}$), peak time (UTC) at which peakflow occurred (UTC), and the difference between start time and peak time (in hours). This latter variable is a proxy for the time-to-rise and has been associated to the "flashiness" of the event.

Along with the events dataset, we supply metadata for each station containing static information about the USGS station's ID, latitude (decimal degrees), longitude (decimal degrees), hydrologic unit code (HUC), agency, degree of regulation, gauge name, drainage area (km^2), contributing drainage area (km^2), computed flows ($m^3\ s^{-1}$) for recurrence intervals for 2, 5, 10, 25, 50, 100, 200, and 500 yrs, and computed flows ($m^3\ s^{-1}$) for warning, minor, moderate, and major flooding. The degree of regulation field comes directly from USGS metadata for peakflow data and has values of either "Yes", "No", or "Undefined".

USGS Dataset Usage Considerations:

USGS streamflow measurements benefit from automation, suffer little in the way of human-induced subjectivity, and have high temporal resolution (generally 15 min) resulting in long-term, continuous records at each gauge site. These instruments, however, require electrical power and road access for communications, regular instrument maintenance, and manual measurements to empirically establish a rating curve (i.e., the relationship between the measured stage and the desired discharge). The costs associated with these requirements imply that automated streamflow measurements are not as common in small basins where flash floods are more likely to occur. Events are thus limited to those that occurred within a gauged basin.

Shapefiles of basin boundaries are helpful when studying the rainfall contributing to a USGS-gauged flash flooding event. This dataset is publicly available from the USGS at http://water.usgs.gov/lookup/getspatial?streamgagebasins. Information regarding the use of the USGS Instantaneous Data Archive (IDA) data, which is the source of the dataset described herein, is on the IDA web site at http://ida.water.usgs.gov/. Future updates (2013 and beyond) of this dataset will use the USGS Water Data for the Nation web site at http://waterdata.usgs.gov/, and information regarding the data use is available on it.

Each station's event data and metadata are grouped by first-level, two-digit hydrologic unit code (HUC; see Fig. 2), which represents a basin scale at the regional level. Use of kmz files yields quick-and-easy displays, while the provision of shapefiles enables more in-depth spatial analysis using GIS software. The comma-delimited files can be read by a number of commonly available statistical software packages. Some users may also wish to access the text files directly for use in originally developed code and scripts.

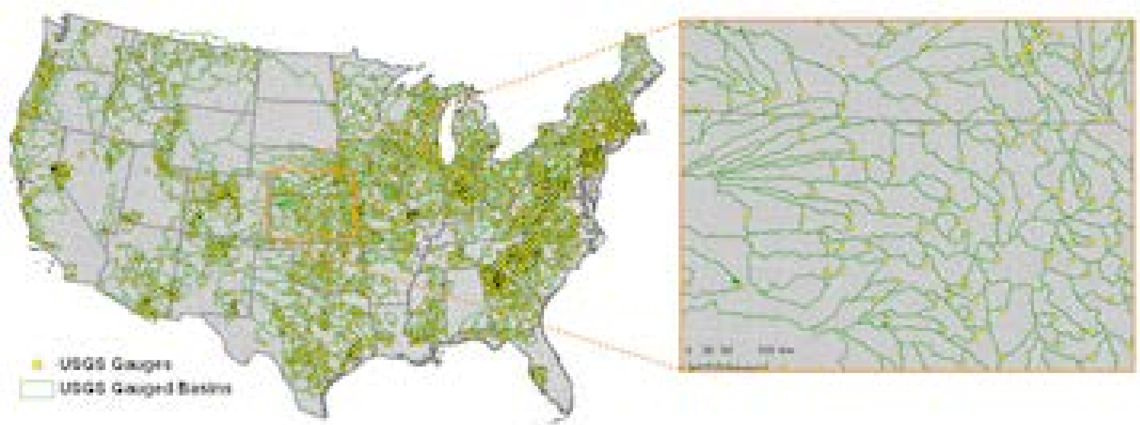

Figure 2.1: USGS Streamgauges

USGS streamgauges with defined stage heights associated to bankfull conditions, warning(action), minor, moderate, and major flooding. The basin boundaries are also shown and the shapefiles are available from the USGS.

2.2 NWS Storm Reports

NWS Dataset Description:

This dataset includes all 19,419 flash flooding reports recorded by the NWS across the US from Oct 2006 through Dec 2011 (see Fig. 2.2). Prior to Oct 2007, storm reports were nominally recorded by each county. Thus, a single data point in the dataset is representative of flash flooding somewhere within the larger county boundary. A transitional period existed from 2006-2007, and after 2007, a majority of reports are recorded by forecaster-drawn bounding polygons with as many as 8 vertices.

Each report, which according to the NWS Storm Data Directive must have posed a threat to life or property and had a report of moving water with a depth greater than 0.15 m (6 in) or more than 0.91 m (3 ft) of standing water, contains a unique ID, the three-letter abbreviation of the NWS forecast office (WFO) who reported the event, beginning and ending time of event (UTC), state, county, NWS region, direct/indirect fatalities and injuries (if applicable), a dollar estimate of property and crop damage (if applicable), details about the event including its cause (e.g., heavy rain), source of report (e.g., law enforcement), event and episode narratives, and vertex coordinates in decimal degrees of latitude and longitude as well as the range (mi) and azimuth (e.g., NE) from the nearest city.

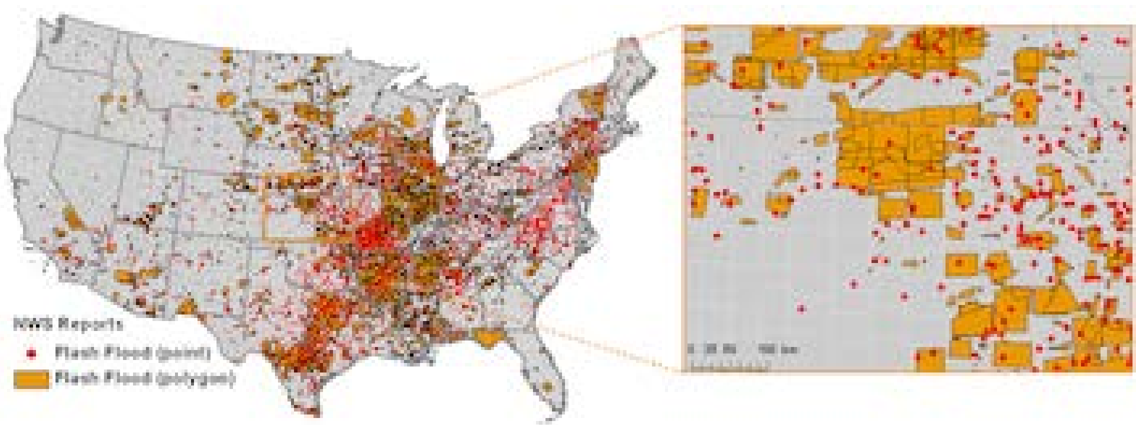

Figure 2.2: National Weather Service reports of flash flooding from 01 Oct 2006 to 31 Dec 2011 from the Stormdat program

NWS Dataset Usage considerations:

The NWS reports are recorded by operational forecasters who monitor their respective regions of responsibility across the US during all hours of the day, all days of the year. The reports can come from trained spotters, emergency management personnel, law enforcement, and the public. Big, high-impact events that may not have been reported in the USGS dataset are much more likely to be contained in this dataset. Users can assume that a suspect event (e.g., from a model forecast) that was not recorded in the NWS dataset either didn't occur or occurred in a sparsely populated region without reliable observers. When studying the rainfall for a specific event, considerations for the time and spatial displacement of the causative rainfall must be made.

Consistent with the USGS dataset, we segregated the NWS flash flooding reports into regional, two-digit HUC basins and also by point-based reports (representative of the county) versus the more specific bounding polygons. Some of the event narratives were too long to fit within the maximum allowable character fields in the kmz and shapefile formats. The full details are preserved in the comma-delimited text files.

2.3 SHAVE

SHAVE Dataset Description:

Flash flood data were added to the Severe Hazards Analysis and Verification Experiment during the summers of 2008-2010 (May through Aug). Overall, 9,369 reports were collected during SHAVE (see Fig. 2.3). Details obtained directly from the public through a questionnaire include the depth and movement of flood waters, lateral extent of water out of the stream, incidence of rescues and evacuations, start and end times of impacts, respondent-estimated frequency of event, and types of impacts. Entries often include detailed comments to assess the uncertainty and validity of the reports as well as to include other anecdotal responses that didn't readily fit into one of the survey questions. The SHAVE dataset was post-processed in order to better classify the impact types and to incorporate additional geographical attributes into each report, including land use, local upslope, contributing drainage area, compound topographic index, and population density (see Calianno et al., 2012 for details).

