FINAL
CONTRACT REPORT

HURRICANE PREPAREDNESS AND RECOVERY BY A TRANSPORTATION AGENCY

CENTER FOR RISK MANAGEMENT
OF ENGINEERING SYSTEMS
UNIVERSITY OF VIRGINIA

Contract Research
by
Virginia Transportation Research Council

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Center for Risk Management of Engineering Systems
University of Virginia

Project Monitor
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Contract Research Sponsored by
Virginia Transportation Research Council

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NOTICE

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Each contract report is peer reviewed and accepted for publication by Research Council staff with expertise in related technical areas. Final editing and proofreading of the report are performed by the contractor.

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EXECUTIVE SUMMARY

A hurricane can be crippling to a regional transportation system such as the Hampton Roads District of Virginia. Preparedness and recovery by the highway agency, in coordination with localities and emergency services, is critical to minimizing the short, medium, and long-term effects of the event. In prior efforts, investigators characterized costs, risks, and benefits of managing spares of signs, signals, and lights in anticipation of hurricane damage (Lambert et al. 1998). In addition, use was made of probabilistic hurricane forecasts for inventory planning and operation. Based on the prior efforts, the research problem is identified as follows: (1) improving the basis for priority setting in recovery efforts; and (2) adoption elsewhere (i.e., in addition to sign-signal-light inventory) in the agency of risk-cost-benefit assessments and evaluation to improve the agency's preparedness and response capability.

Purpose and Scope

The goal of the effort was to improve hurricane preparedness and recovery of the Virginia Department of Transportation (VDOT) through the identification of planning and management options and the assessment and evaluation of the associated costs, benefits, and risks. There are seven related objectives: (1) a review of the literature and other agencies' experience; (2) development of a software-based platform for recovery priorities; (3) time-to-recovery analysis (4) analysis of schedule dependencies among agencies; (5) decision support for resource allocation for hurricane recovery; and (6) characterization of preparedness and recovery alternatives; and (7) trade-off analysis performed on recovery/preparedness alternatives.

The focus of this project is the Hampton Roads District of VDOT, which includes most of southeastern Virginia and the eastern shore. This area includes the heavily populated Hampton Roads metropolitan area, and the remainder of the district is rural. The district lies on the Atlantic Ocean at the mouth of the Chesapeake Bay, which is why it is such a highly sensitive area for hurricanes. The ideas and methodologies are applicable anywhere, but the data collection focuses on southeastern Virginia.

Methods of Analysis and Results

The effort introduces new approaches for improving VDOT's hurricane preparedness and recovery capabilities. The developed approach has six parts.

Development of a Software-Based Platform for Recovery Priorities

The goal is a methodology for setting recovery priorities following a large-scale disaster in VDOT's Hampton Roads district. The methodology will suggest which roads are the most important to restore immediately following the disaster and which roads can stand to wait for other roads with a greater need.

There are a number of criteria that can serve for the prioritization. Population, traffic, and road type and mileage are several important factors. But a distinguishing feature of this effort is the use of "critical" facilities, defined as any facility necessary for the well-being of a community.

The prioritization model uses a grid, and each grid cell receives a priority score. The user may choose any or all of critical facilities, population, road mileage, and user-defined data to drive the priority model to best address a current situation. Shading or colors are used to show high, medium, and low priority cells.

Figure ES.1 shows a sample of results of the prioritization model. On the left, the output is displayed with numbers and different shades that represent high (■), medium (□), and low (▩) priority cells. The user can alter the percentile distribution of colors to create the most informative view. The right side displays the priority scores laid over a map.

Alternately using several different choices of factors, the user can determine which cells are consistently the highest priority zones, which zones are consistently at the bottom of the chain, and how the priorities change in the short, medium, and long-term following the disaster. The model is primarily intended for supporting gross resource allocation decisions.

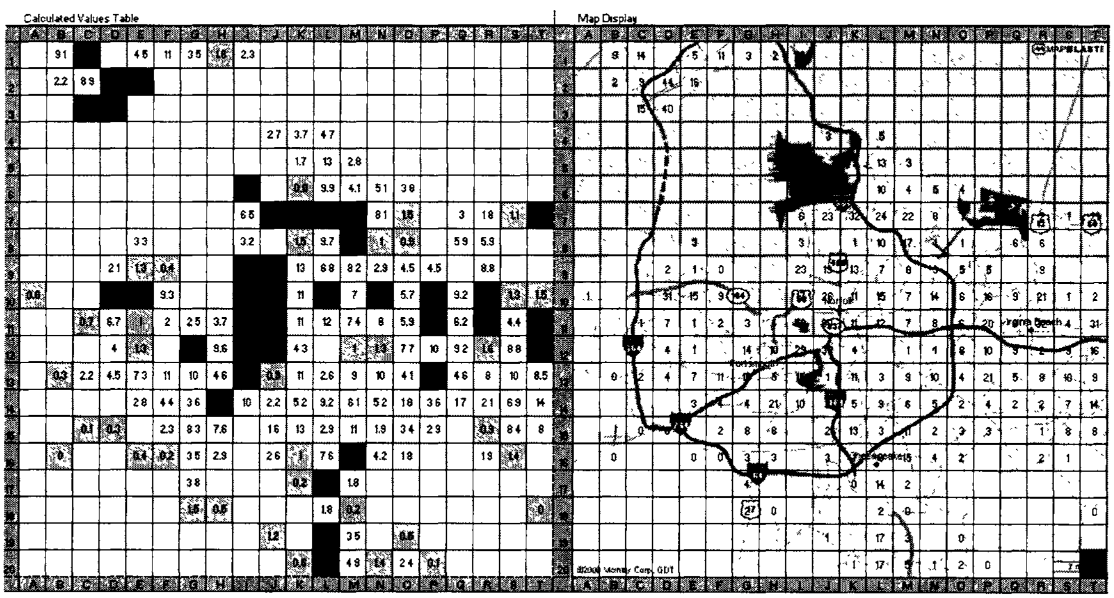

Figure ES.1 Outcome of the prioritization model

Time-to-Recovery Analysis

The scheduling of post-hurricane repair activities could be investigated to arrive at improvements that could reduce the time to recovery following a natural disaster. The effort describes a framework to utilize in such investigation. For VDOT to apply the developed framework, it would have to gather the necessary data.

A network model of the required activities and their relationships is used to determine the critical path and formulate an estimate of the overall completion time required by the repair process. A tradeoff analysis between time to recovery and pre-hurricane resource investments is performed to suggest how project duration can be reduced.

The schedule analysis is illustrated on a typical repair process. The time estimates obtained may not be accurate. In order to obtain accurate time estimates, VDOT can get historic data from previous work schedules. A schedule analysis of a typical post-hurricane repair process, which demonstrates the dependant relationships among repair activities, reveals the network diagram presented in Figure ES.2. Further analysis determines the activities that lie on the critical path of the process. Delays in the critical activities can cause a delay in the overall repair completion time. An examination of the critical path indicates that the length of time and level of resources required by the repair process are highly dependent on each individual activity being completed within the allotted time and budget. There is little slack in the repair schedule. If more resources are allocated at increased cost, the duration of the activities can be reduced. Tradeoff analysis reveals that the length of time required to complete the activities lying on the critical path of the repair process can be reduced by eight weeks without a significant increase in cost.

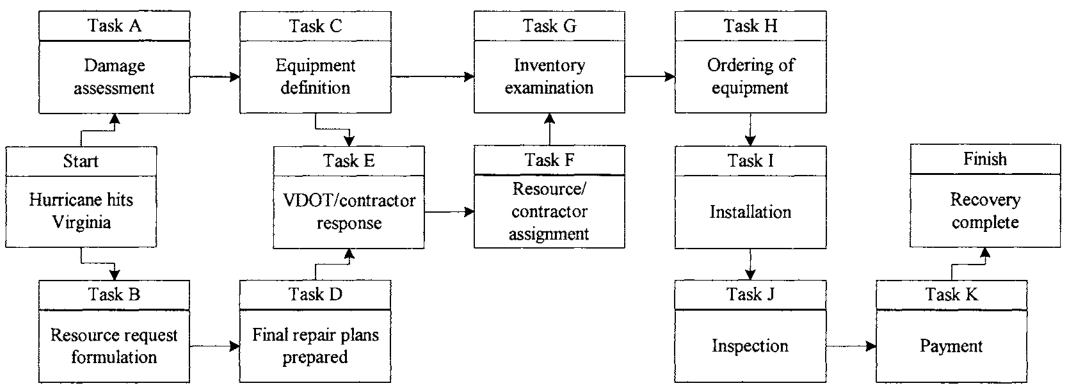

Figure ES.2 Network diagram of the post-hurricane repair process

The installation process, task I, is determined to be the most time consuming and variable activity based on data collected through interviews with VDOT personnel. A reduction in the length of time required by the critical activities in the installation process yields a shorter overall time to recovery. One way to shorten the installation process is to divide it into sub-tasks that can be performed simultaneously. In addition, pre-hurricane investments should be investigated in terms of the impact additional resources have on the time to completion of the installation process.

Analysis of Schedule Dependencies Among Agencies

An examination is conducted into the issue of time to recovery discussed above on a macro level by considering various schedule dependencies that occur among involved agencies as opposed to a pseudo-schedule outlining the general tasks in the post-hurricane process. Schedule dependencies among the activities of the numerous federal, state, and local agencies and organizations that participate in the pre and post disaster processes frequently arise. In many cases, one agency's duties cannot be started until activities that other agencies are responsible for have been completed. The schedule dependencies can lengthen the time to recovery, and therefore increase the magnitude of the impacts of the disaster. An analysis of potential opportunities for advancing the schedule researched from the agencies involved can aid in VDOT's decision making.

A framework has been developed that measures and compares dependency scenarios of potential opportunities for reducing delays. Critical inter- and intra-agency scenarios are identified that require future further investigation according to the extent of their overall significance to the time to recovery. The tool for measuring the magnitude of a delay takes into account its "Severity" with regard to its time duration, the number of "Agencies Involved," its "Likelihood" of occurring in the future, the range of "Items Waited On," its "Controllability" for the future, the number of associated "Cascading Effects," its "Maturity," and the "Number of Similar Scenarios."

A list of 48 delay scenarios was gathered for analysis through interviews with state agencies from Virginia, Florida, North Carolina, and California of the accounts they hold concerning their participation in the pre- and post-event processes of past natural disasters, especially in terms of the situations where they were waiting on their state DOT and vice versa. Ten of these scenarios were collected from Virginia agencies, 18 concern intra-agency delays identified within NCDOT, and the remaining 20 scenarios are various anecdotes from the other states.

Categorizing all of the dependency scenarios into the common functions within the organizational structure of a state DOT identifies those functions that are involved with a significant number of scenarios. According to the sample of 48 delay scenarios collected, *Information Management* and *Operations* are associated with 31% and 23% of the scenarios, respectively, which are primarily due to the unavailability of accurate real-time road status information. Additional analysis reveals the pairs of organizational functions that, when interacting, are the sources of many scenarios. Figure ES.3b displays the number of scenarios associated with each pair of organizational functions, and Figure ES.3a is a key defining the pairs of functions that lie on the horizontal axis of Figure ES.3b. Analysis of the dependency scenarios indicates that the interaction of *Information Management* and *Operations* introduces 23% of the scenarios collected and the interaction of *Operations* and *Structure and Bridge* introduces 19% of the scenarios, which suggests a lack of communication among these organizational functions.

	Administration	Environ., & Regulatory Affairs	Equipment	Finance	Info. Management	Legal / Authorization	Materials	Operations	Personnel	Structure
Administration		Ad-Env	Ad-Eq	Ad-Fin	Ad-Info	Ad-Leg	Ad-Mat	Ad-Op	Ad-Per	Ad-Str
Env., Reg. Aff.			Env-Eq	Env-Fin	Env-Info	Env-Leg	Env-Mat	Env-Op	Env-Per	Env-Str
Equipment				Eq-Fin	Eq-Info	Eq-Leg	Eq-Mat	Eq-Op	Eq-Per	Eq-Str
Finance					Fin-Info	Fin-Leg	Fin-Mat	Fin-Op	Fin-Per	Fin-Str
Info. Manage.						Info-Leg	Info-Mat	Info-Op	Info-Per	Info-Str
Legal / Auth.							Leg-Mat	Leg-Op	Leg-Per	Leg-Str
Materials								Mat-Op	Mat-Per	Mat-Str
Operations									Op-Per	Op-Str
Personnel										Per-Str
Structure										

Figure ES.3a Key for denoting pairs of organizational functions within the state DOT

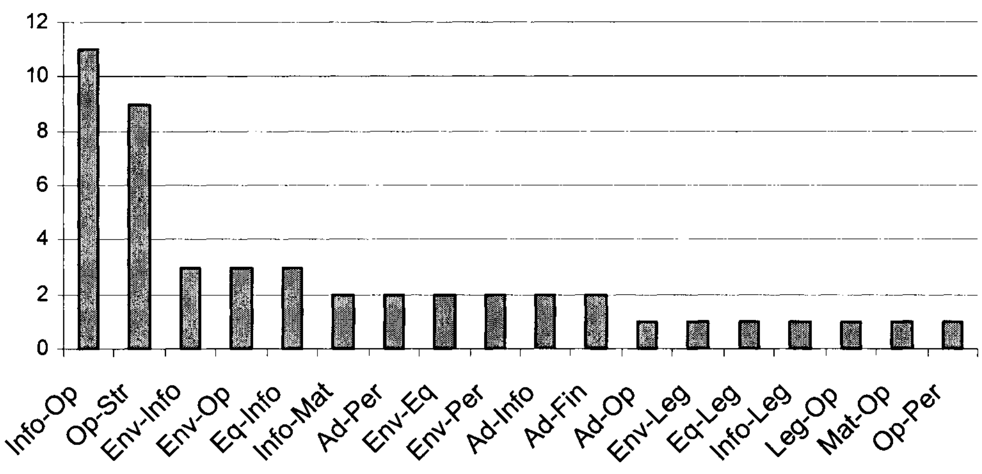

Figure ES.3b Number of scenarios collected that are associated with pairs of organizational functions within the state DOT

Various recommendations regarding an enhancement of VDOT's current computer-based information system, VOIS, and an increased level of communication encouraging more shared information among involved agencies could decrease the likelihood of many delays in the future by supporting a higher level of agency coordination during pre and post disaster processes. Other recommendations are proposed regarding evacuation processes, equipment standardization, and a statewide radio communication system.

Decision Support for Resource Allocation for Hurricane Recovery

The effort addresses decision support for resource allocation in order to aid managers in VDOT in the event that a hurricane affects the Tidewater region of Virginia. Examples of recovery activities are clearing debris from an interstate, repairing slope failure on a primary road, and repairing damage to a bridge on a secondary route. In September of 1999, Hurricane Floyd sent heavy rains into the Tidewater region of Virginia. These storms resulted in extensive flooding and many instances of severe damage to local interstate, primary, and secondary roads. The VDOT Emergency Operations Center received over 100,000 phone calls as a result of Hurricane Floyd, a category I hurricane. Equipped with a generic method for classifying and prioritizing these calls, volunteers were challenged in organizing recovery efforts.

The effort has developed a method to systematically prioritize recovery activities in order to effectively aid in decisions concerning resource allocation for VDOT in the event of a natural disaster. In order to achieve this, a tool was developed that utilized multi-objective decision analysis in order to prioritize recovery activities based on available data. Data were collected through contacts in VDOT and were used to conduct a case study. The case study analyzed recovery activities resulting from the September 1999 Hurricane Floyd strike on Virginia. The data provided also had to be used to determine the performance indices/objectives to use to prioritize and evaluate the effectiveness of the recovery activities. These objectives were to fall under the three categories of risk reduction, performance gain, and resources used. The indices that are used include average daily traffic (ADT), population density, and total estimated cost. The decision to include these indices meant that those activities located in highly populated areas on a route with heavy traffic flows would receive high priority. The third factor to consider in resource allocation decisions would be cost. From the data provided, multi-objective charts developed from this study were created, as shown in Figure ES.4.

The use of this tool should result in better overall management and allocation of resources. Resources go where they are most needed and where they will contribute the most to the recovery efforts. The developed charts should also result in improved communication between VDOT and other state agencies and help VDOT managers show other state agencies where the resources are going and why. Finally, the new technology will provide better prioritization of preparedness and recovery activities in the short, medium, and long term and show what recovery activities need to be completed before other recovery activities can begin.