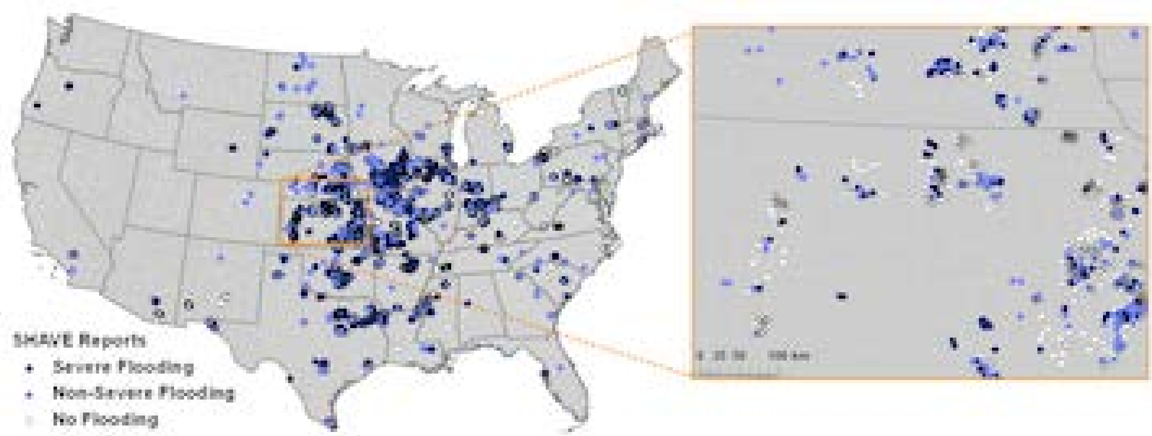

Figure 2.3: SHAVE reports of no flooding, non-severe flooding, and severe flooding obtained from the public during the summers of 2008-2010

SHAVE Dataset Usage Considerations:

This dataset differs significantly from the others in that it is experimental, storm-targeted, and point-based. The objective of the data collection was not to encapsulate all flash floods occurring across the US during the experimental period, but rather focus on individual storm events and collect very detailed, high-resolution information. In the NWS and USGS datasets, users can assume that a missing report can typically be considered as a non-event, unless there were no observers nearby or there was an instrument or communications failure. The same assumption does not apply to the SHAVE dataset. We have thus recorded and supplied all instances of reports of "no flooding" in the dataset. In fact, this class comprises 73% of the total reports. These reports must be used when determining when an event (e.g., from a model forecast) did not occur. Users are encouraged to read the SHAVE metadata file to access additional details about each field in the reports; all of which are available in the kmz, shapefile, and comma-delimited text formats for each 2-digit HUC.

2.4 Summary of Results

The outcome from this task is now available via the FLASH (Flooded Locations And Simulated Hydrographs) project website and the FLASH Flood Observation Database for the nation can be downloaded at http://www.nssl.noaa.gov/projects/flash/database_2011v1.php

The database includes:

- streamflow measurements maintained by the US Geological Survey (USGS);
- reports of flash flooding in the National Weather Service Storm Events Database;
- public survey responses about flash flood impacts collected during the Severe Hazards Analysis and Verification Experiment (SHAVE).

To provide a more complete depiction of flash flooding across the US, the assembled database combines the high-resolution details from SHAVE, the broad spatial coverage and event narratives from the NWS storm reports, and the automated streamflow measurements from USGS.

CHAPTER 3 FLASH FLOOD PREDICTION SYSTEM

In order to develop the Flash Flood Prediction System for Oklahoma, we set up the distributed CREST hydrological model (Wang et al. 2011) in a broader area: the Arkansas & Red River basins, which enclose the Oklahoma. After model benchmarking, a semi-operational flash flood prediction system is available at http://flash.ou.edu/. Below are detail summary on the Distributed Hydrological Model, the study area; and the data.

3.1 Distributed Coupled Routing and Excess Storage (CREST) Model

The project team at OU HyDROS Lab (http://hydro.ou.edu), together with collaborators at NASA Marshall and Goddard centers, have jointly developed the **C**oupled **R**outing and **E**xcess **ST**orage (CREST; Wang et al. 2011) distributed hydrological model. The CREST model has been used to simulate and forecast hydrometeorological variables such as streamflow, soil moisture, and actual evapotranspiration using input from gridded meteorological forcing fields, nominally rainfall observed from the Tropical Rainfall Measurement Missions (TRMM) [http://eos.ou.edu; 19, 20], as shown at (http://eos.ou.edu). The CREST model has been used to continually simulate streamflow, soil moisture, actual ET and other hydrological variables with input from gridded meteorological forcing fields at global and regional scales (http://eos.ou.edu; Khan et al. 2011a, Khan et al. 2011b). This model has also been validated globally using gauge data from a 10-year flood event database, Global River Data Centre and NASA Global land Data Assimilation (Wu et al. 2011, Xue et al. 2011). The CREST model structure and calibration technique is briefly discussed below.

CREST model structure:

Comparing to the previous v1.6, the framework of CREST v2.0 was redesigned to better suit distributed hydrological modeling and data management. As shown in Fig. 3.1, the modularity in design enables the CREST v2.0 more flexibly to I/O spatially distributed data and more conveniently to include sequential data assimilation, optimization tools, and parallelization of tasks. The modular structure consists of a main program and a series of independent subroutines, called modules. Each module deals with a specific feature of the hydrologic process that is to be simulated, such as evapotranspiration, infiltration, interaction with groundwater, generation of surface flows, and routing from cell-to-cell.

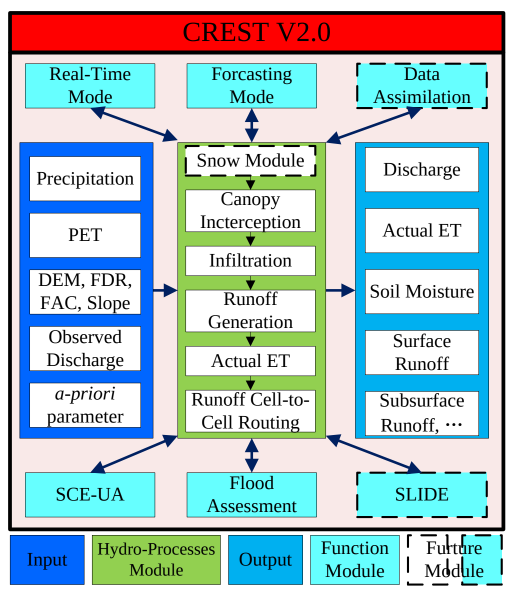

Figure 3.1: Modular Design Framework of CREST v2.0

CREST model calibration strategy:

SCE-UA (Shuffled Complex Evolution method developed at The University of Arizona) has shown promise as an effective and efficient global optimization technique for calibrating hydrological models (Duan et al. 1994), especially for high-dimensional distributed hydrological models. Thus, we have embedded the SCE-UA into the CREST v2.0, in addition to the existing ARS, as the default optimization strategy to improve the performance of the CREST. In CREST v2.0, the 18 parameters were classified into physical parameters, conceptual parameters and adjustment parameters.

The model shows a varying degree of sensitivity to different physically-based or conceptual-type parameters. The *a-priori* values of the physical parameters are now derived from global geomorphological characteristics (e.g. soil types and depth, topography, land cover, etc.). Provided the existence of rainfall-runoff observations on basins, the model can be calibrated by adjusting the multipliers of the spatially variable a-priori parameters with the automated optimization algorithms (Vrugt et al. 2005, Winsemius et al. 2009). Finally, some of physically-based parameters can be transferred to adjacent basins using the 'hydrologic similarity' approach recommended by previous studies (Koren et al. 2003). This effectively reduces the dimensionality of the parameter space and enables more efficient model calibration.

In addition, we have also adopted a cascading calibration method using the SCE-UA algorithm to calibrate the CREST model from the upstream interior basins to the outlet of the parent basins automatically. This method can utilize all the available data to reduce the uncertainty of the parameters in the CREST model, resulting in the most accurate performance.

3.2 Study Area

The Arkansas-Red Basin River Forecast Center (ABRFC) issues operational products. These basins are preferred for study because of the diversity of precipitation and terrain as well as the location and number of observed streamflow gauges (see Fig. 3.2). Additionally, ABRFC and corresponding Weather Forecast Offices (WFOs) were early adopters of efforts to catalog flooding through the use of polygon area extents, which will provide an additional form of validation for land surface water extent estimates.

The basins are diverse in terms of precipitation amounts with the 219 mm average annual precipitation minimum occurring in the west while gradually increasing eastward to an average annual maximum of 1797 mm. The precipitation over the basin comes heavy rainfall events during the warm season driven primarily from mesoscale convective complexes, localized intense convection and land-falling tropical systems. Elevation follows a decreasing gradient from west to east with the highest elevations of 4225 m occurring on the western edge of ABRFC in the Rocky Mountains. Snowmelt in the Rocky Mountains feeds the headwaters of the Arkansas and Red rivers. The elevation minimum of 60 m occurs in the eastern portion of the basin as it drains into the Mississippi River. The combined contributing drainage area for the basin is 544,006 km^2.

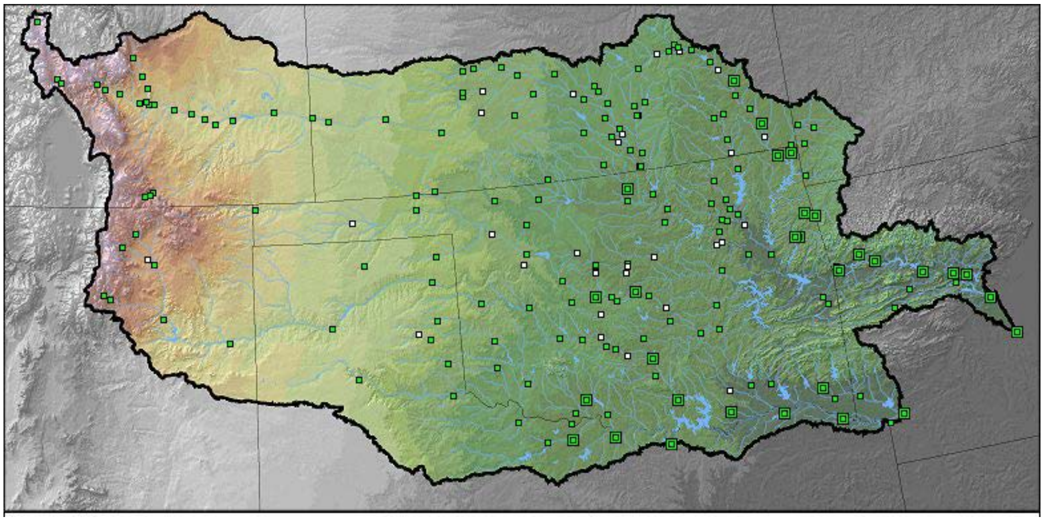

Figure 3.2: The ABRFC River Basin and Its Streamflow Stations

3.3 Data Used in this study

The United States Geologic Survey maintains and operates a collection of 371 stream gauges in the ABRFC region. The annual peak flow values for each stream gauge are also flagged according to whether the USGS believes the flow value to have some contribution from snowmelt runoff or regulation. There are 50 gauges in the region which are not flagged as having contributions due to snowmelt or regulation making them ideal candidates for hydrologic modeling efforts focusing on natural rainfall. The gauges are diverse in terms of contributing basin drainage area with individual gauges ranging from 36.78 km2 to 4853.64 km2 providing spread across the range of scales from flash flood to river flood.

The forcing data is the 1-km every 5-minute radar QPE products from OU/NSSL: http://nmq.ou.edu/.

3.4 Analysis of Results

In this task, the OU team focused on the development of the flash flood prediction system. It will be used to evaluate the performance of the system at a later stage. The below briefly summarizes study area operation and several site-based evaluation results.

a) Streamflow Simulation from the March 2012 Thunder Storm and Tornado Event

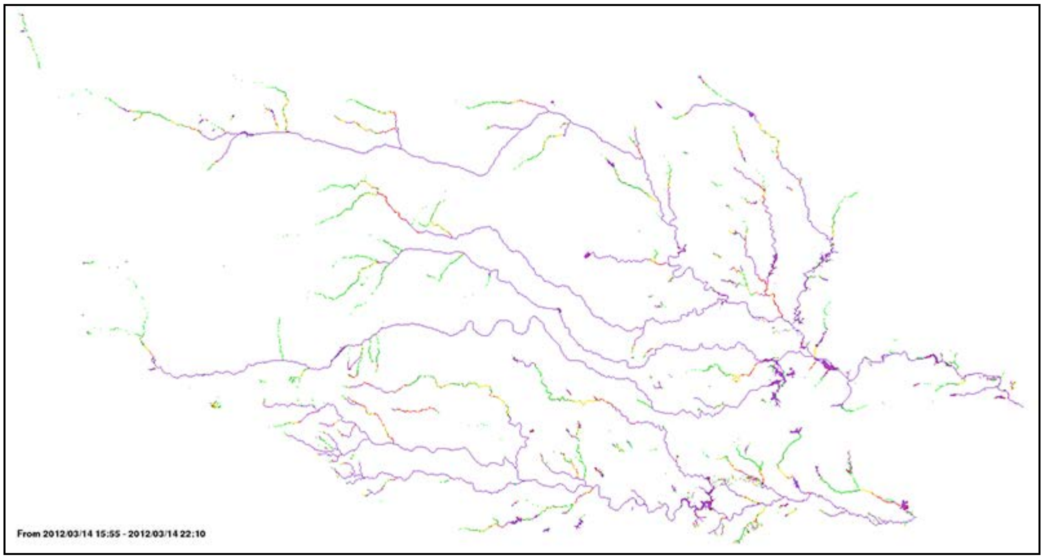

Figure 3.3: Streamflow Simulation

This study also investigates a method to supply uncertainty estimates to flood predictions based on deterministic river basin response simulations from an uncalibrated, distributed hydrological model. A 15-year radar rainfall archive was used to run a hydrological model, thus providing a time series of simulated flows at every model grid cell (see Fig. 3.3). At grid cells corresponding to streamgauge locations, the time periods at which observed streamflow exceeded pre-computed observed flow frequency thresholds (e.g. 2-, 5-, 10-year return period flows) were identified. The distributions of simulated flows within (i.e. flooding at the respective frequency threshold) and outside (non-flooding at the respective frequency) these time intervals were then computed. The accuracy of the method is evaluated during an independent validation period where probabilities of flood >0.9 during flood cases are predicted more than 90% of the time, while probabilities of flood equal to zero occurred 75% of the time during non-flood cases.

b) Selected USGS Streamflow Stations' Results

In order to quantitatively analyze the performance of simulated streamflow against observed streamflow, the CREST model parameters are calibrated using the automatic calibration method (SCE-UA) by maximizing the NSCE value between the simulated and observed daily streamflow. Fig. 3.4 and 3.5 compares the simulated streamflow with the observed streamflow at hourly scales.

Fig. 3.4 and 3.5 show that general agreement exists between the observed and simulated streamflow. As summarized in Tables 3.1 and 3.2, the statistical indices show that there is very good agreement between the simulated and observed hydrographs in the calibration period, and reasonable simulations occurred in the validation period as well. Based on the criteria of the statistical indices in Moriasi et al. (2007), the model calibration and results validation based on CC values indicate that the CREST model is well benchmarked by the in situ data at the hourly time scale, so it can be used to for flash flood prediction.

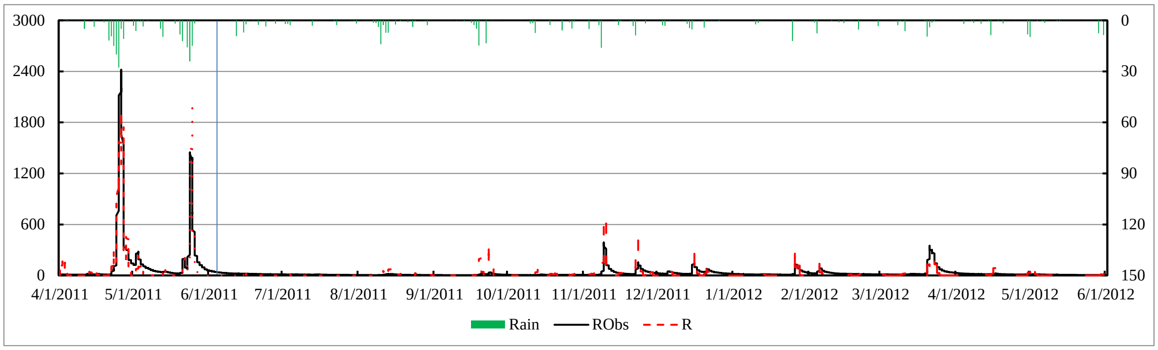

Figure 3.4: Evaluation of Model Flood Prediction

Table 3.1: Comparison of observed and simulated streamflow under calibration and validation period for Station 07196500

Calibration		Validation	
NSCE	0.86	NSCE	0.01
Bias(%)	-18.25	Bias(%)	-32.69
CC	0.93	CC	0.73
RMSE	139.15	RMSE	33.24

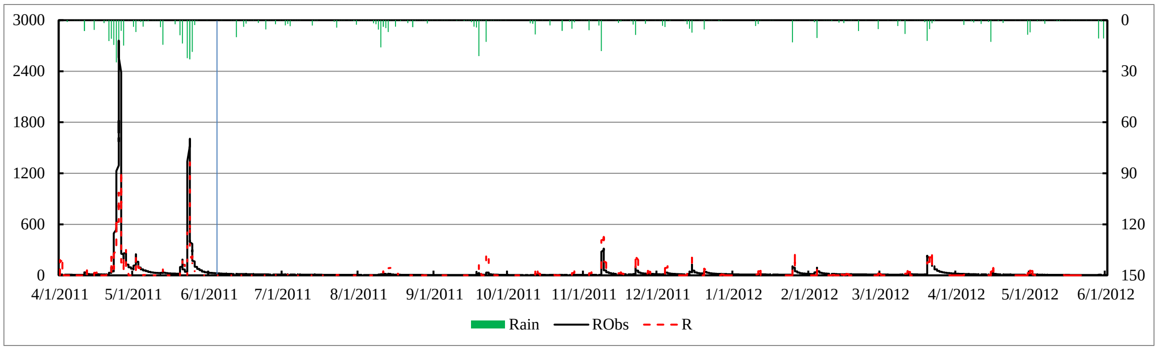

Figure 3.5: Evaluation of Model Flood Prediction

Table 3.2: Comparison of observed and simulated streamflow under calibration and validation period for Station 07195500