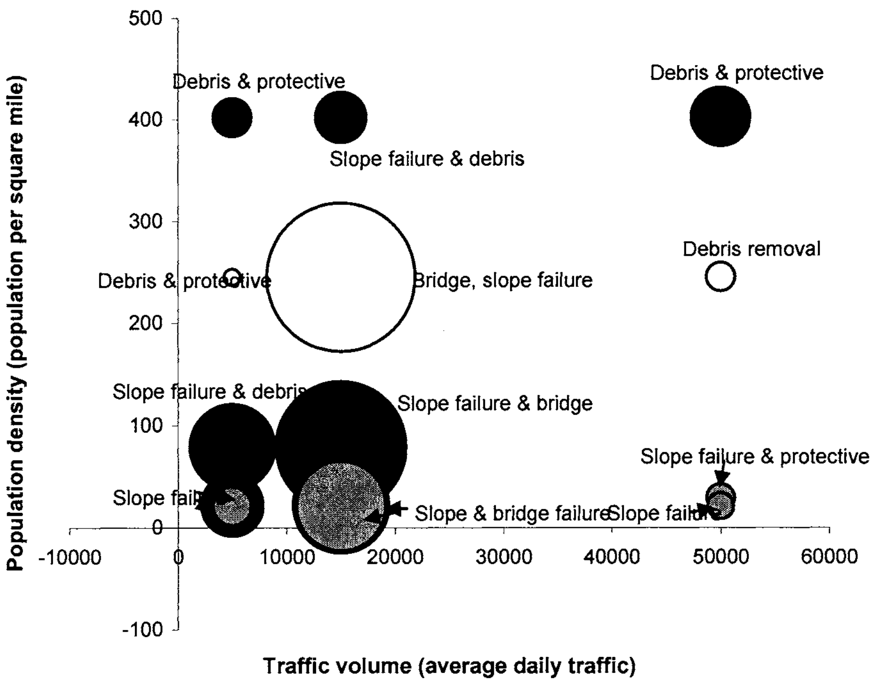

Figure ES.4 Recovery activities plotted for counties in Hampton Roads (icon area is proportional to activity cost)

Characterizing Preparedness and Recovery Alternatives

The effort describes a methodology for developing and characterizing hurricane preparedness and recovery alternatives for a highway agency in both the pre- and post-event phases of a hurricane. The study includes two major parts: (1) A characterizing template and (2) a variety of case studies consisting of hurricane preparedness and recovery alternatives. When creating post-event plans and decisions, a highway agency considers the possibility of adverse events that damage road systems. Events such as storm surges, high wind speeds and heavy traffic wear are possible in a hurricane.

In the case studies part of the project, three different alternatives were analyzed to improve signs. Each alternative looked at trying to improve the resilience, robustness, and redundancy of different road systems. Furthermore, each alternative was looked at to show whether the alternative needed action in the pre-event (before the hurricane) or post-event (after the hurricane). The pre-events and post-events were broken down further into short-, medium-, and long-term events. Short-term events were the hours to days before the hurricane hit. Medium-term was weeks to months or, basically, during the hurricane season. Long-term was the preparation years in advance or basically general advancements in the building of the systems to be better prepared. The same time frames apply for post-events except they are the recovery efforts after the hurricane.

In addition to looking at the time frames for each alternative, the case studies also looked at what the impacts of each alternative would be and whether they aid in evacuation. The impacts of each alternative are based on goals of highway agencies that are aimed at protecting life, property, and the environment. So the impacts that the case studies look at are cost, recovery time saved, human lives and the safety of the public, economic impact to the community, property saved, and protection of the environment. After looking at the possible impacts, the case study looks at how each alternative can be improved or enhanced and the ways are to prevent against stronger winds, and higher storm surges, or to handle greater traffic flows. Finally, the last part of the case study shows whether or not each alternative helps in the aid to evacuate the area.

Table ES.1 A case study characterizing the enhancement of signs

Alternatives:	Redundancy	Resilience	Robustness	Short term	Medium term	Long term	Short term	Medium term	Long term	Time savings	Cost savings	Lives saved	Economic impact	Environmental impact	Private property	Wind velocity	Storm surge	Traffic flow	Aids in evacuation
1. Strengthen signs			●			●				◒	◒					●			●
2. Store extra signs	●				●					●						●			
3. Detachable signs		●		●		●	●			◒	◒					●			●

Table ES.1 shows the case study performed. The case study looks at trying to improve signs. The case study has three alternatives to try and prevent or at least minimize the damage from the wind. To fill out a case study, the user fills in solid circles where each area has an impact on the alternative. If the alternative enhances the system through robustness, then the cell under robustness would get a solid circle. Likewise, if an alternative saves the highway agency time and money, then solid circles would be placed in the columns as well. If there is only a minor impact, say in the area of economic impact, then a half filled in circle demonstrates a minor impact to the area because of the alternative. Finally, depending on whether the alternative would be receptive to wind damage, storm surge damage, or say another destructive force, then the user-defined force would be replaced in the column.

Trade-off Analysis Performed on Recovery/Preparedness Alternatives

The effort develops a cost, risk and benefit decision framework for VDOT for their pre- and post-event phases in a hurricane. The study involves two major parts; the first explains the enhancement capabilities of road systems, and the second describes the spreadsheet tool for cost, risk, and benefit tradeoff analyses.

The enhancement of road systems through increasing their robustness, redundancy, and/or resilience can minimize the impacts of the adverse events as well as improve the highway infrastructure in a hurricane (as explained in the previous section). The main methodology, here, is to develop hurricane tradeoff analyses that compare different enhancement alternatives.

Each alternative has the ability to enhance a variety of road systems to different levels. While one alternative might have enhanced bridges more than smart highway systems, due to a flood prone environment, another alternative might have enhanced only signs, signals, and lights in an attempt to minimize fallen debris on highways. Either way, the alternatives allow a highway agency to understand how to enhance a wide variety of road systems that are affected by hurricanes. With this knowledge and the tool provided by the effort, a highway agency can make educated decisions about which alternatives are more cost and risk efficient. The following describes the tool as well as the associated tradeoff graphs.

The spreadsheet tool is used to apply the methodology to analyze the post-event phases of the events. The methodology can be applied to other events similarly. The tradeoffs among enhanced alternatives are in terms of the risk metrics: damage, repair cost, time to recover, and the cost to the industry and or stakeholders. The metrics measure the degree of a storm surge or wind speed-related impact. Different road systems have different values for the risk metrics. Therefore, by plotting the values, a decision maker can see the tradeoffs between different alternatives. Figure ES.5 shows the tradeoff graph that plots the cost of alternative versus the ratio of repair cost to reconstruction cost, or damage. The different curves refer to the different wind speed impact scenarios that may occur.

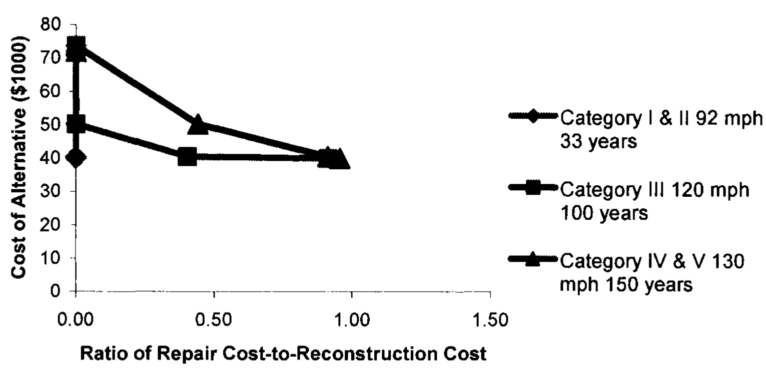

Figure ES.5 Tradeoff graph between different designs of cantilever signs in cost of alternative and ratio of repair cost to reconstruction cost after various wind speed impacts

User Input Worksheet

STORM SURGE

Yellow Filled Cells Indicate User Input Area

1. What road system is being considered?

cantilever signs

Press here to go to the Wind impact section → Wind Impact

2. Enter ultimate storm surge levels and costs of alternatives for storm surge impact analysis

The cost of an alternative could be either a lump sum or an annualized cost. Once the type of cost is chosen, the cost for all alternatives should be consistently used throughout the design selection process. The original cost of the road system should also be incorporated into the cost.

	Alternatives									
	1		2		3		4		5	
Enhancement Level	No change		+1 foot		+2 feet		+3 feet		+4 feet	
	Ultimate storm surge	Cost	Ultimate storm surge	Cost	Ultimate storm surge	Cost	Ultimate storm surge	Cost	Ultimate storm surge	Cost
cantilever signs	7	500	8	650	9	720	10	850	11	950

Introduction / User Input / Storm Surge / Wind Velocity / Tradeoff-StormSurge / Tradeoff-WindVelocity

Figure ES.6 Tradeoff graph between different designs in cost of alternative and ratio or repair cost to reconstruction cost after various wind speed impacts for cantilever signs

Conclusions

The hurricane preparedness and recovery efforts of a transportation agency can be improved through a number of methods.

First, a priority setting tool can be used to determine the area most in need of service during the aftermath of a disaster. Critical facilities need to be identified. With the model, a VDOT engineer can quickly make high level resource allocation decisions based on the criteria he feels are most important, and can change those criteria over the course of the recovery.

Second, a schedule analysis of the time-to-recovery efforts can also be conducted to determine the critical activities that need to be monitored closely to prevent and avoid unnecessary delays.

Third, using the methodology developed for analyzing dependency scenarios among agencies, dependency scenarios can be subjected to a categorical and comparative analysis, which can aid the state transportation agency's decision-making and subsequently reduce the overall time to recovery following a hurricane. The methodology, which is of great value to a state transportation agency because of the versatility it exhibits, can be applied to various geographical scales, types of disasters, and agencies.

Fourth, a method to systematically prioritize post-event activities in order to effectively aid in decisions concerning resource allocation for VDOT in the event of a natural disaster has been proposed. The developed tool utilizes multi-objective decision analysis in order to prioritize post-event activities based on available data.

Fifth, numerous alternatives that increase redundancy, robustness and resilience are available. It is therefore important to determine the impacts each alternative makes to cost, time savings, human life, economic, environment, and property. The proposed template for the characterization of alternatives enables the decision maker to make more knowledgeable decisions.

Sixth, with the characterization of alternatives, a systematic approach to cost-benefit analysis of recovery and preparedness alternatives can be utilized. It is necessary to determine the tradeoffs among alternatives.

Recommendations

Development of a Software-Based Platform for Recovery Priorities

- Adopt a systematic approach to priority-setting for recovery.
- Adopt the grids for priority-setting.
- Use various grid-size resolutions (District, Residency, smaller).
- Adopt the demonstrated metrics (populations, mileages, stakeholder facilities, etc.).
- Add a metric to represent the degree of recovery.
- Use the developed software and demonstrate with GIS divisions.
- Consult VDOT District staff to determine appropriate metrics to use.

Time-to-recovery Analysis

- Apply the methodology to actual data and post-hurricane processes.
- Examine the feasibility of dividing activities into sub-tasks that can be performed simultaneously.
- Examine the impacts of assigning more resources to the installation process.
- Examine various schedule configurations of activities and potential sub-activities.
- Investigate opportunities for further time and cost savings in the post-hurricane process.

Analysis of Schedule Dependencies Among Agencies

- Perform a more extensive data collection possibly with an online surveying tool.
- Analyze individual scenarios collected using PERT, an activity network modeling tool, to identify potential opportunities for advancing the schedule in the post-hurricane process.
- Investigate the costs and benefits of pre-hurricane resource investments on the alternatives identified from the PERT models.

Development of Decision Support for Resource Allocation for Hurricane Recovery

- Adopt a systematic approach to resource allocation for recovery.
- Represent the variety of recovery projects across regions.
- Analyze the balance among all project impacts and costs.
- Use the approach to improve the allocation of resources to diverse projects.
- Project resource allocation needs from past storms to the estimate needs in future storms.

Characterization of Preparedness and Recovery Alternatives

- Generate more alternatives using the methodology given.
- Perform more case studies for different types of destructive forces.
- Extend to different types of disasters such as earthquakes, flooding, and snowstorms.

Decision Trade-off Analysis on Recovery and Preparedness Alternatives

- Expand upon the methodologies presented in this report by collecting data that will focus on the approach analysis used.
- Adopt a systematic approach to cost-benefit analysis of recovery and preparedness.
- Expand the functionality of the tool to evaluate additional natural disasters such as earthquakes, tornadoes, snowstorms, floods due to rainfall, and any such event where the impacts can be lessened through mitigation.
- Expand the functionality of the tool to incorporate additional enhancement alternatives in addition to wind speed, storm surge, and traffic flow.
- Use the flexibility of the framework to maximize VDOT's understanding of their preparedness efforts.

INTRODUCTION

Hurricanes along the east coast of the United States are potentially very destructive to the transportation infrastructure. A storm becomes a hurricane when it demonstrates a rotary circulation and reaches a constant wind speed of 74 mph. The strength of its winds can cause considerable damage and they range in categories from 1 to 5, with 1 being the weakest and 5 being the strongest. Each category of hurricane represents a unique level of damage to a transportation system as is summarized in the Saffir-Simpson Scale in Table 1. Hurricane force winds can result in damage that includes destruction of signs, bridges, tunnels, and smart highway equipment.

Table 1. Saffir-Simpson Scale

Category	Winds (mph)	Damage
I	74-95	Minimal
II	96-110	Moderate
III	111-130	Extensive
IV	131-155	Extreme
V	>155	Catastrophic

According to the National Hurricane Center, Virginia has taken only four direct hits from hurricanes in the last 100 years, with only one of those being a "major" hurricane (category III and above). Many more hurricanes, such as Floyd in 1999 and Camille in 1969, have caused severe damage in Virginia but were not direct hits. However, with an average of 10 tropical cyclones in the Atlantic each year (of which six become hurricanes), the threat is always there.

A hurricane can be crippling to a regional transportation system such as the Hampton Roads District of Virginia. Preparedness and recovery by the highway agency, in coordination with localities and emergency services, are critical to minimizing the short-, medium-, and long-term effects of the event. In prior efforts, investigators characterized costs, risks, and benefits of managing spares of signs, signals, and lights in anticipation of hurricane damage (Lambert and Haimes 1998). In addition, use was made of probabilistic hurricane forecasts for inventory planning and operation. Based on the prior efforts, the research problem is identified as follows: (1) improvement of the basis for priority setting in recovery efforts and (2) adoption elsewhere (i.e., in addition to sign-signal-light inventory) in the agency of risk-cost-benefit assessments and evaluation to improve the agency's preparedness and response capability.

PURPOSE AND SCOPE

The goal of the current effort was to improve hurricane preparedness and recovery of the Virginia Department of Transportation (VDOT) through the identification of planning and management options and the assessment and evaluation of the associated costs, benefits, and risks. The developed approach is in six parts: (1) development of a software-based platform for recovery priorities; (2) time-to-recovery analysis; (3) analysis of schedule dependencies among agencies; (4) development of decision support for resource allocation for hurricane recovery; (5)

characterization of preparedness and recovery alternatives; and (6) decision trade-off analysis on recovery and preparedness alternatives.

1. Development of a Software-Based Platform for Recovery Priorities

In order to prioritize the recovery following a disaster, the study aims to determine the criteria that are necessary for prioritizing disaster recovery efforts in addition to the various classes of facilities that are critical to the vitality of a community are identified. Critical facilities are facilities necessary for the well-being of a community, and they include emergency facilities such as hospitals and fire stations, centers of commerce, and schools. Some facilities have to be repaired immediately after a disaster such as hospitals and fire stations. Other facilities may not be in immediate need of recovery or repair but require repair in the medium- or long-term timeframe. The effort therefore aims to account for facilities that people need access to following a disaster in the short-, medium-, and long-term timeframe.

2. Time-to-recovery Analysis

The effort examines the scheduling of the post-hurricane repair process to demonstrate the activities that most influence the overall time to recovery. By identifying the relationships among activities making up the repair process, a critical path of events is identified, which exposes potential bottlenecks in scheduling. Examination of the critical path would indicate the activities that need to be completed on schedule and the level of resources necessary to accomplish the recovery efforts. Investigation of the cost-benefit tradeoffs between time to recovery and pre-hurricane investments of resources helps determine how to avoid costly project delays.

3. Analysis of Schedule Dependencies Among Agencies

Recovery efforts involve several federal, state, and local agencies and organizations. It is not uncommon that schedule dependencies would arise among the activities of the different agencies and organizations. In many cases, the duties of one agency cannot be started until activities of another agency are completed. Because of schedule dependencies, time to recovery can be lengthened and the magnitude of the disaster impacts can increase. It is thus important to conduct an analysis of the schedule dependencies and explore opportunities for reducing intra- and inter-agency schedule dependencies that arise in the pre and post-disaster processes. The study develops a tool that can be used in measuring the magnitude of the delay. Several indices for magnitude of delay measurement are proposed and graphical representation of the dependency scenarios based on the indices is utilized.

4. Development of Decision Support for Resource Allocation for Hurricane Recovery

In post-hurricane efforts, VDOT managers would have to determine where to allocate funds, personnel, and equipment. Multiple objectives need to be considered. The study aims at improving the allocation of resources for preparedness and recovery. A tool that utilizes multi-objective decision analysis in order to prioritize recovery activities based on available data is developed. The tool needs to balance equitably the objectives of risk reduction, performance gain, and resources (including cost). Indices of performance are developed to quantify the objectives and multi-objective charts are created to offer support for resource allocation. Use of the tool would result in better overall management and allocation of resources.

5. Characterization of Preparedness and Recovery Alternatives

A methodology for developing and characterizing hurricane preparedness and recovery alternatives for a highway agency in both the pre- and post-event phases of a hurricane is developed. A template for characterizing preparedness and recovery alternatives is proposed. The alternative can be characterized in terms of its attributes of redundancy, robustness and resilience, its association with pre-events and post-events, and its impacts on cost and environment, among others. Several classes of alternatives are identified and analyzed. The tool can aid VDOT in evaluating preparedness and recovery alternatives.

6. Decision Trade-off Analysis on Recovery and Preparedness Alternatives

The enhancement of road systems through increasing the robustness, redundancy and/or resilience can minimize the impacts of the adverse events as well as improve the highway infrastructure in a hurricane. The study aims to develop hurricane tradeoff analysis that compare different enhancement alternatives. The effort extends the cost-risk-benefit analysis developed in a previous effort (Lambert and Haimes 1998) to other components of the highway infrastructure. Work done to improve the recovery of highway signs, signals, and lights has been extended to improve the recovery of bridges, tunnels, and smart highway systems. The tradeoff analysis would allow VDOT to understand how to enhance a wide variety of road systems that are affected by hurricanes. With the knowledge and the tool provided by the effort, VDOT can make educated decisions about which alternatives are more cost- and risk-efficient.

The focus of this project is the Hampton Roads District of VDOT, which includes most of southeastern Virginia and the eastern shore. This area includes the heavily populated Hampton Roads metropolitan area, and the remainder of the district is rural. The district lies on the Atlantic Ocean at the mouth of the Chesapeake Bay, which is why it is such a highly sensitive area for hurricanes. The ideas and methodologies are applicable anywhere, but the data collection focuses on southeastern Virginia.

LITERATURE REVIEW

The need for maintaining and improving natural disaster preparedness and recovery efforts has been addressed from various perspectives. Heaney et al. (2000) present the engineering research perspective for developing more sustainable natural disaster management. Heaney discusses lessons learned from past hurricanes and other natural hazards and summarize the impacts of disasters on infrastructure including communications, bridges, and transportation systems. Higgins et al. (2000) examine the roles of public transportation agencies in extreme events and provide guidance for emergency management planning in coordination with the efforts of their local jurisdiction. Schiff (1995) summarizes the recovery of road and bridges following the 1994 Northridge earthquake in California and discusses the impacts the destroyed road system had on other agencies involved in the disaster recovery. Recommendations for enhanced recovery plans and further research were developed (Schiff 1995). Juhl (1993) discusses the collaboration of the Federal Emergency Management Agency (FEMA) and a software company to take steps to increase the efficiency of the pre- and post-disaster processes by developing database applications using GIS. Ardekani (1992) evaluates the response following the 1989 Loma Prieta earthquake in California and provides recommendations for the preparedness of transportation agencies in the future. Ross (1988) identifies numerous effects natural disasters have on transportation systems.

The importance of systematic planning of the pre- and post-disaster procedures has been recognized. Kovel (2000) discovered that the development of these preparation and recovery strategies is not given precedence over other tasks due to a lack of effective tools for use in the planning process. One tool to ensure an effective allocation of highway resources is a multiobjective analysis of the alternatives (Chowdhury et al. 2000). Gharaibeh and Darter (1999) developed a tool that can aid preparedness and recovery by prioritizing highway reconstruction activities. Boyd et al. (1998) describe the activities that are crucial for emergency management in transit to maintain adequate preparedness and recovery procedures. A design for evaluating the costs and benefits associated with preparedness activities was developed by Masri and Moore (1995). Tavano (1995) further discusses the necessary activities to perform in the pre-event period to achieve a sufficient level of hurricane preparedness. Hancock et al. (1993) emphasize that the use of innovative techniques for emergency response planning is essential and identify the need for a systematic approach in evaluating the capabilities of agencies involved in disaster preparedness and recovery. Ullman et al. (1991) examine the roles of agencies involved with emergency traffic management operations and highlight the importance of planning. Motivated by the need for a systematic study of the post-disaster process to improve emergency planning, Kozin and Khou (1990) developed a formulation of lifeline-restoration processes during recovery.

Gunes and Kovel (2000) explain the need for comprehensiveness in planning for the pre- and post-disaster periods and find that emergency disaster management should not limit its focus to the direct, immediate effects of a natural disaster. Preparedness and recovery efforts become more beneficial when the complexity of managing these processes is realized (Gunes and Kovel 2000). Parentela and Nambisan (2000) stress that a prerequisite for the development and implementation of adequate emergency response plans is an extensive range of information regarding factors and issues such as the environment, the capabilities of emergency response providers, and the economy. Crichlow (1997) describes how recoveries from natural disasters are complex events.

Agency coordination before and after a natural disaster has been widely recognized as an important contribution to the efficiency of a recovery effort. Grajek and Gibson (2000) find that completion times of activities can be reduced with effective partnering and coordination of involved parties. Mondul (1997) stresses that information should be shared among agencies using the road system in the preparation and recovery processes. Through a survey, Kovel (1995) found that a higher level of agency coordination would benefit these processes. Barnett (1987) explains that the procedures to follow during recovery should reflect statewide multi-agency coordination and communication in terms of responsibilities, authority, and capabilities.

The Transportation Research Board (1984) discusses the importance of identifying authority and communication channels among involved agencies and the private sector.

Schedule analysis was examined by Wang and Demsetz (2000), Mulholland and Christian (1999), Bubshait and Cunnigham (1998), McGough (1982), and Peer (1974). Babcock (1999) provides a range of network scheduling techniques and their applications including the *program evaluation and review technique* (PERT) and *critical path analysis* (CPA). Babcock states that the *critical path* of a sequence of events represents the longest path from one event to another. Babcock presents methods of formulating the time duration of a critical path. The time duration of the critical path associated with a hurricane recovery, called the *time to recovery,* can be defined by the length of time it takes a region to return to its pre-disaster status from the point immediately following the strike or onset of the disaster. Babcock demonstrates that the time to recovery can be reduced if the *critical path* of the recovery process is shortened. Therefore, it is important to eliminate any unnecessary delays introduced by schedule dependencies among recovery activities that lie on the critical path. The issue of scheduling has primarily been considered in terms of managing activities that comprise construction projects and has not been viewed comprehensively on a meta-level with such applications as an entire disaster recovery effort. When examined on a larger scale, schedule analysis can suggest improvements to reduce the time it takes a region to fully recover from a natural disaster.

The importance of managing the potential risks to infrastructure including facilities that could suffer negative impacts from a natural disaster has been addressed by Hastak and Baim (2001), Haimes and Jiang (2001), and Ezell and Farr (2000). Hooke (2000) and Hecker et al. (2000) discuss the assessment of risk specifically associated with natural disasters. In addition, the Permanent International Association of Road Congresses (1999) develops methodologies incorporating risk management and emergency planning, and Housner and Chung (1997) provide evaluations of risk assessment and disaster recovery. Chang and Shinozuka (1996) and Staneff et al. (1995) explain that risks and impacts from natural disasters are important factors to be taken into account when determining the life-cycle and management of infrastructure.

This report draws upon and extends the work that was done by VDOT on disaster response and recovery (1995, 1996, 1997a, 1997b, 1997c, 1998, 1999, 2000).

METHODS OF ANALYSIS

The recovery process following a hurricane is complex. Several models can be formulated to address the different aspects of the system. The effort employs the use of hierarchical holographic modeling (HHM) in order to achieve its goal of improving VDOT's preparedness and response capability following a hurricane. Hierarchical holographic modeling is used as a way to account for diverse scenarios within VDOT and the community that could occur when a region is affected by a hurricane. The HHM in Figure 1 identifies the different perspectives that can be used to view the hurricane recovery system while encapsulating the gestalt (integrated parts) of the sources of risk to the system.

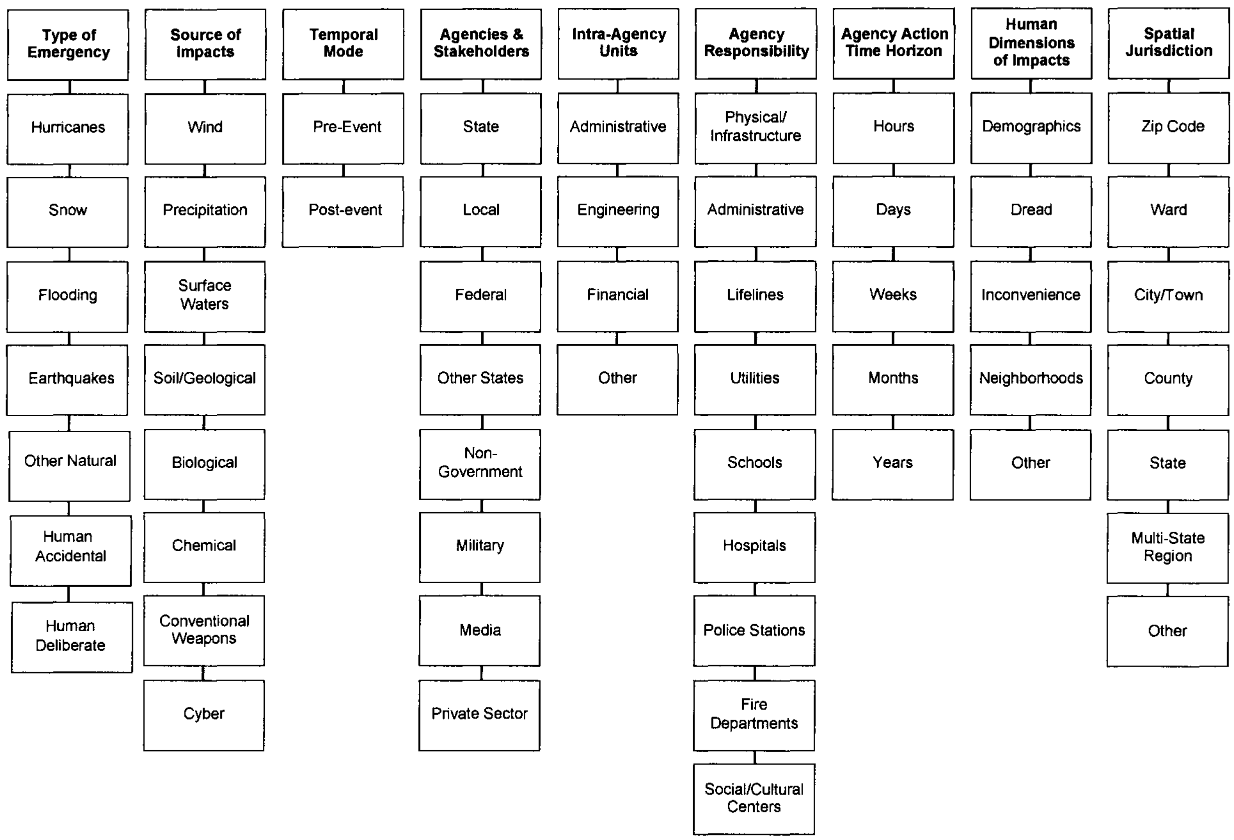

Figure 1. Hierarchical holographic model for Virginia transportation hurricane preparedness and recovery

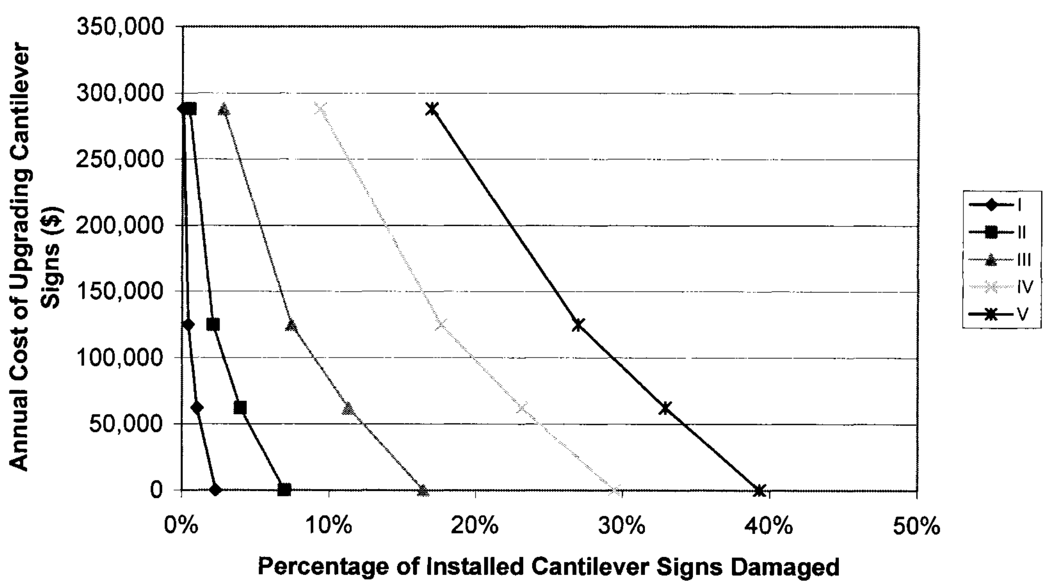

Figure 2. Trade-off analysis performed on cantilever signs for all categories of hurricanes (I-V) from sign-signal-light inventory project (Lambert and Haimes 1998)

The effort relies in part on the adoption of strategies from prior efforts addressing sign-signal-light inventory levels. A method for performing trade-off analyses has been projected from the sign-signal-light inventory to the current effort. A sample trade-off analysis is shown in Figure 2.

In addition to hierarchical holographic modeling and the trade-off analyses adopted from prior efforts, the effort introduces new approaches for improving VDOT's hurricane preparedness and recovery capabilities. The developed approach is in six parts: (1) development of a software-based platform for recovery priorities; (2) time-to-recovery analysis; (3) analysis of schedule dependencies among agencies; (4) development of decision support for resource allocation for hurricane recovery; (5) characterization of preparedness and recovery alternatives; and (6) decision trade-off analysis on recovery and preparedness alternatives.

Development of a Software-Based Platform for Recovery Priorities

There are a number of criteria that can be used to determine the most important roadways including population, average daily traffic, highway length, and highway capacities. For this effort, a key criterion for prioritization is the location of certain critical facilities in the highway network.

Classification of Critical Facilities

A critical facility is a facility served by the transportation system that is necessary for the well-being of a community. Following a major disaster, it is vital to restore transportation access, via the road network, to these critical facilities that provide vital services to as many people as possible. Hierarchical holographic modeling is used to help identify as many types of facilities as possible, and to group the types of facilities into categories and sub-categories.

Information Gathering and Data Input

Once categories of facilities are created, the next task is to locate all of these facilities. The project covers the Hampton Roads District of VDOT, which includes the counties of Accomack, Greensville, Isle of Wight, James City, Northampton, Southampton, Surry, Sussex, and York and the cities of Chesapeake, Emporia, Franklin, Hampton, Newport News, Norfolk, Poquoson, Portsmouth, Suffolk, Virginia Beach, and Williamsburg. The map seen in Figure 3 illustrates the area covered, with the district borders outlined.

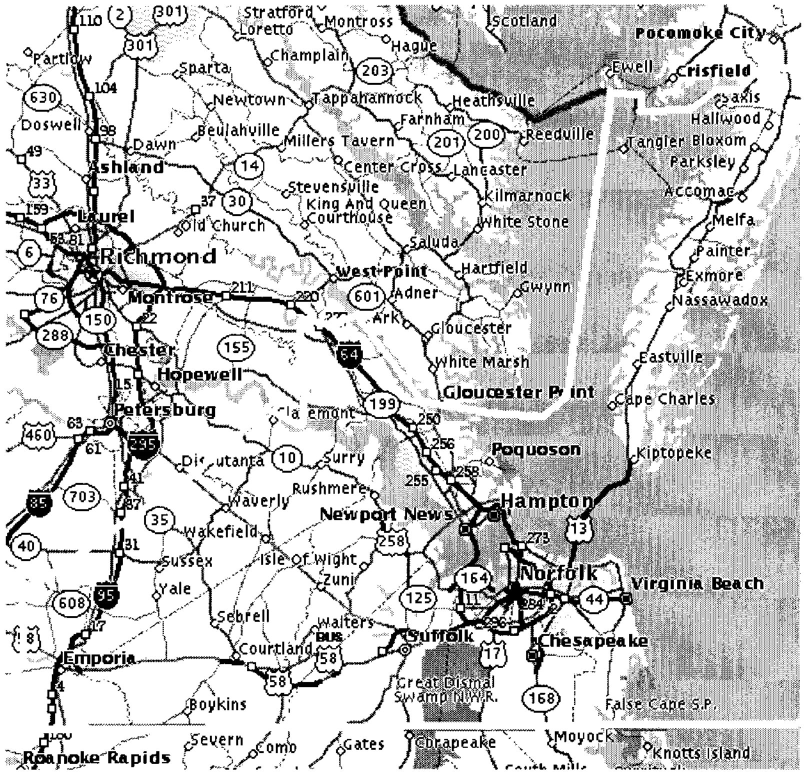

Figure 3. VDOT's Hampton Roads District

The facilities are located using the ArcView GIS program, which provides geocoding of addresses. Geocoding allows a user to enter in addresses of buildings (facilities) and locates them by their street address. Road maps with address data are required for geocoding. The best source found for the address information is a database of addresses and telephone numbers compiled by facility type at http://www.yahoo.com.