Calibration		Validation	
NSCE	0.64	NSCE	-0.78
Bias(%)	-35.97	Bias(%)	-26.46
CC	0.84	CC	0.7
RMSE	189.21	RMSE	26.15

HAPTER 4 GIS DATABASE FOR FLASH FLOOD EMERGENCIES

4.1 Introduction

A geographic information system (GIS) database is established in this project to support road closure decisions under flash flood emergencies. An Esri ArcGIS 10 geodatabase file is used to store and manage various data sets (including both spatial and non-spatial data) that were collected and generated in this project. Major data sets in this GIS database include the digital elevation data (in raster format) covering the entire territory of Oklahoma at a 1/3 arc-second (about 10 meters) resolution level, Oklahoma road networks (both primary and secondary roads) as line features, various levels of administrative areas (e.g., state, county, U.S. census tract and block group) as polygons, and the U.S. flash flood observation data for Oklahoma. Non-spatial data sets, such as various demographic data, are also maintained in the database. The ArcGIS geodatabase file provides an integrated and efficient database environment to manage all these data sets. The database is used to support geographic visualization and spatial analysis related to road closure decisions under flash flood scenarios.

Various data sets that could be used to support making road closure decisions under flash flood emergencies were identified, located, and acquired in this project. The data collection effort includes both spatial and non-spatial data that could be used in the system. All the data sets related to the flash flood emergency project were stored and/or managed in an Esri ArcGIS 10 geodatabase file, which is able to handle various data formats, including spatial data in both raster and vector formats, and non-spatial data in tables.

Figure 4.1 is a screenshot of the ArcGIS 10 geodatabase file established in this project and shows how all the data sets are stored and organized in the database. As shown in the figure, the spatial data sets in this project are managed with two types of ArcGIS datasets, which are Feature Datasets and Raster Mosaic Datasets.

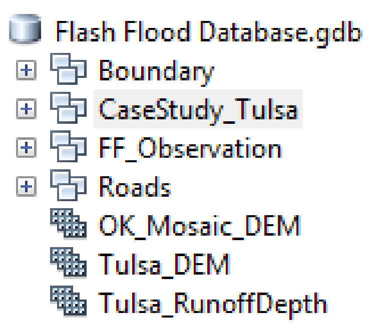

Figure 4.1: The Structure of the Flash Flood

4.2 Feature Datasets

According to Esri's definition, an ArcGIS Feature Dataset is a collection of feature classes as well as other types of vector datasets such as feature-linked annotations, network dataset and topologies. In this project, features datasets are used to manage vector spatial data such as administrative boundaries and roads. Each feature dataset may contain multiple feature classes and all feature classes in the same feature dataset share the same spatial references, including spatial extend and map projection. Four feature datasets were established to store four types of feature classes in this project:

- The "Boundary" feature dataset contains four feature classes, each representing the geographic boundaries of a certain level of legal entities (note: "A legal entity is a geographic entity whose boundaries, name, origin, and area description result from charters, laws, treaties, or other administrative or governmental action." (U.S. Census Bureau, 2012)). Figure 4.2 shows the spatial relationship of the four feature classes which are the geographic boundaries of the state of Oklahoma, counties, census tracts and block groups in Oklahoma. Most of the data in this feature dataset were acquired from the 2010 Tiger/Line Shapefiles (http://www.census.gov/geo/www/tiger) released by the U.S. Census Bureau. The demographic attribute data including total population and population of racial groups were collected using 2010 American Fact Finder (also supported by the U.S. Census Bureau) and joined to the feature classes.

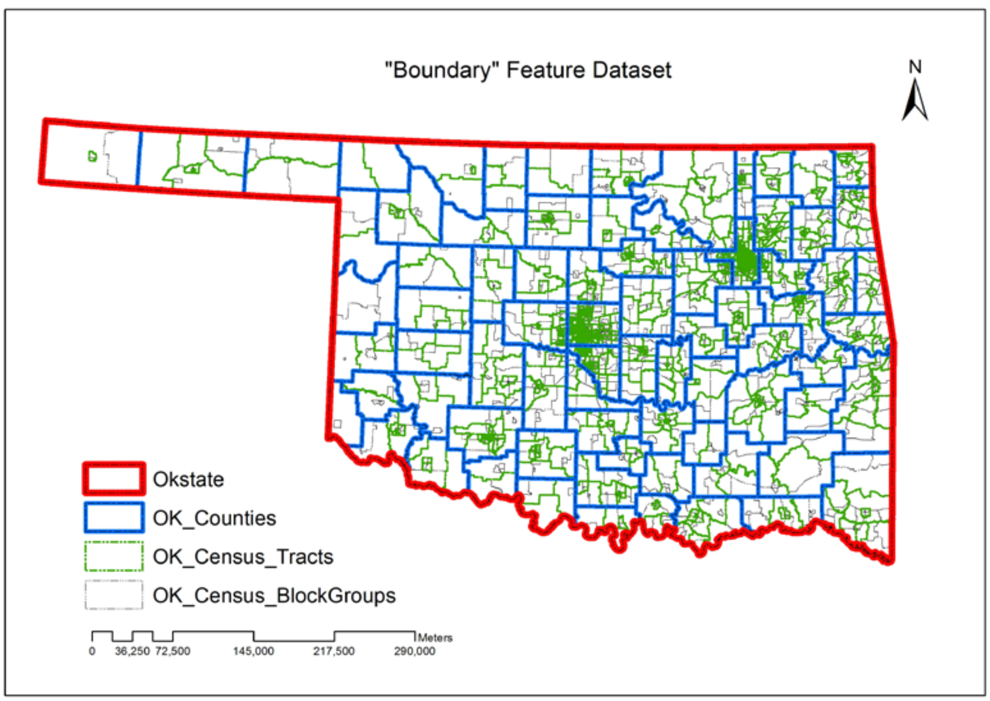

Figure 4.2: "Boundary" Feature Dataset

- The "FF_Observation" feature dataset consists of 1) Oklahoma stream flow measurements operated and maintained by the U.S. Geological Survey (USGS), 2) reports of flash flooding events in Oklahoma recorded in the National Weather Service (NWS) Storm Events Database, and 3) public survey of responses about the impacts of flash floods in Oklahoma collected by the Severe Hazards Analysis and Verification Experiment (SHAVE) project. The data in this feature dataset were downloaded from the FLASH Flood Observation Database website (http://www.nssl.noaa.gov/projects/flash/database_2011v1.php). This dataset is included in the GIS database because it is one of the important sources to examine the influence of the historical flash flood events on local communities and residents.

- The "Roads" feature dataset is comprised of two linear feature classes representing two road networks in Oklahoma at different levels of details. The "Major_RITA2012" feature class is obtained from the National Transportation Atlas Database (http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_atlas_database/2012/index.html) provided by the Bureau of Transportation Statistics and the Research and Innovative technology Administration in 2012. This major road network contains all Oklahoma principle arterials and rural minor arterials defined in the highway function classes (http://www.fhwa.dot.gov/planning/processes/tools/nhpn/). The "Secondary_Tiger2012" feature class is a much more detailed road network，including secondary road, local neighborhood road, rural road, city street, vehicular trail, ramp, service drive, walkway, stairway, private road for service vehicles, parking lot road, and bike path (see definitions at http://www.census.gov/geo/www/tiger/tgrshp2009/TGRSHP09AF.pdf). This feature class was obtained from the 2012 Tiger/Line Shapefiles database (http://www.census.gov/cgi-bin/geo/shapefiles2012/main) released by the U.S. Census Bureau. Figure 3 shows the spatial relationship of the two feature classes.