Highway and road data are very important pieces of information for the analysis. The roads are the basis of the model, as their location determines where work needs to be done. In particular, the length of roads is important and also must be categorized by the different types of roads. The highway data are also used for geocoding purposes to locate the facilities by street address. The two sources of highway data are Network Level Basemap of VDOT and U.S. Census Bureau maps. Another important piece of data to consider is population. Population is important to the model because the goal is to get as many people to as many facilities as quickly as possible. While the facilities are most important, the location of the people is very important to the model as well. The population data come from the GIS center at the University of Virginia. The population data are population blocks, each of which has between 0 and 100 people.

Priority Setting Tool

The effort develops a priority setting tool that can be utilized in setting recovery priorities following a large-scale disaster. The prioritization tool is implemented in a Microsoft Excel spreadsheet and is made available online for the use of VDOT. The software ArcView GIS and Microsoft Excel are utilized in the development of the hurricane recovery software because the two packages are comprehensive and easy to use. Data including populations, highway mileage, and critical facilities are derived from the ArcView database, and Microsoft Excel is used to analyze the results. The tool also accepts three user inputs such as highway damage and severity of the disaster, and the output can be customized to look at short-, medium-, or long-term recovery. The intent of the user input section is twofold. The primary reason is to allow the model to have real-time data in it. Real-time data would most likely be estimated damage accounts or costs of repairs or data that do not exist until after the damage from the disaster is assessed. Second, the user input section allows the inclusion of new important data that have not yet been compiled. The user does not have to use any of the user input sections.

The prioritization tool makes use of the grid method. The area where recovery efforts are needed is divided into grids. Each grid section will contain critical facilities, people, and roads. The data gathered will be tabulated by grid section, and then the map area will be prioritized by grid section in the analysis. The underlying database beneath the user interface locates the facilities and road segments that belong in each grid section. By determining the highest priority grid sections, the user will know which roads to fix first.

The data inputs associated with the various grid sections are used to determine the priority scores of each grid section. While the score is not necessarily a meaningful number, its relative rank against the other cells in the grid determines the priority of the cell. Therefore the results can be displayed by, for example, looking at the highest 5% cells. The calculation of the priority scores is user-dependent and can be adjusted to reflect the desired recovery timeframe.

The priority score is a simple product and/or quotient. The user selects the pieces of data to use in the calculation. The pieces of data are critical facilities, population, road mileage, and the three user inputs the user selects to multiply the factors in various combinations. The logic is that if, for example, the user wants to base the prioritization on facilities and population, then multiplying those two together will give a good measure of priority. The highest score would be given to areas with high facilities and a high population; having one high and one low leads to a medium score, and both low is the lowest priority.

The user may wish to divide instead of multiply. Continuing from the example above, if the user wants to use population and facilities as the criteria but wants to give the high priorities to areas with high facilities and low population, then he or she can divide facilities by population. The general formula used to determine the priority score for each cell grid as follows:

$$\frac{Facilties \times Population \times RoadMileage \times User\#1 \times User\#2 \times User\#3}{Facilties \times Population \times RoadMileage \times User\#1 \times User\#2 \times User\#3} = priorityscore$$

Time-to-Recovery Analysis

The scheduling of post-hurricane repair activities could be investigated to determine improvements that could reduce the time to recovery following a natural disaster. The effort describes a conceptual framework to utilize in such investigation. The effort examines the scheduling of the post-hurricane repair process to demonstrate the activities that most influence the overall time to recovery. The typical series of tasks completed during the post-hurricane repair process is displayed in Figure 4.

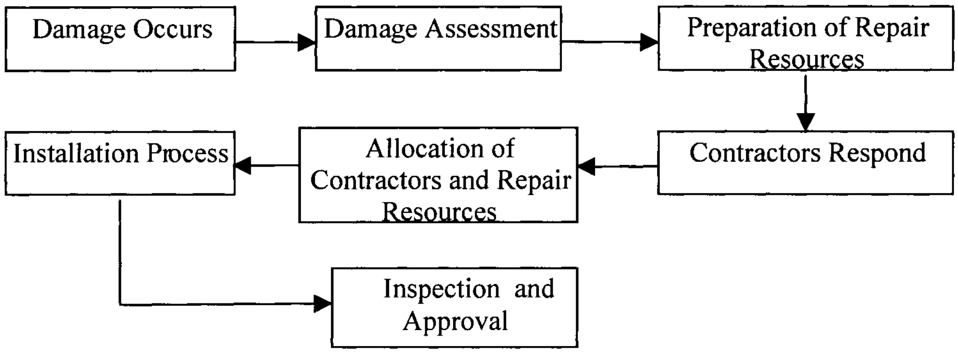

Figure 4. Flowchart of the repair process

To perform a time-to-recovery analysis, identification of the repair activities is important. A network diagram demonstrating the relationships among the activities is also useful. The post-hurricane repair process including the required activities, and their relationships can be analyzed using the Program Evaluation and Review Technique (PERT) and the Critical Path Method (CPM). PERT and CPM provide a visual display of the sequence of necessary activities to complete a project, which can be used to monitor a project throughout its lifecycle. The PERT and CPM methods assume that the activities involved have clearly defined beginning and ending points and that sequential relationships among activities can be identified at the start of the project. The network methods are also used to demonstrate time-cost tradeoffs resulting from the reallocation of resources among activities.

The PERT technique is probabilistic in nature and is designed for projects where there is little direct experience with the activities involved and thus little certainty associated with the time required for each activity. The CPM technique is more deterministic in nature and is designed for projects in which activity times are known with certainty. The VDOT repair process is likely to be a combination of the two project types. Because it is unlikely that post-hurricane activities of VDOT always start and finish at defined times, the PERT method, which requires that the time values be only approximations, is more suitable for analyzing the repair process. VDOT can determine the time value estimates from previous work records or experience.

Calculation of Time Statistics

To analyze a project using the PERT technique, three time estimates are required for each activity that must take place:

1. *Most optimistic time, a:* The shortest time in which an activity can be completed.

2. *Most likely time, m:* This is the mode of the distribution of the time required to perform an activity, that is, the activity most often requires *m* time units for completion.
3. *Most pessimistic time, b:* An estimate of the longest possible time needed to complete an activity.

Using the three time durations, the mean and standard deviation can be calculated for each activity, which account for uncertainties in the time estimates. The mean and standard deviation are used to calculate the probability distribution of each activity. The distribution, called *beta*, can take on a variety of non-symmetric shapes allowing the mode, which is the most likely time, to fall anywhere between the two end points, which represent the most pessimistic and the most optimistic times.

The mean of the beta distribution, which represents the expected completion time of an activity, is given by a weighted average of the three time estimates:

$$t_e = \frac{a + 4m + b}{6}$$

The standard deviation of any activity is given by $\sigma = \left(\frac{b-a}{6}\right)$.

Determination of Critical Path

The network diagram of the repair process is constructed. The beginning and end points of a task are described by two events known as the tail and head events. Each task is represented by one and only one arrow, with direction of progress specified by the arrow direction.

The first phase of the critical path calculations is the forward pass. Calculations start from the start node and move until the end node is reached. The earliest start time, ES_i, of all the tasks emanating from event *i* represents the earliest occurrence time of event *i*. The formula used in calculating earliest start time is $ES_j = \max_{\forall i} \{ES_i + D_{ij}\}$, where D_{ij} is the expected duration of activity (i,j) and ES_0=0.

The second phase of the critical path calculations is called the backward pass. Calculations begin at the end node and move backwards to the start node. The objective is to compute the latest completion time, LC_i, for all the activities coming into event *i*. For the end event, $LC_n = ES_n$. In general, for any node *i*, $LC_i = \min_{\forall j} \{LC_j - D_{ij}\}$.

An activity lies on the critical path if it satisfies the following conditions: (a) $ES_i = LC_i$, (b) $ES_j = LC_j$, and (c) $ES_j - ES_i = LC_j - LC_i = D_{ij}$. The conditions indicate that there is no slack or float time for critical activities.

To determine the total float (TF), the latest start (LS) and earliest completion (EC) times are obtained for activity (i,j). The formulae used are $LS_{ij} = LC_j - D_{ij}$ and $EC_{ij} = ES_i + D_{ij}$. Total float is $TF_{ij} = LC_j - EC_{ij} = LS_{ij} - ES_i$.

The critical path of the repair process is the sequence of activities that is associated with the greatest cumulative elapsed amount of time from the point when the hurricane hits to the point when all repair activities have been completed. The critical path is a path from the start node to the end node that consists entirely of critical activities. Any delays in the critical activities cause a delay in the overall repair completion time. As such, all critical activities have zero float time.

Analysis of Project Completion Probabilities

Since the time estimates for the activities in a PERT network involve some uncertainty, a measure of the probability that an activity is completed in a specific amount of time is developed. Network analysis is based on the central limit theorem, which assumes normality regardless of the parent distribution of individual activities. Applying the central limit theorem, the probability distribution of the critical path is approximately normally distributed where the mean, $E\{\mu\}$, is the sum of the individual expected completion times and the variance, $var\{\mu\}$, is the sum of the squares of the individual standard deviations of the critical activities.

The probability that the project can be completed in X time units (specified by the analyst) is computed as $P\left\{z \le \left(X - E\{\mu\}/\sqrt{\text{var}\{\mu\}}\right)\right\}$, where z is the standard normal distribution with mean zero and variance one.

A plot of the normal probability curve of completion time for the post-hurricane repair process based on the critical path is constructed. Using a normal probability plot, the probability that the process exceeds a certain amount of time can be determined. It is important to recognize that the analysis hinges on the identification and characteristics of the critical path. If activities are added or removed from the project's activity list, then the critical path and the probabilities of completion change. The critical path could change if one or more critical activities are completed in a shorter time than expected.

Resource Allocation and Crashing

Allocating additional resources to an activity to reduce its time duration is called *crashing* the activity. The expected time to complete the activity is called the *normal time* (NT), which is equivalent to the expected completion time, and the cost of completing the activity in this time is called the *normal cost* (NC). The shortest possible time in which an activity can be completed is called the *crash time* (CT), which is equivalent to the most optimistic completion time of each activity, and its associated cost is called *crash cost* (CC). The per time unit cost of reducing an activity, called the per unit crash cost is:

per unit crash cost = (CC-NC)/(NT-CT)

Because crashing a non-critical activity does not affect the overall project time to completion, only critical activities that can be crashed are considered. The activities to be crashed are chosen in order of increasing expense. Therefore, the activity with the smallest crash cost is chosen to be crashed first followed by the next highest crash cost. This progression continues until all critical activities have been crashed. The appearance of more than one critical path may arise. To reduce the time of the project, it is necessary to reduce the time of the critical paths simultaneously. The decision maker can perform a trade-off analysis between the savings in project time and the cost of crashing.

Analysis of Schedule Dependencies among Agencies

An analysis of scenarios depicting potential opportunities for schedule improvement can aid in the decision-making process of VDOT. Dependency scenarios of a particular region's experiences preceding and following a natural disaster in the past are gathered from various Virginia agencies such as VDOT, the Virginia Department of Emergency Management, the Virginia Department of Health, and the State Police. In addition, the scope of the research incorporated agencies in California, Florida, and North Carolina, including their respective state transportation agencies. Accounts of the agencies' experience with disaster recovery are gathered through phone interviews, emails, and facsimiles. The interviews include such questions as "What is a case in which you have not been able to start an activity you are responsible for because you are waiting on VDOT to complete a prerequisite task, and vice versa?" A list of the questions can be found in Appendix A.

Another source of schedule dependency scenarios is a report developed by the North Carolina Department of Transportation (NCDOT report, 2000) describing lessons learned from Hurricane Floyd. In particular, it evaluates the effectiveness of the resource allocation and communications and information management procedures following the hurricane, and discusses the intra-agency dependencies encountered caused by issues such as lack of equipment standardization. The report, which is based on interviews of staff members from the central office and field units, also includes suggestions for improvement.

A particular dependency scenario could apply within a range of geographic scales such as a specific city intersection, a whole group of city blocks, or an entire county. A scenario could also exist on any time horizon ranging from the hours and days following the disaster in the short term to the months and years in the long term.

Categorization of Dependency Scenarios

Each dependency scenario is classified according to the organizational function of the state transportation agency. Two organizational units have been determined and associated with each dependency scenario: one unit as the primary contributor and the other unit as the secondary contributor associated with the dependency. The categorization is used to identify the units that are the sources of a significant number of dependencies in order to highlight areas needing further examination and improvement by VDOT. The following categories are used:

- Administration
- Environmental, Planning, and Regulatory Affairs
- Equipment
- Finance
- Information Management (includes the communication and availability of the information to other agencies)

- Legal/Authorization
- Materials
- Operations (includes functions of field units, maintenance units, and loss control units)
- Personnel
- Structure and Bridge (includes the reconstruction or repair of roads, bridges, etc.).

Measurement of Dependency Scenarios

A methodology for measuring and comparing dependency scenarios is developed. Eight indices for measuring the dependency scenarios are proposed. The indices express the "size" of the dependency according to a three-level scale: *low*, *moderate*, and *high*.

The first index is *severity* of the dependency in terms of the length of time involved relative to a time horizon, which is either classified as the short term following the disaster (hours, days), the medium term (days, weeks), or the long term (months, years). The measure of severity according to a three-level scale is seen in Table 2.

Table 2. Severity measures using time horizon in order to determine magnitude of dependency

	Horizon		
Length of Time of Delay	Short Term	Medium Term	Long Term
Hours	High	Low	Low
Days	High	Moderate	Low
Weeks	High	High	Moderate
Months	High	High	High
Years	High	High	High

The second index refers to the *involved agencies* or the number of agencies affected by the delay. A value of *low* indicates the occurrence of an intra-agency delay within VDOT and that no other agencies are involved. A value of *moderate* indicates that one other agency is involved, while a value of *high* indicates that multiple other agencies are involved.

The third index represents the *likelihood* or the potential that the dependency will happen in the future. A *low* value indicates that the dependency is unlikely to occur. A value of *moderate* indicates that the dependency has not occurred in the past, but it is likely to occur in the future nonetheless. A value of *high* indicates that the dependency has occurred in the past and is likely to occur again.

The fourth index considers the *items waited on* by an agency, which include personnel, materials, equipment, and authorization. If no items are waited on, a value of *low* is given. If one item is waited on, a value of *moderate* is given. A *high* value is given if a combination of several items is being waited on.

The fifth index is *controllability* or the ability to control the cause(s) or components of the dependency. A value of *low* indicates that a resolution for the dependency is being developed for the future at a low cost. A value of *moderate* indicates that alternatives are being considered for the future but a resolution would have a high cost. A value of *high* indicates that nothing can be done to avoid the dependency in the future.

The sixth index considers *cascading effects* brought about by the dependency. Cascading effects signify the extent to which the delay serves as input to more delays and/or problems or the scope of the succession of subsequent delays and/or problems that arise from the delay. The effects are measured according to the magnitude of the scope.

The seventh index is *maturity,* which is the level of preparation and development associated with the procedures or activities involved. Examples are the level of training performed and instruction received by the workforce involved and the extent to which the procedures involved have been practiced.

The eighth index measures the *prevalence of similar scenarios,* which takes into account if the scenario is an isolated instance or if it occurs in numerous situations.

All eight indices and their measurement on a three-level scale are summarized in Table 3.

Table 3. Summary of index definitions for measuring the magnitude of a dependency according to a three-level scale

	Scale		
Index	Low	Medium	High
Severity	See Table 2	See Table 2	See Table 2
Involved Agencies	No other agencies	One other agencies	Multiple agencies
Likelihood	Unlikely to occur	Has not occurred in the past, but likely to occur	Has occurred in the past, likely to occur again
Items Waiting on	None	One item	Combination of many items
Controllability	Controllable at low cost	Controllable at high cost	Uncontrollable
Cascading Effects	None	One	Multiple
Maturity	Mature	Immature	Highly immature
Number of Similar Scenarios	None	One	Many

Graphical representation of the scenarios based on the indices is utilized in order to better understand the dependency and to compare the magnitude of multiple scenarios.

Development of Decision Support for Resource Allocation for Hurricane Recovery

Post-event activities include the activities aimed to repair the highway system following a natural disaster and include those activities taking place in the short-, medium-, and long-term time horizons following the disaster. To effectively aid in the decisions of which highway repair projects to undertake with available funds following a hurricane, multiple objectives need to be considered. The objectives need to be incorporated into a comprehensive tool that effectively communicates relevant data and ideas to decision-makers in VDOT and other state agencies. An equitable balance among risk reduction, performance gain, and resources (including cost) needs to be developed.

In order to evaluate individual activities against risk reduction, performance gain, and resources used, indices of performance are proposed to quantify the objectives and to evaluate the effectiveness of post-event activities:

For the risk reduction objective, the indices are:

- Lives saved (in week following disaster strike)
- Decrease in safety hazards (in months following disaster strike)
- Decrease in environmental threats (in years following disaster strike)

For the performance gain objective, the indices are:

- Travel time saved (minutes per peak hour)
- Increase in ADT (average daily traffic)
- Number of lanes cleared and rebuilt (in months following disaster strike)
- Increase in accessible critical facilities by highway network (in week following disaster strike)
- Number of people affected (population density statistics)
- Road type (interstate, primary, or secondary roads)
- Length of road section (miles)

For the resources objective, the indices are:

- Estimated cost of completion ($)
- Use of materials
- Personnel

Once the objectives are quantified, the evaluation of activities using multiple criteria can help show the tradeoffs of each activity for every objective. Multi-objective charts are created where the post-event activities are plotted in three dimensions.

Figure 5 shows the purpose of the decision tool. A, B, C, and D represent various post-event activities, which could include bridge scour, debris removal, slope repair, and bridge repair. Performance indices are used to label the horizontal and vertical axes. The activities that perform better against the performance gain metric are positioned above others, whereas activities that perform well against the risk reduction metric are plotted to the right of others. Activities that maximize both performance gain and risk reduction are plotted in the upper right hand corner of the graph. The activities that are do not perform well against the chosen indices are located closer to the lower left-hand corner near the origin.

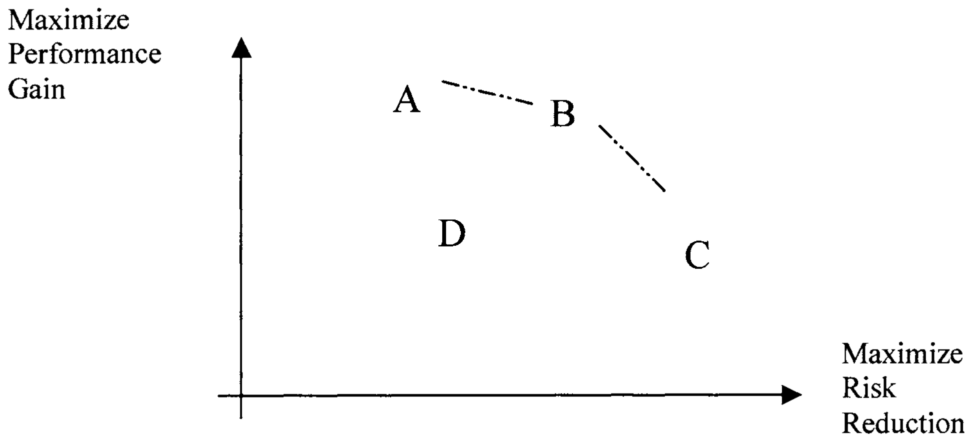

Figure 5. Multi-objective tradeoffs in resource allocation in disaster recovery

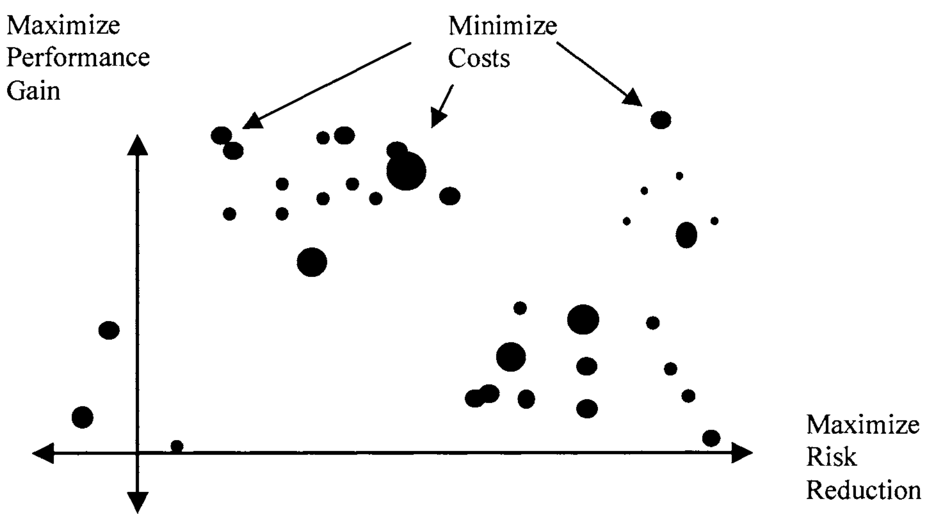

Figure 6. Multi-objective tradeoffs in three dimensions in resource allocation for disaster recovery

Figure 6 accounts for three objectives by making the size of the data point proportional to the estimated cost of the post-event activity. Larger circles represent activities with relatively large costs, and activities with relatively small costs are represented with smaller circles.

Characterization of Preparedness and Recovery Alternatives

The aftermath of natural disasters can have road systems in complete disorder resulting in having some communities stranded. There are numerous alternatives that are available to aid a state transportation agency in its preparations before a hurricane and its recovery efforts after a hurricane. To help perform a better assessment of the risks, costs, and benefits of these preparedness and recovery alternatives, a tool is developed to aid the evaluation of alternatives.

Road systems can be enhanced through the attributes of redundancy, robustness, and resilience. Improving the resilience of the system consists of returning the system back to normal with minimal replacement of materials or upgrading of systems. It attempts to have the system "bounce back" immediately after the hurricane. Improving the robustness of a system seeks to upgrade the system so that road systems are stronger and can withstand stronger hurricanes. It might seek to improve the maximum wind velocity or the higher storm surge it can handle. Improving the redundancy of the system consists of adding a number of equipment in a certain area so that if one piece of the system fails, the system can still function because backup units are available.

Furthermore, each alternative is looked at to show whether it is most associated with pre-event (before the hurricane) or post-event (after the hurricane) activities. The pre-event and post-event phases are broken further into short, medium, and long term. Short-term events are the hours to days before the hurricane hits. Medium-term refers to weeks and months during the hurricane season. Long-term events are preparations performed years in advance. The same time periods apply for post-events except that the aftermath of the hurricane is addressed.

In addition to the time periods, an alternative can be characterized in terms of its impacts. The impacts of each alternative are based on VDOT's goals of protecting life, property, and the environment. The impacts include cost, recovery time saved, human lives and the safety of the public, economic impact to the community, property saved, and protection of the environment.

The study also looks at how each alternative protects against stronger winds, prevents against higher storm surges, or handles increased traffic. An alternative can also be characterized by whether or not it aids in the evacuation or repopulation of the area.

A template for the characterization of preparedness and recovery alternatives is developed. Each cell can have a filled circle, a half-filled circle, or no entry, depending on the characterization of the alternative. A filled circle signifies that an alternative has a major impact in that characteristic. A half-filled circle suggests minor impact, while no entry implies that the alternative does not display such characteristic. For instance, if the alternative enhances the system through robustness, then robustness would receive a filled circle. Likewise, if the alternative contributes to savings in time and cost, then filled circles would be placed in the respective cells. If there is only minor impact, then a half-filled circle is used. The proposed framework is applicable to a wide range of alternatives and disaster scenarios.

Decision Trade-off Analysis on Recovery and Preparedness Alternatives

Each type of road system has a different level of robustness, redundancy, and resilience. There needs to be a model that predicts road system damage in a hurricane of a particular category given the strength and the inventory status of each equipment type, both in storage and on the roadways. Various enhancement alternatives can be considered to improve resilience, robustness, or redundancy.

One hypothetical alternative might be to enhance all shoulder-mounted and cantilever signs, with respect to robustness, so that the maximum wind speeds these two types of equipment can withstand will increase by 20 mph, and forego enhancing any other road systems. As a result, monetary expenditures may be minimized while recovery time and repair costs may increase. Another alternative might be to enhance all sand dunes, with respect to redundancy and robustness, so that the maximum storm surge level the road system can withstand will increase by 4 ft, and forego any other enhancements.

To better define the degree of enhancing road systems, it is necessary to know the measurements of road systems in terms of ultimate wind velocity, ultimate storm surge level, and maximum sustainable traffic flow. The ultimate wind velocity is the maximum wind speed a single road system can withstand without failure. The ultimate storm surge is the maximum amount of flood level a single road system can withstand without failure. The maximum sustainable traffic flow is the maximum number of traveled vehicles over the road system without failure. It is possible that not all road systems can be enhanced with regard to wind velocity, storm surge, and traffic flow.

Table 4 shows examples of road systems rated from low to high, signifying the degree of immediate threat that wind, storm, or traffic wear has on the particular road system. A full circle signifies high threat, which can be interpreted as the most immediate threat that wind, storm, or traffic may have to the road system. Similarly, a half-filled circle represents a medium threat while no circle represents a low threat.

In order to analyze the different attributes, three levels of enhancement are considered. Furthermore, wind speeds, storm surge levels, and traffic flow are enhanced by increments of 10 mph, 1 ft, and 500,000 vehicles, respectively. As an example, a non-enhanced cantilever sign can withstand a maximum wind speed of 117 mph. Enhancing to the first level or grade will bring the maximum wind speed that the sign can withstand to one 127 mph. The second enhancement grade increases the ultimate wind velocity by 20 mph, and the third increases the ultimate wind velocity by 40 mph. Table 5 summarizes the three levels of enhancement. These levels of enhancement are denoted as the two letter symbols, for example, w1 refers to a wind velocity enhancement of 1 level, i.e., 10 mph.

Table 4. The immediacy of threat that wind velocity, storm surge and traffic flow have on various road systems

Damageable Road Systems	Ultimate wind velocities (mph)	Ultimate storm surge (feet)	Maximum sustainable traffic flow (# vehicles)
Signs, Signals and Lights			
Shoulder-mounted signs	●	◒	
Cantilever signs	●	◒	
Two-pole span signs	●	◒	
Traffic signals systems	●	◒	
High mast lighting structures	●	◒	
Roadway lighting structures	●	◒	
Bridges			
Beam Bridges		◒	●
Truss Bridges		◒	●
Tunnels			
Soft ground		●	◒
Sub aqueous		◒	●
Smart highway systems			
Motion detectors	●		◒
Alert signs	●		◒
Cameras			
Radar detectors	●		◒
Flood Mitigation			
Sand dunes	◒	●	
Rocks	◒	●	

Table 5. Enhancement options and levels notation

Enhancement levels	Enhancement Options		
Each advancement in the enhancement level refers to: *+10 mph in Ultimate Wind Velocity (w)* *+1 foot in Ultimate Storm Surge Level (s)* *+ 500,000 in maximum sustainable traffic flow (t)*	Wind Velocity (w)	Storm Surge (s)	Traffic Flow (t)
Enhancement level 0: *- No change*	w0	s0	t0
Enhancement level 1: *- Advance one enhancement level from level 0*	w1	s1	t1
Enhancement level 2: *- Advance two enhancement levels from level 0*	w2	s2	t2
Enhancement level 3: *- Advance three enhancement levels from level 0*	w3	s3	t3

The notation proposed allows the precise definition of an alternative that specifies the level to which each type of road system is enhanced.

Each alternative has the ability to enhance a variety of road systems to different levels. While one alternative may enhance bridges more than smart highway systems, due to a flood prone environment, another alternative may enhance only signs, signals and lights in an attempt to minimize fallen debris on highways. Either way, these alternatives allow VDOT to understand how to enhance a wide variety of road systems that are affected by hurricanes. With the knowledge and the tool provided by the project, VDOT can make educated decisions about which alternatives are more cost and risk efficient.

The enhancement alternatives comparison tool is implemented in a Microsoft Excel spreadsheet. The main methodology that the comparison tool follows involves comparing the enhancement of a single road system to different levels with respect to wind speed, storm surge and traffic wear. The model cannot compare the costs and benefits of multiple road systems against a different array of alternatives. It is limited to analyzing the enhancement capabilities of one road system at a time. The comparison tool has the flexibility to analyze any road system with respect to any enhancement option. VDOT may consider using additional options other than wind speed, storm surge, and traffic flow. The tradeoff analyses can provide VDOT with important information about the costs, risks, and benefits of enhancing a road system.

The comparison tool requires input from the user. The access to accurate, historical data is important to the success of the use of the tool. The type of road system to consider and the design alternatives are required. For each design alternative, the user supplies the name, cost of reconstruction, and design load, which is the wind speed in miles per hour that the road system is designed to withstand without having significant damage.

In order to assess the relationship between wind speed and damage, three questions are asked:

1. What is the greatest wind velocity that results in no damage cost?
2. What is the repair cost of VDOT equipment for a wind speed equal to the design load?
3. What is the lowest wind speed that results in total reconstruction cost?

The resulting estimated relationship is called the damage function. The answers to these questions give three points on a graph of (repair cost)/(reconstruction cost) versus (impact force)/(design load) as shown in Figure 7. The first and third questions are answered in terms of percentages of design load. The answer to the second question is in terms of a percentage of reconstruction cost. With respect to Figure 7, the answer to the first question gives a point on the horizontal axis from where the function begins to increase linearly. The next question locates a point where the horizontal coordinate is 1 because the wind speed is equal to the design load. The answer to the question gives the value for the vertical component of the point. Answering the third question locates a point where the vertical component is always 1 but the horizontal component depends on the answer. An assumption made is that the non-dimensional relationship assessed is applicable to all of the relevant alternatives.

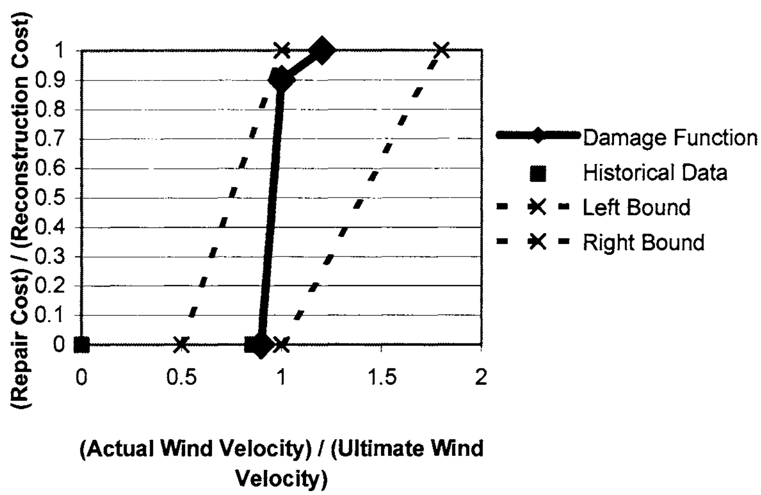

Figure 7. Damage function plotted along with historical data

Historical data on actual wind speed-related incidents are also obtained. The data entered should be relevant to impacts on the road system of concern because impacts on other road systems might not have the same repair cost. The historical data are plotted along with the relationship assessed previously. From the plot, the closeness of the damage function to the historical data is determined. If the damage function and historical data are significantly different, the estimated relationship can be modified to better reflect the historical trend. It is, however, possible that historical data may not be very close to the real relationship especially when there is little relevant data on actual wind speed impacts. The historical data are not used to calculate damage directly; they help in the modeling only as a basis for comparison with the estimated relationship. It is assumed that a straight-line interpolation of the points assessed is sufficiently accurate to describe the relationship.

The relationship between wind speed and time to recover is also assessed. Time to recover is the time it takes to repair the road system so that it is functional and operable. As with wind speed and damage, questions are asked to determine the relationship with wind speed and time to recover. Historical data on the time to recover after wind speed impacts (up to four accidents) are obtained. A comparison between the estimated relationship and historical trend is performed and subsequent adjustments may be made. Figure 8 shows an example of the relationship between wind speed and time to recover.

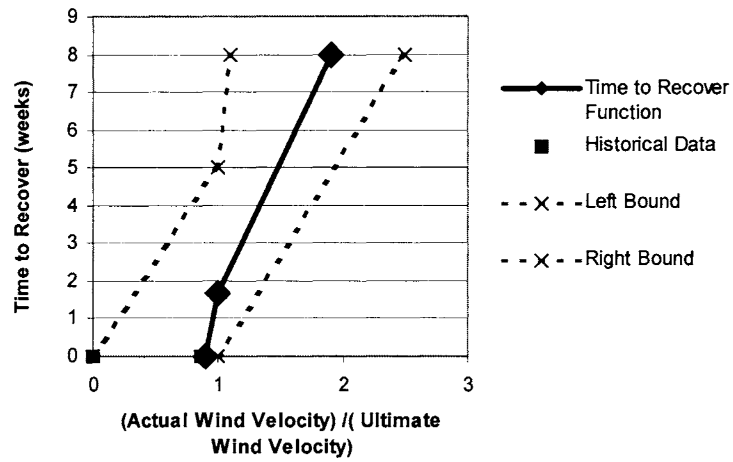

Figure 8. Plot of time to recover versus wind impact for historical data and estimated relationship

Information about closure costs is also important. For different lengths of closure of the road system, an estimate of the cost to industry is needed.

The data obtained are used to calculate the costs of construction of the alternatives and various risk metrics. The reconstruction cost is plotted on the vertical axis, while a risk metric is plotted on the horizontal. In this way, the user could see the present investment and the risk of a wind speed accident. There are four risk metrics that describe the consequences of a wind speed impact:

1. Ratio of Repair Cost-to-Reconstruction Cost
2. Repair Cost
3. Time to Recover
4. Cost to Industry

Three scenarios of wind speed under which to evaluate the alternatives are considered. For each scenario, the hurricane magnitudes and the return period of the event are pre-set as hurricane categories [I to II], [III], and [IV to V]. Information pertaining to the return periods is provided in Table 6.