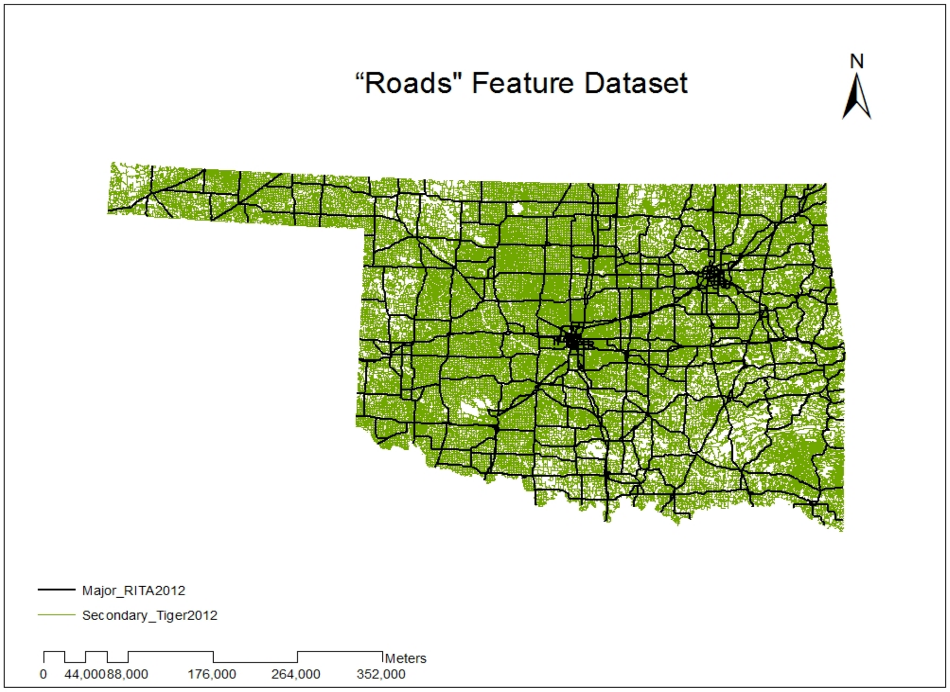

Figure 4.3: "Roads" Feature

- The "Tulsa" feature dataset contains a variety of geographic data in Tulsa County (see Figure 4.4), which is used as a case study area in this project to test-run the decision support system. This dataset contains five feature classes. The "Tulsa_County" feature class is the geographic boundary of Tulsa County, which is a subset of the "OK_Counties" feature class in the "Boundary" feature dataset. The "MajorRITA2012_Tulsa" and "SecondaryTiger2012_Tulsa" are the subsets of the "Major_RITA2012"and "Secondary_Tiger2012" in the "Roads" feature dataset respectively. They are created by clipping the two "Roads" feature classes by the geographic boundary of Tulsa County. "SigLight_Sample" is a point feature class representing the locations of the "Turn Around Don't Drown (TADD)" signal lights. As the real TADD location data is not readily available at the moment, a set of hypothetical locations of TADD signal lights are generated and used in this feature class. The "WaterLine" feature class, acquired from the 2012 Tiger/Line Shapefiles database, represents linear hydrographies in Tulsa County. It is used to facilitate the visualization of streams locations and the comprehension of the areas threatened by flash floods.

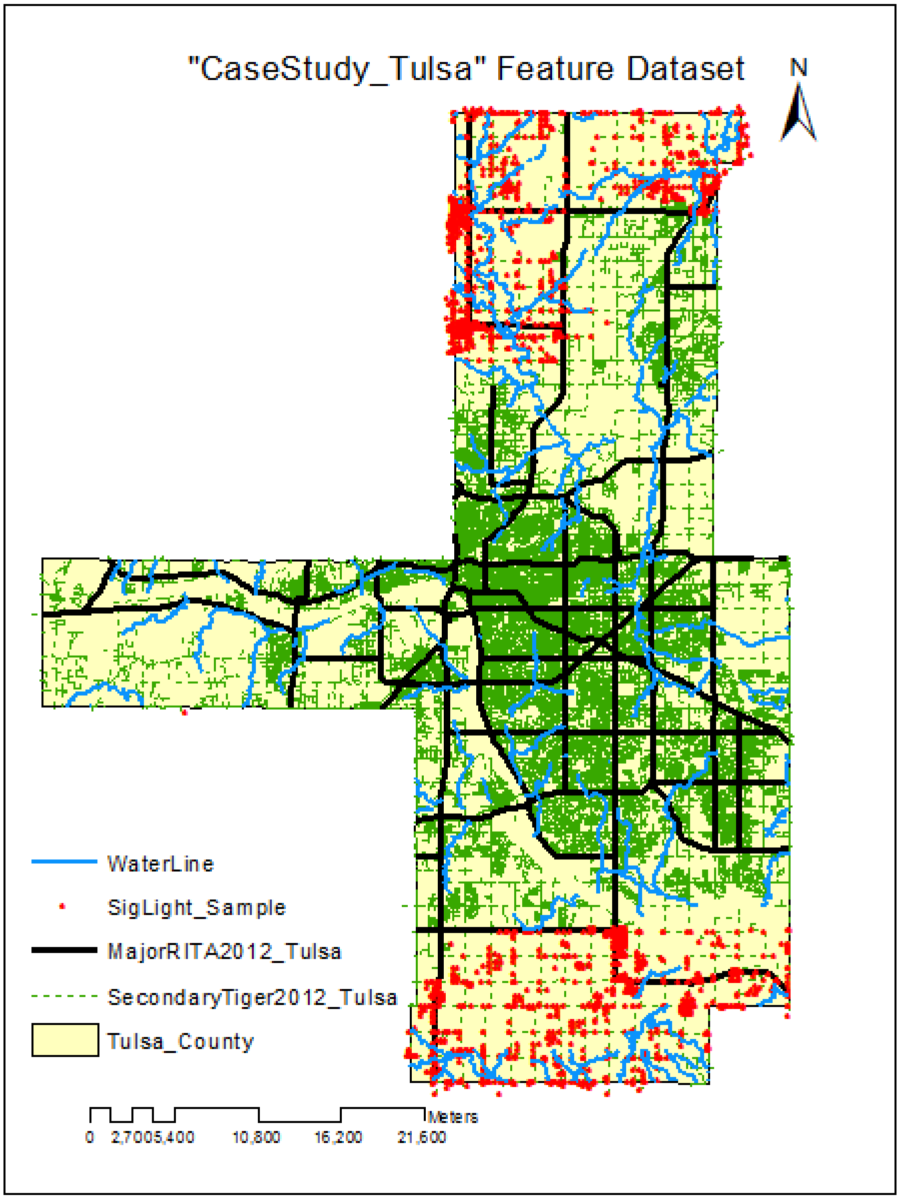

Figure 4.4: “CaseStudy_Tulsa” Feature

4.3 Raster Mosaic Datasets

In addition to the feature datasets, three raster mosaic datasets were established to manage raster datasets in the GIS database. According to Esri’s definition, a raster mosaic dataset is a data model used to organize a collection of raster datasets which will be stored as a catalog and viewed as a whole image (ArcGIS 10 Resource Center). The “OK_Mosaic_DEM” mosaic dataset is the terrain dataset created from 36 DEM tiles from the National Elevation Dataset (NED) maintained by the USGS (http://ned.usgs.gov). The mosaic terrain dataset provides a seamless terrain representation covering the entire territory of Oklahoma at a 1/3 arc-second (about 10-meter) resolution. The “Tulsa_DEM” dataset is a subset of the “OK_Mosaic_DEM” mosaic dataset which covers only the Tulsa County (Figure 4.5).

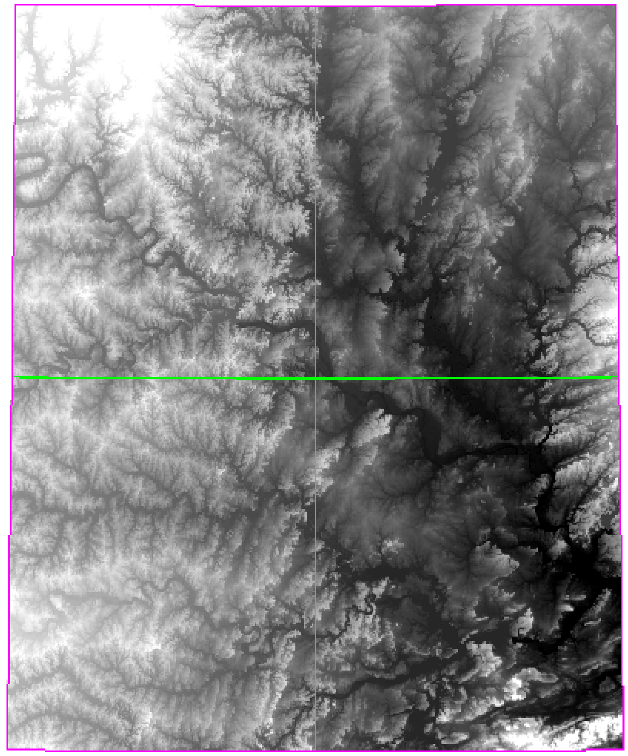

Figure 4.5: “Tulsa_DEM” Mosaic

Different from the previous two mosaic datasets, the “Tulsa_RunoffDepth” is a raster dataset that contains the outputs created by the flash flood prediction module. This dataset actually holds a collection of eight raster layers covering the same area – Tulsa County, but for different times. The eight raster layers represent the simulated flash flood surface water runoff depth in Tulsa County at a three-hour interval from UTC 06/14/2010 00:00:00 to 06/14/2010 21:00:00. A time field was added in the mosaic dataset’s attribute table to indicate the time for each raster layer. This dataset can support temporal visualization which shows the flash flood surface water runoff depth changes over time.