Table 6. U.S. mainland hurricane strikes by states, 1900-1996
(National Hurricane Center, 1999)

Area	Category Number					All	Major
	I	II	III	IV	V		
U.S. Texas to Maine	58	36	47	15	2	158	64
Texas	12	9	9	6	0	36	15
Louisiana	8	5	8	3	1	25	12
Mississippi	1	1	5	0	0	7	6
Alabama	4	1	5	0	0	10	5
Florida	17	16	17	6	1	57	24
Georgia	1	4	0	0	0	5	0
South Carolina	6	4	2	2	0	14	4
North Carolina	10	4	10	1	0	25	11
Virginia	2	1	1	0	0	4	1
Maryland	0	1	0	0	0	1	0
Delaware	0	0	0	0	0	0	0
New Jersey	1	0	0	0	0	1	0
New York	3	1	5	0	0	9	5
Connecticut	2	3	3	0	0	8	3
Rhode Island	0	2	3	0	0	5	3
Massachusetts	2	2	2	0	0	6	2
New Hampshire	1	1	0	0	0	2	0
Maine	5	0	0	0	0	5	0

Graphs that show the tradeoffs among the alternatives under the wind speed scenarios are produced. The final choice of a design is based on the user's best judgment after looking at the tradeoffs under the different scenarios. The decision is usually not fully determined by the tool. There may be factors that cannot be measured which affect the decision. For example, a user or stakeholder of the industry might not choose any enhancement that has even a small-expected downtime because of inconvenience to motorists. This inconvenience is difficult to measure.

The analysis performed assumes that any damage however minor will be repaired. If the assumption is not true, then repeated occurrences of a certain type of event such as a moderate wind speed impact could cause greater consequences than what the model in the tool predicts. The model assumes that the road system is in undamaged condition before an event occurs.

The comparison tool can also be used to analyze the storm surge. The method of analysis is the same as that with wind speed.

RESULTS AND DISCUSSION

Development of a Software-Based Platform for Recovery Priorities

Classification of Critical Facilities

Critical facilities are the facilities that provide those services that people need to go about their lives. Figure 9 gives the Hierarchical Holographic Model of types of critical facilities.

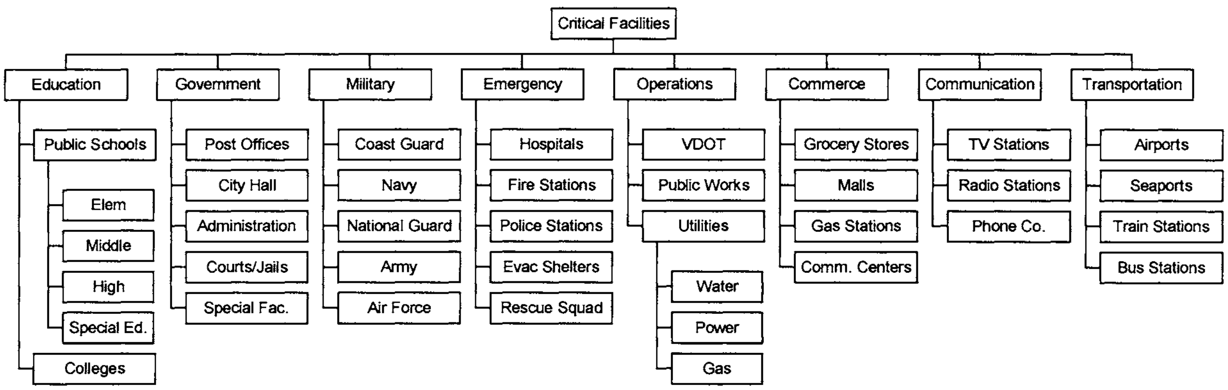

Figure 9. Classification of critical facilities

Education facilities are vital to the restoration of normal life in a community. While schools would expect to be out for a few days, safely returning the children to school as quickly as possible is important. The safe return to school includes the transportation to and from school (buses). Schools are broken down into sub-categories of elementary, middle, and high schools; special education centers; and colleges. Schools can also be important because some of them serve as evacuation centers, though a school functioning as an evacuation center moves into the emergency facilities category.

Government facilities can be important to the recovery process, because restoring normal government action is a key part of restoring a community to normal life. Some government facilities may require immediate access, but most fall into longer-term repair of the community. Sub-categories include post offices, local government administrative buildings, courts, jails, and other specialized government offices and buildings.

Military facilities are fundamental to national defense. It is vital that access to them is restored in a timely manner. The National Guard may also be called in during a disaster for a variety of reasons from preventing looting to rescuing people. For this to happen, access to military facilities must be restored. The military facilities category is divided into branches of the military: Army, Navy, Air Force, Coast Guard, and National Guard.

Emergency services are obviously extremely important resources. Emergency facilities must have access restored to them as quickly as possible, as the immediate aftermath of a disaster will require them. They are not only important in the short term, but very important to the long-term recovery plans as well. Emergency facilities are divided into hospitals, fire stations, police stations, rescue squads and ambulance services, and evacuation shelters. Facilities in the emergency category are all very important to maintain public health and safety. Evacuation shelters are a subset of the schools category because certain schools are usually used as evacuation shelters during and immediately following a disaster.

Facilities that fall in the operations category are facilities that make the community run, including VDOT facilities, public works centers, and utility stations such as power plants, gas hubs, and waterworks. Operations facilities are needed to make the certain vital services work, and restoring these vital services as soon as possible after a disaster may be the most important task in the short-term recovery following a disaster. While the general population does not need access to these facilities, workers do need access and they need it as soon as possible.

Commerce is a broad category of facilities and will contain the greatest number of facilities in the Hampton Roads District. In the short term, people need to get to the store to buy food and other necessities. They need to get to gas stations to fill up their cars. In the long term, businesses need to reopen and return to life as normal. One of the main objectives in long-term recovery is to reestablish commerce as normal in the community. Commerce facilities include sub-categories of grocery stores, gas stations, restaurants, banks, and centers of commerce.

Communications facilities are very important to both short- and long-term recovery. In the short term, people need to be able to communicate with one another and with authorities (911 service). People also need to be able to receive information via television, radio, Internet, or other media. Communications facilities include TV stations, radio stations, telephone company facilities, and internet providers.

Facilities for modes of transportation include airports, seaports, train stations, and bus stations. Restoring access to these facilities is necessary to long-term recovery and restoring life to normal but can also be important in short-term recovery and acute crisis.

Figure 10 shows how some of these data look in ArcView. This particular view shows critical facilities and roads in the Hampton Roads area.

Priority Setting Tool

The recovery priority setting tool developed allows the user to determine the factors to include in the calculation of the priority score. This translates into the user including the data in the model with high values leading toward high priority, including the data in the model with low values leading to a high priority, and not including the data in the model. These choices allow a user-friendly way to create the model and give the user total control over the data going into the prioritization model and how it is used. Instructions on how to use the priority setting tool can be found in Appendix B.

Figure 10. Critical facilities and roads displayed in ArcView

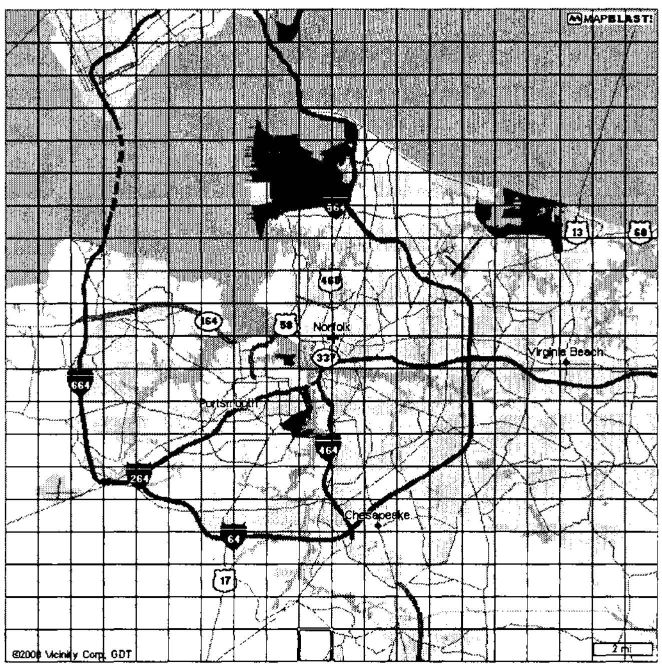

Figure 11. The grid method

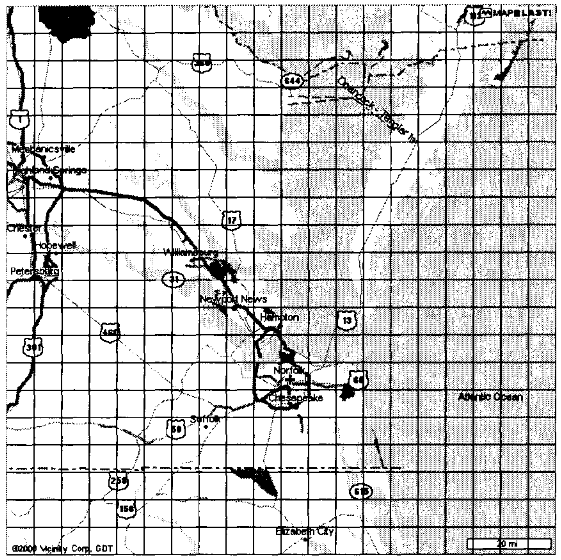

Figure 12. Large-scale map for district-wide priorities

An example of the grids that underlie the prioritization model is seen in Figure 11. The entire Hampton Roads District can be covered with maps such as this one (at this scale). In addition, a map with a much smaller scale that shows the entire district can also be used. There are also other maps at a significantly larger scale that will show priorities for certain heavily populated areas. The suite of maps contains a small-scale wide-area map that sets priorities for the entire district, full coverage of the district at the scale shown in Figure 11, and some large-scale small-area maps that zoom in on heavily populated areas that need prioritization at one more level down.

The data collection and modeling techniques are the same no matter how big or small the area of the map.

An example of the district-wide prioritization map is found in Figure 12. There is little detail, but the map is useful insetting large aggregate priorities across the district. The district-wide map gives the user an idea of the important areas which need to be examined at an increased level of resolution in further analysis. Figure 13 is an example of the highest level of zoom (smallest scale) that this prioritization model supports. These maps will only be used in populated areas (in rural areas there might be only two or three roads across this whole map at this level of zoom). The data collection and modeling techniques are the same no matter how big or small the area of the map.

The user inputs data to determine the priority scores of each grid section. While the output score is not necessarily a meaningful quantity, it is interpreted based on how it compares with the other cells in the grid model. The actual score may carry units of facility-people per mile of road. The relative scores show which five cells are the highest priority and which are the lowest.

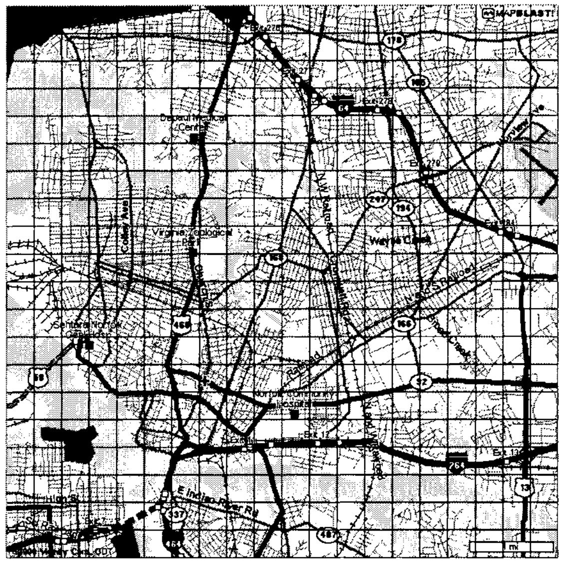

Figure 13. Small-scale map for in-depth analysis of populated areas

There are several ways to view the results. The first is by color-coding the map cells with high, medium, and low priorities. The user may pick whatever percentages they wish to break up the three categories, such as 20%/60%/20% or 33%/33%/33%. An example of that output is shown in Figure 14.

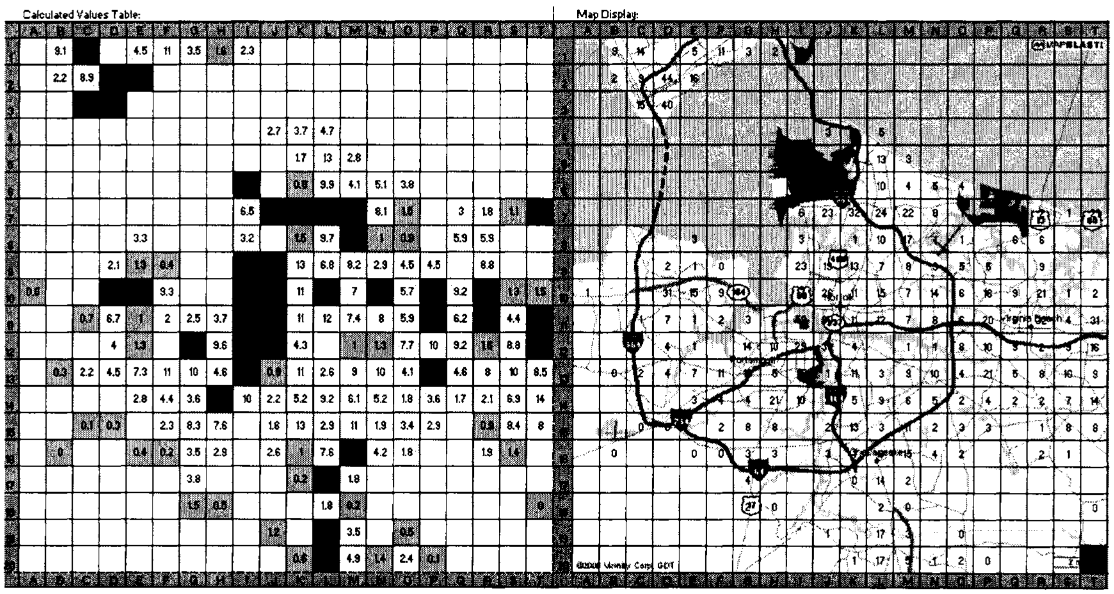

Figure 14. Output analysis of priority setting tool

The left side of Figure 14 is an example of how the user views the output, with the darkest shaded cells indicating high priority, moderately shaded cells signifying low priority, and light shaded cells showing medium priority. Cells with no shading exist when there is no data, most likely where there is an unpopulated area such as ocean or swampland. The right side of Figure 14 is the map with the priority scores laid over the map for use in comparing scores of different areas. This allows the user to see the underlying land area.

There are literally thousands of different combinations of models that could be used as criteria for the prioritization. There are various combinations of facilities, road types, and whether or not to include population and the various user inputs, which could be anything. One of the objectives for this project is to prioritize disaster recovery on a short, medium, and long-term basis.

Table 7 contains several suggestions for short-term, medium-term, and long-term recovery models.

Table 7. Sample models

Time domain	Example priority setting model
Short-term	1) Emergency facilities * population / interstate mile 2) (Ops. + Trans. + Mil.) / primary route mile 3) Schools (Evac. Shelters) * population / interstate mile
Medium-term	1) Schools * population / US highway mile 2) (Comm. + Trans.) * population / primary route mile 3) (Emerg. + Ops. + Mil.) * User Input [damage indicator]
Long-term	1) Commercial * population / primary route mile 2) (All facilities) * population / User Input [recovery cost] 3) (All facilities) * population / secondary mile

The models contained in Table 7 are only samples, though these are all practical models. The point is to show examples of the numerous models that exist and how the user can go about creating models.

Time-to-Recovery Analysis

To illustrate the framework used in the time-to-recovery analysis, a hypothetical repair process is considered. Using information gathered from interviews with VDOT personnel, Table 8 lists the typical repair activities that are completed during the post-hurricane process. Each of the activities has an associated letter and list of prerequisite activities called *predecessors* that must be completed before the activity can begin. For example, task E, which is the disbursement of plans to contractors and VDOT inventories, cannot begin until task C, the definition of damaged equipment, and task D, repair plan preparation, have been completed. The repair project is considered complete at the close of task K, when payment is made to contractors.

Table 8. Descriptions of activities of a hypothetical repair process

Task	Description	Immediate Predecessor(s)
A	Damage assessment conducted	None
B	Requests for resources formulated	None
C	Equipment that must be replaced is defined	A
D	Final repair plans prepared	B
E	Plans and schedules disbursed and responses obtained from VDOT inventories/contractors	C, D
F	Resources and contractors assigned to damaged areas	E
G	Contractors examine inventory	C, F
H	Contractors place order/manufacture equipment	G
I	Install equipment	H
J	VDOT conducts inspections	I
K	Contractors paid	J

A network diagram demonstrating the relationships among the tasks outlined in the Table 8 is shown in Figure 15. The repair project begins on the left, with the start of tasks A and B, which then lead into tasks C and D, respectively.

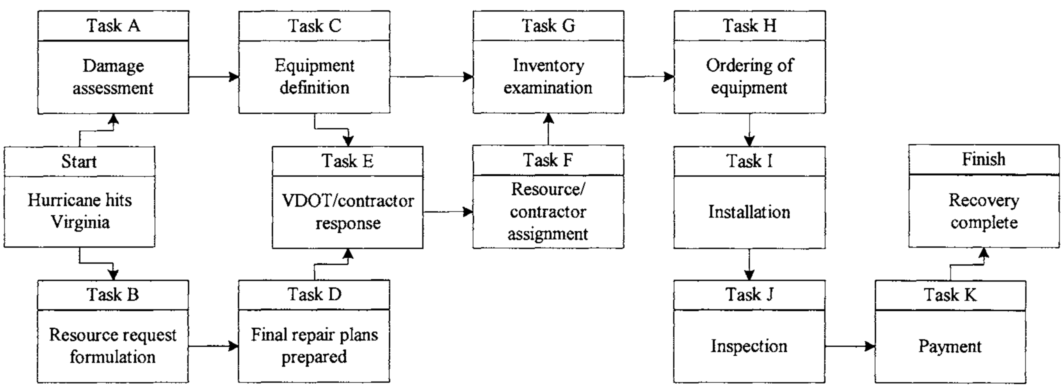

Figure 15. Network diagram of the dependencies among post-hurricane repair activities

Table 9 lists the most optimistic time, most likely time, and most pessimistic time associated with each of the 11 tasks given in Table 8. The three durations of time have been estimated for a Category II hurricane (95-115 mph wind speeds) through interviews with the Richmond EOC, the Suffolk TMS, and the Charlottesville VTRC staff. The table also lists the expected time and standard deviation associated with each task. The table reveals that task I, the installation process, is the most time-consuming activity with an expected time of 6.5 weeks and is also associated with the greatest uncertainty with a standard deviation of 0.83 weeks.

Table 9. Time estimates of the post-hurricane repair process

Task	Time Estimates (weeks) Most optimistic (a)	Most likely (m)	Most pessimistic (b)	Expected Time (t_e)	Standard Deviation (σ)
A – Damage assessment	2	3	4	3	0.33
B – Resource request formulation	1	2	3	2	0.33
C – Equipment definition	1	2	3	2	0.33
D – Final repair plan preparation	1.5	2	3	2.08	0.25
E – Response from VDOT or contractors	2	3	5	3.17	0.50
F – Resource and contractor assignment	1	2	3	2	0.33
G – Inventory examination	1	1.5	2	1.5	0.17
H – Ordering equipment	2	4	6	4	0.67
I – Installation	5	6	10	6.5	0.83
J – Inspection	2	3	4	3	0.33
K – Payment	3	4	5	4	0.33

The activity statistics for each task are computed. The earliest start and completion times, the latest start and completion times, and the total free float for each task can be found in Table 10.

Table 10. Activity statistics (in weeks) of each repair task

Task / Activity (i,j)	Expected Duration (D_{ij})	Earliest Start Time (ES_i)	Earliest Completion Time (EC_{ij})	Latest Start Time (LS_{ij})	Latest Completion Time (LC_j)	Total Float (TF_{ij})	Critical activity?
A	3	0	3	0	3	0	Yes
B	2	0	2	0.92	2.92	0.92	No
C	2	3	5	3	5	0	Yes
D	2.08	2	4.08	2.92	5	0.92	No
E	3.17	5	8.17	5	8.17	0	Yes
F	2	8.17	10.17	8.17	10.17	0	Yes
G	1.5	10.17	11.67	10.17	11.67	0	Yes
H	4	11.67	15.67	11.67	15.67	0	Yes
I	6.5	15.67	22.17	15.67	22.17	0	Yes
J	3	22.17	25.17	22.17	25.17	0	Yes
K	4	25.17	29.17	25.17	29.17	0	Yes

Figure 16 is used to identify the activities on the critical path. According to the time estimates collected, the critical path in the VDOT repair process is represented by A-C-E-F-G-H-

I-J-K. This path is associated with the greatest amount of overall completion time. The only activities not included on the critical path are tasks B and D. The time duration of the path, which represents the overall time to completion of the repair process, is equal to 29.17 weeks, or just over 7 months.

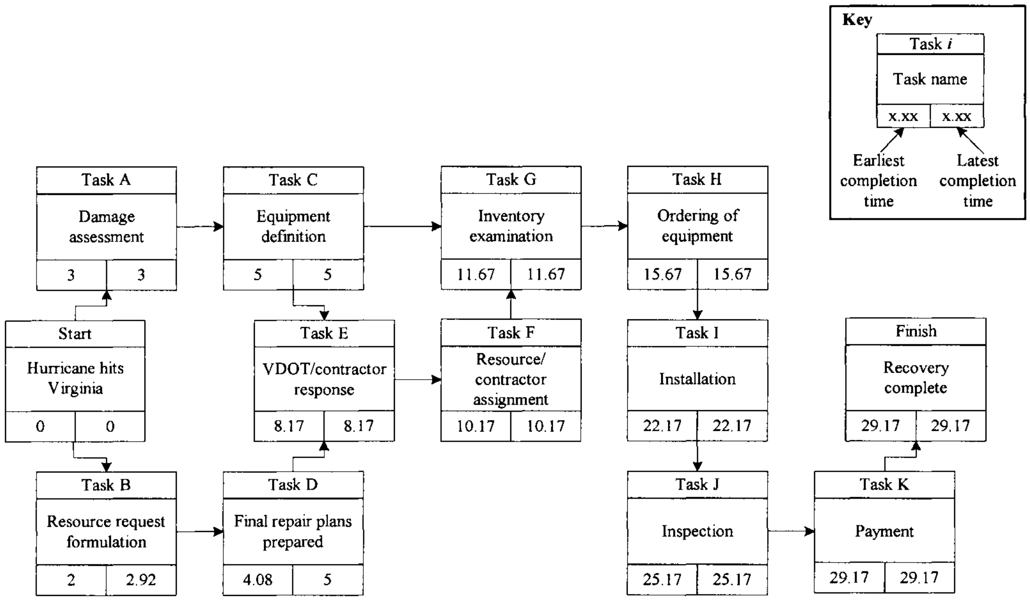

Figure 16. Network diagram of the post-hurricane repair process showing the critical path, the earliest expected completion date, and the latest allowable achievement date for each activity

Since the time estimates for the activities in a PERT network involve some uncertainty, a measure of the probability that an activity is completed in a specific amount of time has been developed. According to the central limit theorem, the probability distribution of the completion date for the repair process is normally distributed. The mean and the variance are determined where the mean is the sum of the individual expected completion times of the critical activities (29.17 weeks) and the variance is the sum of the squares of the individual standard deviations of the critical activities (1.9722 weeks^2).

Figure 17 is a plot of the normal probability curve of completion time for the post-hurricane repair process based on the critical path consisting of A-C-E-F-G-H-I-J-K and the mean and standard deviation calculations from Table 9. Using a normal probability plot, the probability that the process exceeds a certain amount of time can be determined. For example, using normal probability tables, the probability that the overall repair process completion time is greater than thirty weeks is 0.2766. Therefore, there is a 27.66% chance that the repair process is delayed.

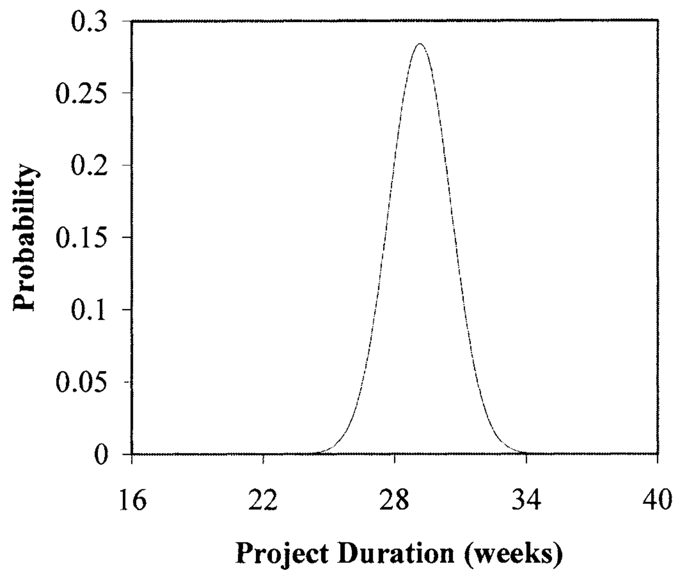

Figure 17. Process completion time distribution

It is important to recognize that this analysis hinges on the identification and characteristics of the critical path. If activities are added or removed from the project's activity list, then the critical path and the probabilities of completion change. The critical path could change if one or more critical activities are completed in a shorter time than expected. If the combined expected time duration of Activities A and C is reduced to three weeks, the critical path changes, and the combined time durations of Activities B and D (three and a half weeks) become more significant. For example, Activities A and C could be completed ahead of schedule because the storm damage is concentrated in a small area. The critical path changes to B-D-E-F-G-H-I-J-K because the overall expected time to completion of the path B-D-E-F-G-H-I-J-K is longer than the expected time to completion of the revised path A-C-E-F-G-H-I-J-K. Figure 18 is a plot of the normal probability curves of completion time for the two paths.

The new, lower curve to the left (representing the critical path B-D-E-F-G-H-I-J-K) of the original probability plot (representing the path A-C-E-F-G-H-I-J-K) shows that it is feasible for the repair process to be completed in less time than the current schedule requires. The faster completion time becomes possible when Activities A and C are completed ahead of schedule.

It is desired to determine the effect of allocating additional resources to an activity to reduce its time duration, also known as *crashing* the activity. Table 11 lists the normal time, normal cost, crash time, and crash cost for each activity. The data has been gathered from interviews with VDOT personnel. The cost values listed are based on the damage associated with a Category II (95-115 mph wind speeds) hurricane. Costs for activities such as contractor and VDOT inventory response (task E), and payment costs (task K) are the administrative costs involved with these activities.

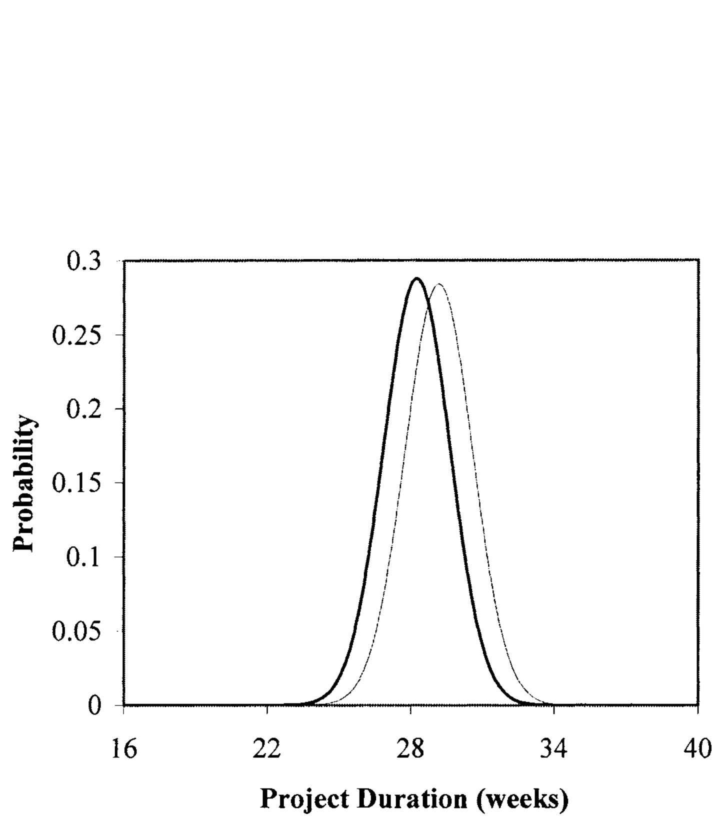

Figure 18. Probability distributions for the critical path and near-critical path

Table 11. Normal and crash data for the VDOT Hurricane recovery project

Task	Normal Time (wk)	Crash Time (wk)	Normal Cost ($)	Crash Cost ($)	Per Unit Crash Cost ($/wk)
A*	3	2	35,000	50,000	15,000
B	2	1	15,000	20,000	5,000
C*	2	1	5,000	7,000	2,000
D	2.08	1.5	10,000	15,000	8,621
E*	3.17	2	5,000	10,000	4,274
F*	2	1	7,500	9,000	1,500
G*	1.5	1	5,000	6,000	2,000
H*	4	2	50,000	75,000	12,500
I*	6.5	5	2,500,000	3,500,000	666,667
J*	3	2	30,000	40,000	10,000
K*	4	3	10,000	15,000	5,000

*Task lies on the original critical path.

Because crashing a non-critical activity does not affect the overall project time to completion, only critical activities that can be crashed are considered. The activities to be crashed are chosen in order of increasing expense. Therefore, the activity with the per unit crash cost in Table 11 (task F) is chosen to be crashed first. Thus, the time required for task F decreases from 2 to 1 week in length, and the project cost increases by $1,500. The next activity to be crashed is task G because it has the next highest per unit crash cost. This progression continues until it is no longer possible to reduce the project time. Figure 19 shows how the cost of the VDOT post-hurricane repair process increases as activities are crashed.

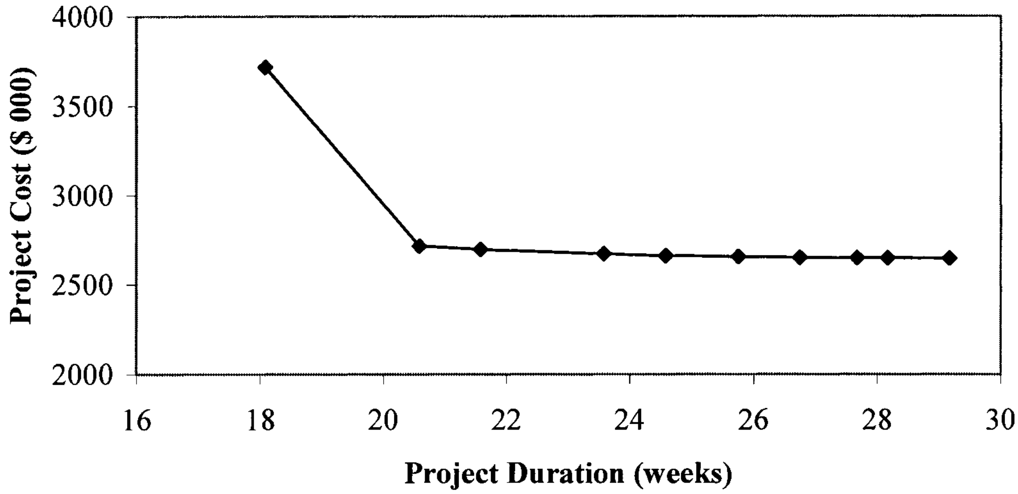

Figure 19. Project cost as a function of completion time for the VDOT hurricane recovery project

Though the project costs remain stable across continual reductions in project time, a significant cost change (increase of more than $1,000,000) occurs when reducing the project time to less than twenty weeks, which results from the crashing of task I, the installation process. Figure 19 indicates that overall project completion time by almost ten weeks without significantly increasing costs (cost increases by $70,000). Trying to reduce the time to recovery beyond the twentieth week is not recommended unless the equipment installation process is improved to incur lower initial costs, which reduce the rise in total expenditure that results from crashing.

The analysis shows that, because nearly all of the activities lie on the critical path, the current schedule of repair activities is sensitive and highly dependent on a majority of the activities being completed on time. The overall repair process completion time can be reduced if the individual activities lying on the critical path of the repair process are completed in less time. The length of time required by an activity depends on the resources available. For example, if more personnel are assigned to the assessment of damage (task A), then A could become a non-critical activity. PERT modeling reveals that, according to the data collected, the installation procedure (task I) is the lengthiest and most variable activity. Therefore, pre-hurricane investments should be further investigated in terms of the impact additional resources have on the time to completion of the installation process. Tradeoff analysis reveals that the length of time required to complete the activities lying on the critical path of the repair process can be reduced from twenty-nine weeks to twenty-one weeks with additional cost of $70,000. If VDOT desires to reduce it to eighteen weeks, then it would have to determine if the additional cost of $1,000,000 needed to allocate more resources is worth the additional three weeks reduction.

Analysis of Schedule Dependencies among Agencies

Table 12 shows five dependency scenarios, where each row characterizes a different scenario, and each column represents a different category. Additional columns provide an index number and title associated with the scenario, as well as the name, state, and type (Communication, Environmental, Fire, Health, Military, Police, Transportation, Utility) of the agency involved, the authority level of the agency (local, regional, state), the time horizon involved (short term, medium term, long term), and whether the scenario occurred during the pre- or post-hurricane phase. The scenarios reported may be selective or isolated instances. A complete list and description of the schedule dependencies can be found in Appendix C.