CHAPTER 5 DEVELOPING GIS-BASED USER INTERFACE

5.1 Custom GIS Interface

A custom GIS interface with add-in tools is developed in ArcGIS to help emergency management officers comprehend various aspects of a flash flood event, evaluate its impacts on the road network and local communities, and make important decisions of road closures to prevent potential life losses. The toolset can identify road segments that are under potential threats during a flash flood event and be used to make road closure suggestions to emergency management officers to prevent potential life losses.

The custom toolset was developed with ArcObjects in the .NET development environment. ArcObjects is a library of Component Object Model (COM) components which build the basis of ArcGIS. It can be used to customize the ArcGIS Desktop applications, or to build standalone GIS applications. In this project, the add-in tool approach with ArcObjects was chosen to create the custom application tools.

Two add-in tools were developed to support visual and spatial analysis for road closure decisions under flash flood emergency scenarios:

- A visual analysis add-in tool implements several methods to help emergency officers comprehend the potential impacts of a flash flood event. These methods include interactive viewing of maps composed of different data layers (e.g., Oklahoma terrain layer, different levels of administrative boundaries, waterline and historical flash flood areas) to enhance the understanding of the characteristics and impacts of a flash flood event, and visualizing the development of a flash flood event over time using an animation approach;
- A TADD decision support add-in tool combines the predicted flash flood areas created from the flash flood prediction module and the road networks to identify roads leading to areas under potential flash flood threats and related TADD signal light to prevent vehicles from entering the areas.

These tools help emergency management officers gain better understanding of the concerned flash flooding event. The spatial analysis tools focus on identifying the road segments that are threatened by a flash flood and determining which TADD gates/lights should be engaged to warn travelers.

5.2 Visual Analysis Add-in Tool

Figure 5.1 is the screenshot of the interface of the visual analysis add-in tool. The components of this tool can be divided into three groups based on their main functions:

- The “Maps” tab controls the visibility of 11 map layers in the map view. The interface contains four groups of checkboxes. When the checkboxes under the “Administrative Boundaries” group are selected/deselected, the geographic extent of Oklahoma State, Counties, Census Tracts, and Census Block Groups will be shown/hidden in the map window. The checkboxes under “Road Networks” group control the visibility of the major/secondary road network in Oklahoma. The “Historical Flash Flood Events” group contains checkboxes that help viewers to browse the distribution of flash flood events reported by NWS, USGS and SHAVE. When the “National Elevation Data” checkbox is checked, the terrain layer of Oklahoma will be displayed in the map window.

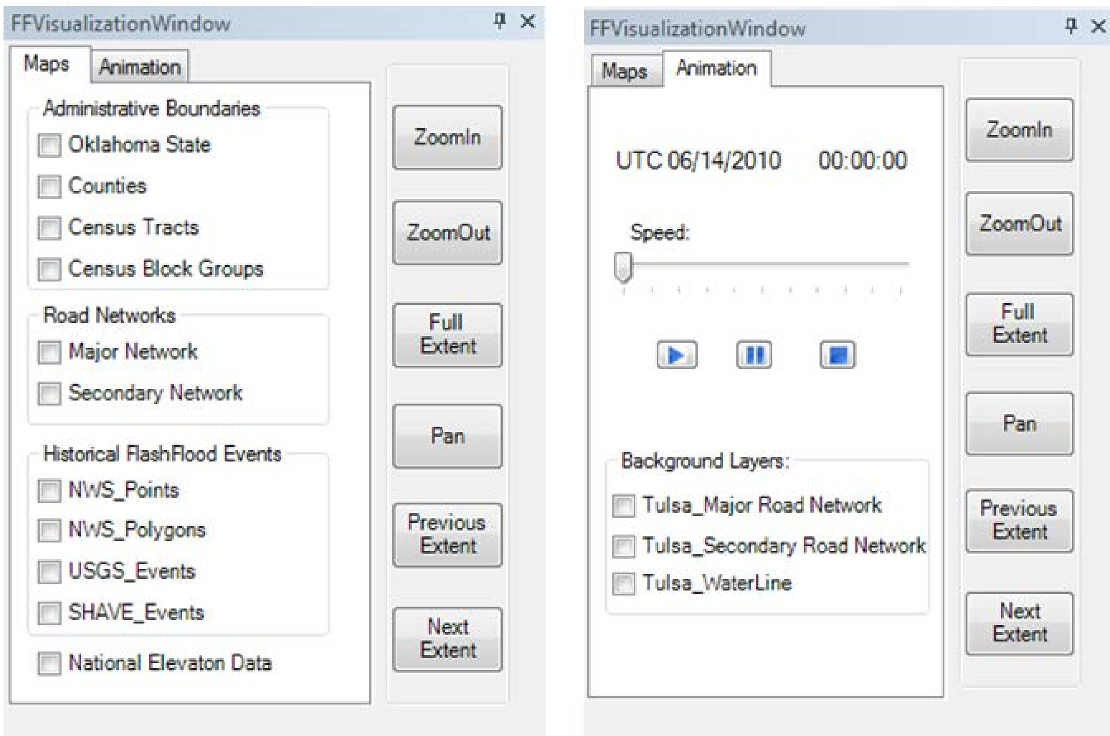

Figure 5.1: Interface of the Flash Flood Visual Analysis Add-in

- The “Animation” tab is used to visualize how a flash flood event dynamically develops through time. In this function, a collection of raster datasets reporting the changes of surface water runoff depths every three hours of a flash flood event occurred in the case study area (i.e., Tulsa County) on 06/14/2010. When the “start” button is clicked, the animation of the development will be displayed in the map window and the label on top of this tab will update with the corresponding timestamp. When the “Pause” or “Stop” button is clicked, the animation will be temporally paused or terminated. In addition, three map layers are provided as the background layers of the animation to help users gain a better understanding of the spatial distribution and impacts of the event. Click the checkboxes under the “Background Layers” group will change the visibility of the three layers.

- A group of buttons located on the right side of the interface control the scale and extent of the map layers displayed in the map window. With this group of buttons, users can zoom in and out on a map view, change the center of a map view with a mouse, and go back to the previous extent.

5.3 TADD Decision Support Add-in Tool

The TADD decision support add-in tool automatically loads in the predicted flash flood data, which is the output from the flash flood prediction module. In the demonstration case, a set of flash flood return period data, which contains 24 raster datasets representing the likelihood of the occurrence of flash flood events in Tulsa County at one hour interval from UTC 06/14/2010 00:00:00 AM to UTC06/14/2010 23:00:00PM, was used as the input to the tool. The tool uses the datasets at different times to delineate the potential flash flooding area at each time instance, and overlays the area with the road network to identify the road segments and related TADD signal lights that are under threat.

Figure 5.2 is a screenshots of the interface of the TADD decision support add-in tool. The whole process starts when users click the "Start" button. The system will display a "done" message every time when the process of a specific time layer has been completed. Two parameters can be set by users. The first one is the time interval, which controls how long the next flash flood prediction data will be loaded and processed after the previous one is finished. For example, if a user enters 30 in the time interval textbox, the flash flood prediction data of 06/14/2010 06:00:00 AM will not be processed until 30 seconds after the process of the flash flood prediction data of 06/14/2010 05:00:00 AM has completed. The other parameter allows users to set the directory and prefix of the results so the users can easily locate results.

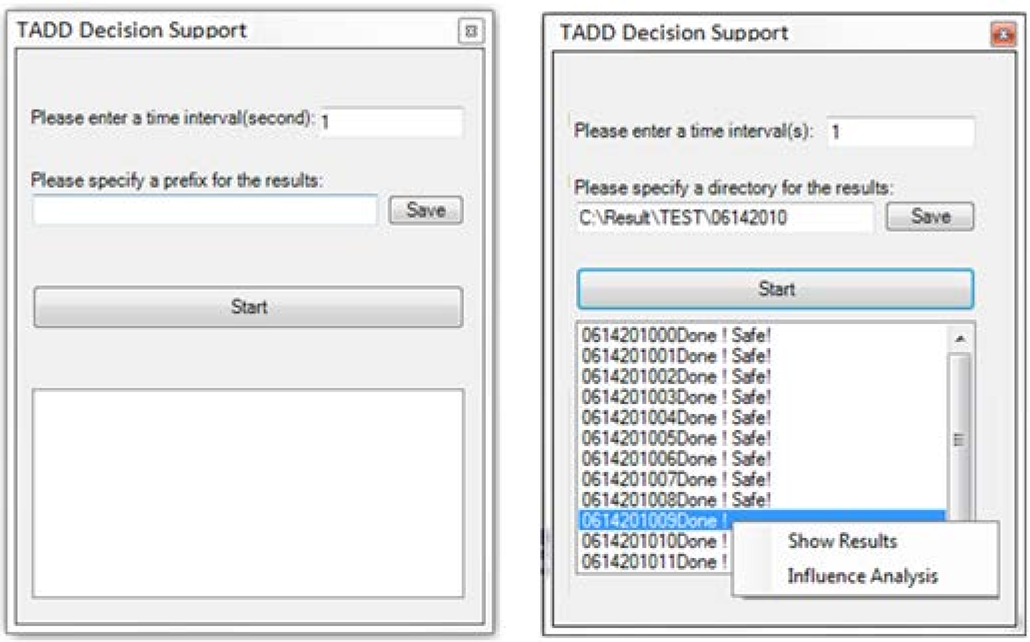

Figure 5.2: Interface of the TADD Decision Support Add-in

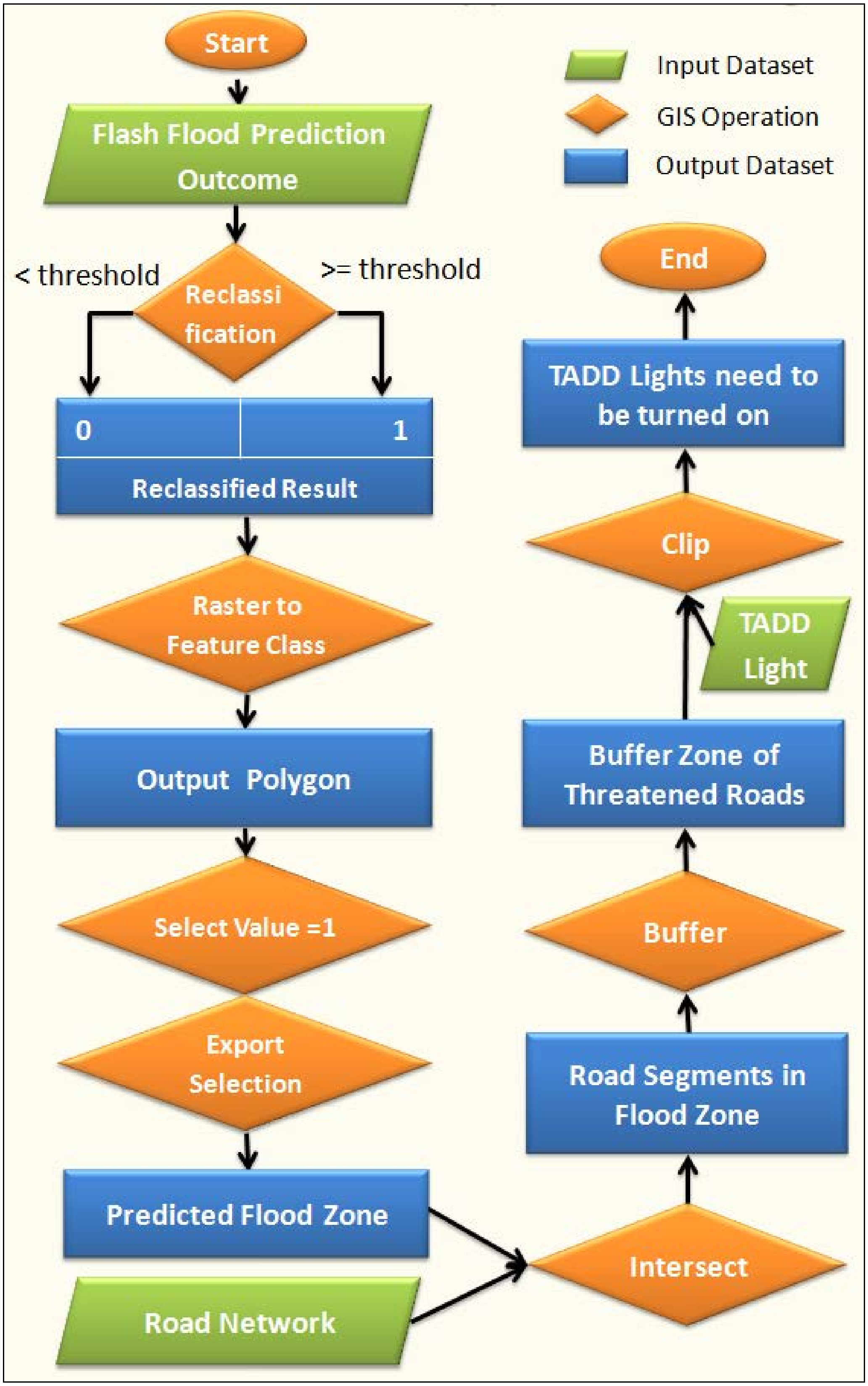

Figure 5.3: Flow Chart of the TADD Decision Support Tool

When the above process is finished, users can right click on the result of each time instance and choose “Show Results” to display the results on the map. In addition, users can also choose the “Influence Analysis” item on the pop-up menu to view the estimated population living in the predicted flash flood areas.

5.4 Flow Chart

The flow chart in Figure 5.3 illustrates the logical steps used in this add-in tool to determine the road segments that are threatened by the predicted flash flood event and the corresponding TADD signal lights that need to be turned on to warn the travelers.

According to the flow chart, when users click the “Start” button, it will trigger the process. A flash flood return period raster dataset is loaded into the system. The values in this raster layer are integers ranging from 0 to 11. Based on a pre-defined threshold value (here we use “2”), a reclassification operation is applied to this layer to create a new raster dataset, which only has 1s (if the original value is equal to or larger than the threshold value) and 0s (if the original value is less than the threshold value). The cells having a value 1 represent the area threatened by the potential flash flood event. The reclassified return period dataset is then converted into a feature class through the “Raster to Feature Class” operation. This feature class inherits the value of the reclassified return period dataset and the areas with a value 1 are used to delineate the flooding zone. In the next step, two operations are carried out to extract flooding zones: “select value = 1” creating a selection of the reclassified feature class containing all polygons whose values equal 1 and “export selection” exporting the selection into a separate feature class. The exported feature class is the flooding zone dataset.

Once the flooding zone dataset is available, the road network feature class is loaded into the system and intersected with the flooding zone dataset. This intersect operation generates a feature class which includes road segments that are within the flooding zone. These road segments are considered to be under the threat of the flash flood event and driver should be informed to avoid these road segments during that time. Therefore, the next step is to locate the nearby TADD signal lights and turn on the lights during the specific time to warn drivers of the potential danger. In order to identify the lights that need to be turned on, a buffer zone (500 meters are used as the width of the buffer zone in this system) is generated using the “buffer” operation. After this step, a point feature class representing all TADD signal lights in the case study area is loaded into the system and then clipped by the buffer zone. The resulting layer from the “Clip” operation contains the TADD signal lights that are located around the roads in the flooding area and should be turned on to prevent life losses.

The same process is repeated for all predicted return period layers at other time instances to create the corresponding TADD light decision suggestion.

CHAPTER 6 ROAD CLOSURE CONTROL MODULE

The Road Closure Control Module will focus on identifying the road segments that will be affected by a predicted flash flood event and sending signals to turn on TADD lights to keep travelers from entering the flooding areas in case of flash flood emergencies. The TADD devices will be designed to receive the control signal and other information from the DSS through their embedded radio modules.

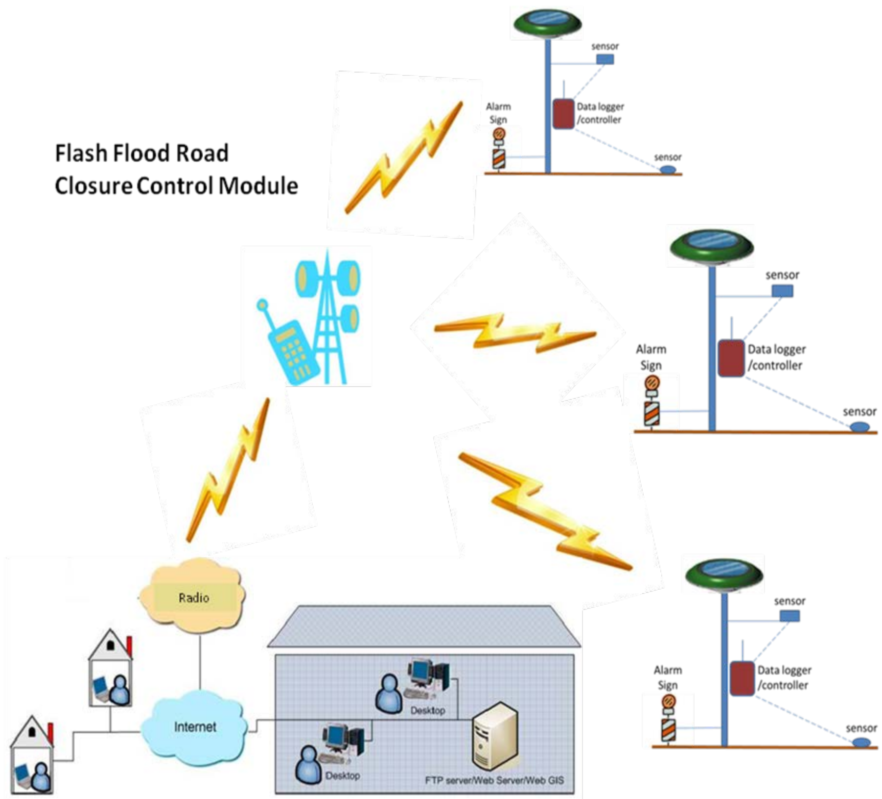

Figure 6.1: Flash Flood Road Closure Control Module

6.1 Hardware for Remote Site

A stand-alone hardware package includes the sensor case, a datalogger, a radio module, a warning light, a solar panel, a rechargeable battery, and a mounting structure, as shown in Fig. 6.2.

- A pressure transducer CS450-L (Campbell Scientific, UT) is used in this project. This sensor directly measures water pressure which is converted to water depth.
- The datalogger is CR850 (Campbell Scientific, UT), which collects signals of sensors, generates signals to control warning lights, and wirelessly communicates with DSS through a radio module.
- The radio module used in this project is RF432 (Campbell Scientific, UT), which is a 2.4GHz spread-spectrum radio. The radio/cellular modem will be used for

communication between the datalogger at the sensing location and the radio system. This will provide global wireless access to the sensor data via the Internet.

- A relay connected to the datalogger is used to drive a warning light. The datalogger provides digital output to indirect control a warning light through a relay.
- The road closure control module is powered by a solar panel. The solar panel charges a battery. Even if the weather cannot support the solar panel to charge the road closure control module, the module can work at least two days.

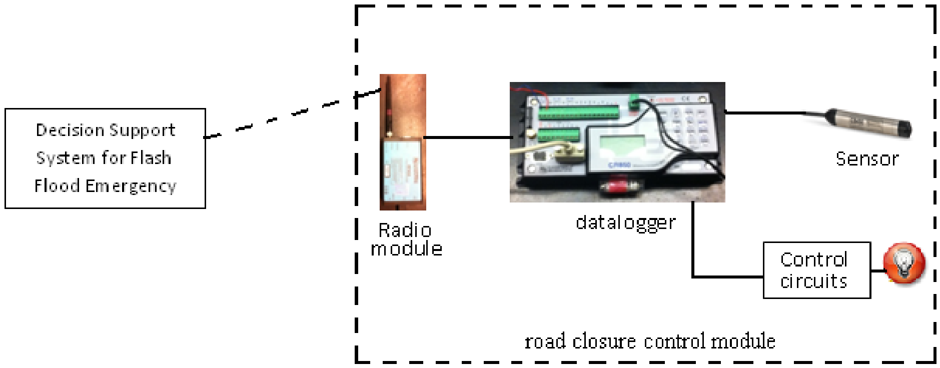

Figure 6.2: Structure of the Road Closure Control Module

Software for Remote Site

The radio module connected to the datalogger was configured as a remote station. Another radio module configured as a base station was connected to the server of DSS. The base station allows multiple remote stations to communicate with it. Each remote station has an identification number. The multipoint network makes that it is possible for DSS to control multiple road closure control modules.

A program was uploaded into the datalogger of the road closure control module. The program has the following functions:

- Periodic scan the sensor to collect and store water pressure data;
- Convent water pressure to water depth;
- Toggle warning light once the water depth is above the predefined threshold;
- Send data to the server of DSS;
- Receive commands from the server of DSS to turn on the warning lights.

6.2 Road Closure Control Module at the Central Server

A computer is configured as an FTP server as well as a Web server to receive, store, display, and manage the data. If an alarm signal needs to be issued, the webserver can send a command to the on-site sensor package through the network to signal the warning.

There are two modes of the Road Closure Control Module: automatic control and manual control. The automatic control mode is turned on by checking the “Auto Control”. It periodically check the GIS Spatial Database to identify road segments that might be affected by the predicted flash flood. The checking frequency is set in “Interval 1”. Then it will start communicating with the dataloggers of these road segments and collect the water depth data. Once the water depth reaches the threshold, the Road Closure Control Module will turn on the TADD lights automatically. If the depth falls below the threshold, or the flash flood prediction of one road segment is cleared, the Road Closure Control Module will turn off the TADD lights.

The manual control mode is turned on by clicking the “Start Monitoring” button. The server will start communicating with the remote dataloggers of the selected road sections and collecting data from them. The water depth data will assist the operators’ decision making. The operator can turn on the TADD lights of some remote sites by clicking the “Warning On” button. When the flash flood warning is cleared, the operator can turn off the lights by clicking the “Warning Off” button.

In addition, to make sure that the remote site devices are working, the server will communicate with each remote datalogger periodically based on the time defined in “Interval 2”. If the communication is failed from a remote site, the devices at that site is suspected to be dysfunctional, and technicians need to be sent to check the devices.

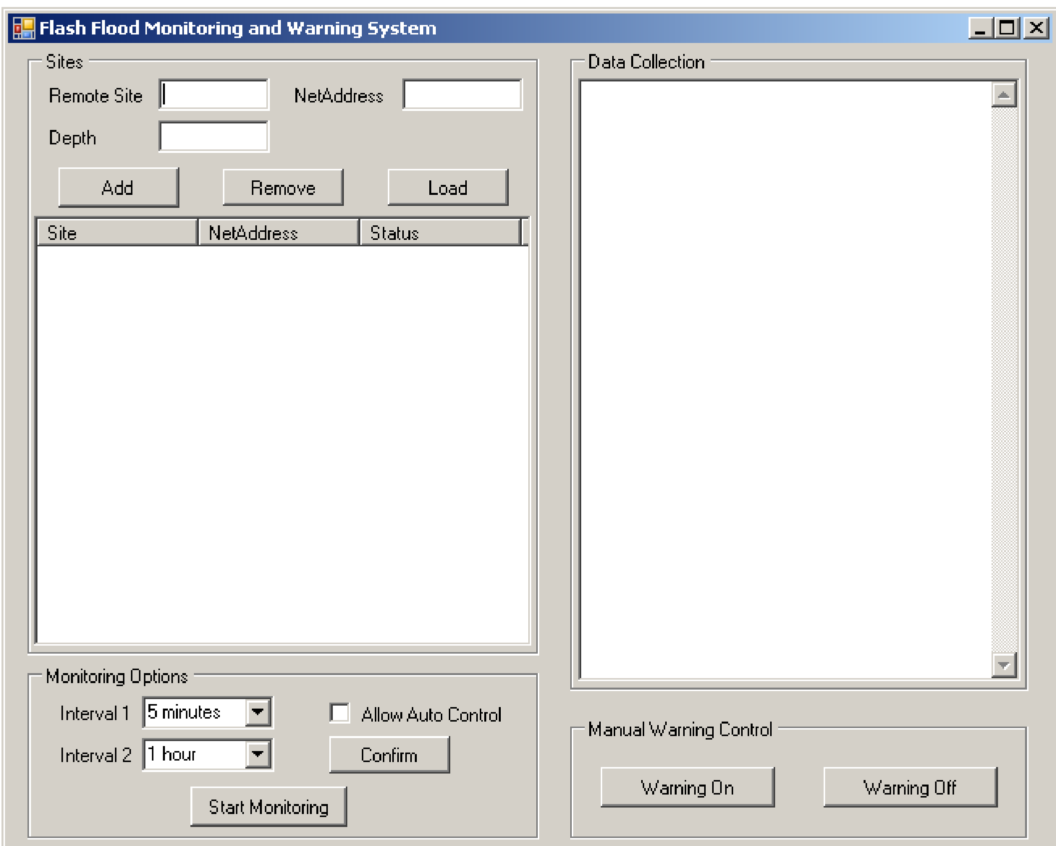

Figure 6.3: Interface of the Road Closure Control Module

All the remote sites are listed in the left window, as shown in Fig. 6.3. When there is no flash flood threat, the color of the characters will stay black and the status will be “Normal”; If a remote site is under the threat of flash flood, that line of characters will change to red and bold, and its status will change to “Alarm”; If the server could not communicate with one remote site, that line’s character will change to yellow and bold, and the status will show “Communication Failed”.

The dataset of remote sites name and address ID can be loaded by clicking the “Load” button. If a new site is considered, its name and address ID can be added by clicking the “Add” button; similarly, the abandoned sites can be removed by clicking the “Remove” button.

CHAPTER 7 CONCLUSIONS

Floods are the most common and widespread of all natural disasters. Due to the changing climate, "100-year floods" now happen every 20 years or less. Among all natural hazards, flash flood ranks as the No. 1 weather-related killer in U.S. According to the National Weather Service Report in 2005, more people die yearly in floods than in any other natural hazards, and more than half of the deaths in flash floods are caused by drowning victims in a traffic environment. The southwestern U.S. (including Oklahoma) is especially dangerous for both people and vehicles encountering the sudden onslaught of water from isolated thunderstorms.

Effective road closure control is critical to save lives facing flash flood emergencies. However, flash floods provide a very short time window (3~6 hours) for authorities to respond the threats. In such a short period, emergency management resources are stretched to the limit. In this project, we develop a decision support system to assist local emergency management officers in making prompt and effective decisions at road closure control.

The decision support system integrate the newly established Oklahoma Flash Flood Database and GIS Spatial Database. The DSS automatically pinpoint and highlight areas under flood threats, and flood areas and roads under threats will be shown in a GIS-based interface. The DSS can automatically monitor the water depth at remote sites and send control signals to close the TADD Gates or turn on TADD Red Lights to close the roads into the dangerous areas.

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