Table 12. Categorization of collected dependency scenarios according to associated organization function involved within state departments of transportation

Dependency Scenario #	Dependency Scenario Name	State	Agency Name	Agency Type	Level of Agency	Pre/Post Disaster	Time Horizon	Administration	Environ., Regulatory Affairs	Equipment	Finance	Information Management	Legal / Authorization	Materials	Operations	Personnel	Structure and Bridge
DS1	Sandbag Requests	VA	Henrico Co. Div. Of Fire	Fire	Local	Post	ST							x			
DS2	Barricade Requests	VA	Henrico Co. Div. Of Fire	Fire	Local	Post	ST			x							
DS3	On-call Personnel	VA	Henrico Co. Div. Of Fire	Fire	Local	Post	ST									x	
DS4	Updated Road Status Info.	VA	Obici Hospital	Health	Local	Post	ST					x					
DS5	Inaccurate Road Information	VA	Obici Hospital	Health	Local	Post	ST					x					

Table 13 depicts the percentage of dependency scenarios with respect to each type of organizational function involved within a state DOT. From the table, one can see the functions that are associated with a minimal number of scenarios (*Environmental and Regulatory Affairs*, *Finance*, *Legal/Authorization*, *Materials*), and those involved with a significant number of them like *Operations* and *Information Management*, which together account for over half of the total number of dependency scenarios. It is important to note that the calculations only reflect a small collected sample of schedule dependencies incurred during the phases before and after a natural disaster.

Table 13. Percentage of dependency scenarios in sample associated with each organizational function

Organizational Function Type	Number of Cases	Percent of Total
Administration	3	6.2
Environmental, Regulatory Affairs	2	4.2
Equipment	4	8.3
Finance	2	4.2
Information Management	15	31.3
Legal / Authorization	2	4.2
Materials	2	4.2
Operations	11	22.9
Personnel	3	6.2
Structure	4	8.3
Total	48	100

Table 14 contains a partial list of dependency scenarios, and the primary organizational function of the state DOT that was involved along with a secondary function associated with the scenario. A scenario of dependency can often be a result of the interaction between the primary and secondary functions. A similar analysis was performed in terms of the pairs of functions involved in each scenario. There are 45 total pairs of functions. A complete list can be found in Appendix C.

Table 14. Categorization of collected dependency scenarios according to the associated *pair* of organizational functions involved within the state departments of transportation. A letter 'P' indicates the primary function involved while a letter 'S' indicates the secondary function.

Dependency Scenario #	Dependency Scenario Name	State	Agency Name	Agency Type	Level of Agency	Pre/Post Disaster	Time Horizon	Administration	Environ., Regulatory Affairs	Equipment	Finance	Information Management	Legal / Authorization	Materials	Operations	Personnel	Structure and Bridge
DS1	Sandbag Requests	VA	Henrico Co. Div. Of Fire	Fire	Local	Post	ST					S		P			
DS2	Barricade Requests	VA	Henrico Co. Div. Of Fire	Fire	Local	Post	ST			P		S					
DS3	On-call Personnel	VA	Henrico Co. Div. Of Fire	Fire	Local	Post	ST	S								P	
DS4	Updated Road Status Info.	VA	Obici Hospital	Health	Local	Post	ST					P			S		
DS5	Inaccurate Road Information	VA	Obici Hospital	Health	Local	Post	ST					P			S		

Table 15 contains the key explaining how the pairs of functions involved in dependency scenarios are recorded. For example, if *Administration* and *Environmental and Regulatory Affairs* are both involved in a scenario, an entry would be placed in the first row, second column. All empty entries represent zero scenarios. Table 16 displays the number of dependency scenarios respective to each pair of functions involved

Table 15. Key for denoting pairs of state DOT functions involved in scenarios

	Admin.	Environ., Reg. Aff.	Equipment	Finance	Inform. Manage.	Legal/ Authoriz.	Materials	Operations	Personnel	Structure
Admin.		Ad-Env	Ad-Eq	Ad-Fin	Ad-Info	Ad-Leg	Ad-Mat	Ad-Op	Ad-Per	Ad-Str
Env., Reg. Aff.			Env-Eq	Env-Fin	Env-Info	Env-Leg	Env-Mat	Env-Op	Env-Per	Env-Str
Equipment				Eq-Fin	Eq-Info	Eq-Leg	Eq-Mat	Eq-Op	Eq-Per	Eq-Str
Finance					Fin-Info	Fin-Leg	Fin-Mat	Fin-Op	Fin-Per	Fin-Str
Infor. Manage.						Info-Leg	Info-Mat	Info-Op	Info-Per	Info-Str
Legal/ Auth.							Leg-Mat	Leg-Op	Leg-Per	Leg-Str
Materials								Mat-Op	Mat-Per	Mat-Str
Operations									Op-Per	Op-Str
Personnel										Per-Str
Structure										

Table 16. Number of dependency scenarios in sample associated with each pair of organizational functions in a state DOT

	Admin.	Environ., Reg. Aff.	Equipment	Finance	Inform. Manage.	Legal/ Authoriz.	Materials	Operations	Personnel	Structure
Admin.				2	2			1	2	
Env., Reg. Aff.			2		3	1		3	2	
Equipment					3	1				
Finance										
Infor. Manage.						1	2	11		
Legal/ Auth.								1		
Materials								1		
Operations									1	9
Personnel										
Structure										

Table 17 displays the percentage of dependency scenarios for the pairs of functions involved within a state DOT (inclusive to all states). The pairs of functions that had no scenarios associated with them are not included in the table. The table identifies those pairs of functions that are associated with a significant amount of scenarios. Again, it is important to note that these calculations only reflect the scenarios of the sample collected.

A dependency scenario can be measured using eight indices as seen in Table 18. A sample scenario is used to demonstrate the scenario measurement. The example occurs in the time following Hurricane Floyd. The Virginia Office of Emergency Medical Services had to wait on VDOT for the availability to current, updated road status information (C. Everette Vaughan, Jr., Director of Emergency Operations at the Office of Emergency Medical Services, Oct. 9, 2000). For this example, the length of the wait is not known; however, it is important to report the length of the wait. For demonstration purposes, it is assumed that this type of delay is likely to happen again. The system is currently updated with new information every four hours (Toth, 2000). In addition, on site personnel do not have the ability to automatically input information themselves from the field. It is assumed that a system with these features could be available at a relatively low cost. This example may no longer be valid because the SmartTravel Center in Hampton Roads is now in place and fully operational.

Table 17. Percentage of dependency scenarios in sample associated with each pair of organizational functions in a state DOT

Pairs of Organizational	Number of Cases	Percent of Total
Information Management - Operations	11.0	22.9
Operations - Structure	9.0	18.8
Environmental, Regulatory Affairs - Information Management	3.0	1.4
Environmental, Regulatory Affairs - Operations	3.0	6.3
Equipment - Information Management	3.0	6.3
Information Management - Materials	2.0	4.2
Administration - Personnel	2.0	4.2
Environmental, Regulatory Affairs - Equipment	2.0	4.2
Environmetnal, Regulatory Affairs - Personnel	2.0	4.2
Administration - Information Management	2.0	4.2
Administration - Finance	2.0	4.2
Administration - Operations	1.0	2.1
Environmental, Regulatory Affairs - Legal / Authorization	1.0	2.1
Equipment - Legal / Authorization	1.0	2.1
Information Management - Legal / Authorizatoin	1.0	2.1
Legal / Authorization - Operations	1.0	2.1
Materials - Operations	1.0	2.1
Operations - Personnel	1.0	2.1
Total	48	100

Table 18. Values of each index for the scenario measured

Severity	Involved Agencies	Likelihood	Items Waiting On	Controllability	Cascading Effects	Maturity	Number of Same Scenarios
Hours in Short Term	Few other agencies	Has occurred in the past, likely to occur again	Information Only	Controllable at Low Cost	Multiple	Mature	Many
Moderate	Moderate	High	Moderate	Low	High	Low	High

The graphical representation also provides a medium for comparing the magnitudes of multiple scenarios. The graphs in Figure 20 assume the axes for the eight indices with the three levels of LOW, MODERATE, and HIGH. The graphs illustrate the differences between scenarios. For instance, the graph of scenario #47 shows that the scenario has low severity, no other agencies involved, has occurred in the past and is likely to occur again, involves no items being waited on, is controllable at a low cost, has no cascading effects, is immature, and has a few other similar scenarios. The graph of scenario #48, however, shows a scenario that has high severity, no other agencies involved, has occurred in the past and is likely to occur again, involves one item being waited on, is controllable at a high cost, has a multiple cascading effects, is mature, and is not similar to any other scenarios, it is an isolated instance of a delay.

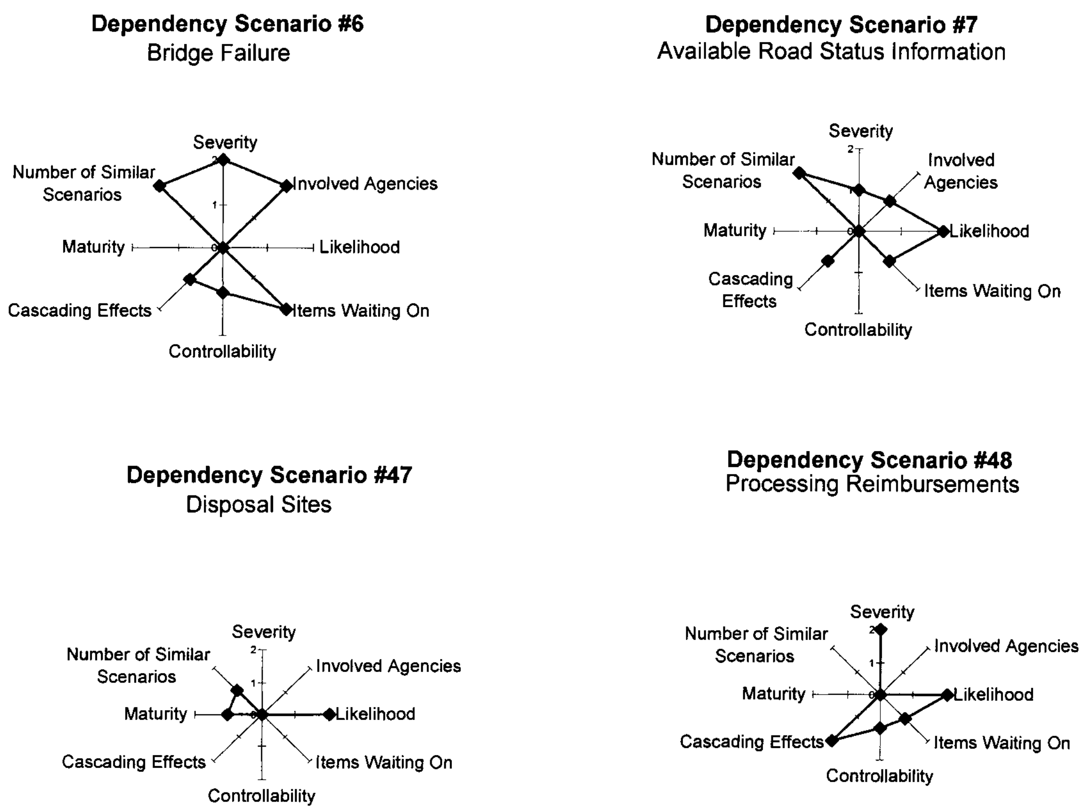

Figure 20. Comparison of dependency scenarios collected using the eight indices developed

Development of Decision Support for Resource Allocation for Hurricane Recovery

The decision support for resource allocation is implemented in a case study. Data has been collected in coordination with Mr. Perry Cogburn of the VDOT Emergency Operations Center. Mr. Cogburn supplied data for VDOT post-event efforts after Hurricane Floyd struck Southeastern Virginia in September of 1999. Table 19 shows a sample of the data.

The data include 624 specific examples of post-event activities from thirty-nine separate cities/counties. Twenty-five activities occurred on interstates, 165 on primary roads, and 164 on secondary roads. The information included a description of improvement, costs, and road type.

Table 19. Sample of Hurricane Floyd post-event data provided by VDOT [Cogburn 2000]

County/City	Type of Improvement	Total Cost	Number of Interstate Sites	Number of Primary Sites	Number of Seconday Sites
Greensville	Slope failure & protective	$13,830	2	0	0
	Slope failure & debris	$98,875	0	4	0
	Debris removal	$44,346	0	0	7
Isle of Wright	Slope failure & bridge	$1,020,630	0	7	0
	Slope failure & debris	$754,754	0	0	12
James City	Debris removal	$7,304	1	0	0
	Bridge, slope failure	$1,703,126	0	9	0
	Debris & protective	$15,000	0	0	6
Southhampton	Slope failure and debris	$57,631	0	11	0
	Slope failure and debris	$144,082	0	0	20
Surry	Slope and bridge failure	$235,439	0	3	0
	Slope failure	$33,381	0	0	1
Sussex	Slope failure	$6,007	1	0	0
	Slope and bridge failure	$206,242	0	3	0
	Slope failure	$51,485	0	0	4
York	Debris and protective	$30,000	1	0	0
	Slope failure and debris	$179,534	0	8	0

Performance indices have been generated using the available data. The data contain cost information used to satisfy resource use requirements. The data also include location and road type data that could be used to derive statistics to satisfy performance gain objectives. In order to compensate for the lack of data on risk reduction objective, performance gain indices had to be used on both axes. Location data could be used to find population density statistics related to each post-event activity, and road type data accompanied with location data could be used to find average daily traffic (ADT) data for the area affected by each post-event activity. The three indices, cost, ADT, and population density, have been chosen based on the data available. Activities located in areas with high population and on roads with large daily traffic volume will receive precedence in receiving resources from VDOT.

Using the data supplied and the selected performance indices, post-event activities resulting from Hurricane Floyd are charted and mapped using Microsoft Excel. Figure 21 shows an example of the data being plotted using the multi-objective analysis. It can be seen that activities A, B, and C have the same traffic volume. Activity B has higher cost (indicated by size of circle), followed by activity A, and then activity C. In terms of population density, activity C occurs in an area with higher population density than activities B and A. If VDOT wants to select activities associated with the highest population density area, then, among the three activities, activity C would be selected. If cost is the main criteria, then activity C is chosen because it yields the lowest cost among A, B, and C. If another activity (D) is considered, it can be seen that this activity involves higher traffic volume, has slighter higher cost than C, and has approximately the same population density as activity C. If a trade-off was made involving C and D, the decision maker would have to consider if the additional cost involved in activity D is worth the additional traffic volume it addresses.

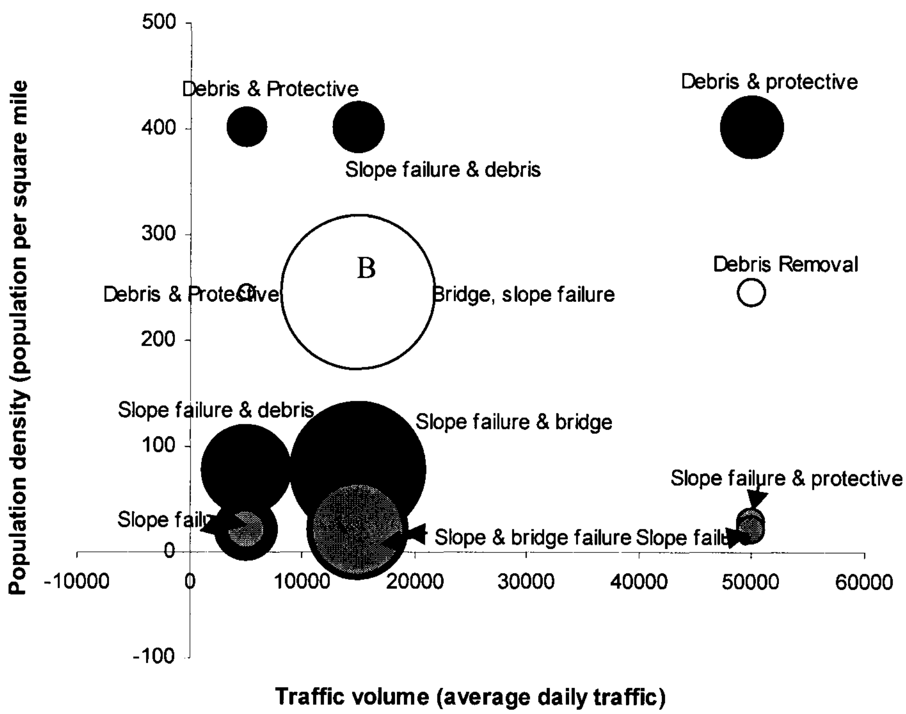

Figure 21. Post-event activities plotted for counties in Hampton Roads

Charts are created for individual counties and cities as well. The charts are then placed on top of the corresponding location. The legend to the charts for individual counties and cities is in Figure 22. The map of Hampton Roads overlain with the multi-objective charts is shown in Figure 23.

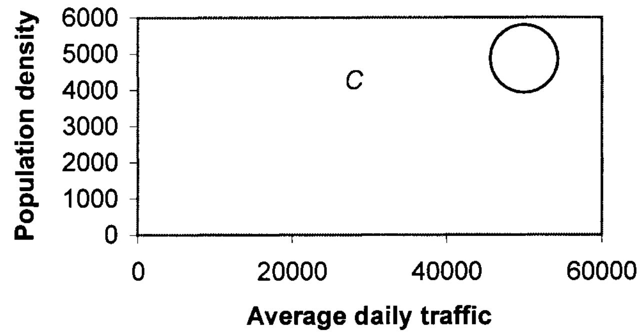

Figure 22. Legend for charts located within Hampton Roads map

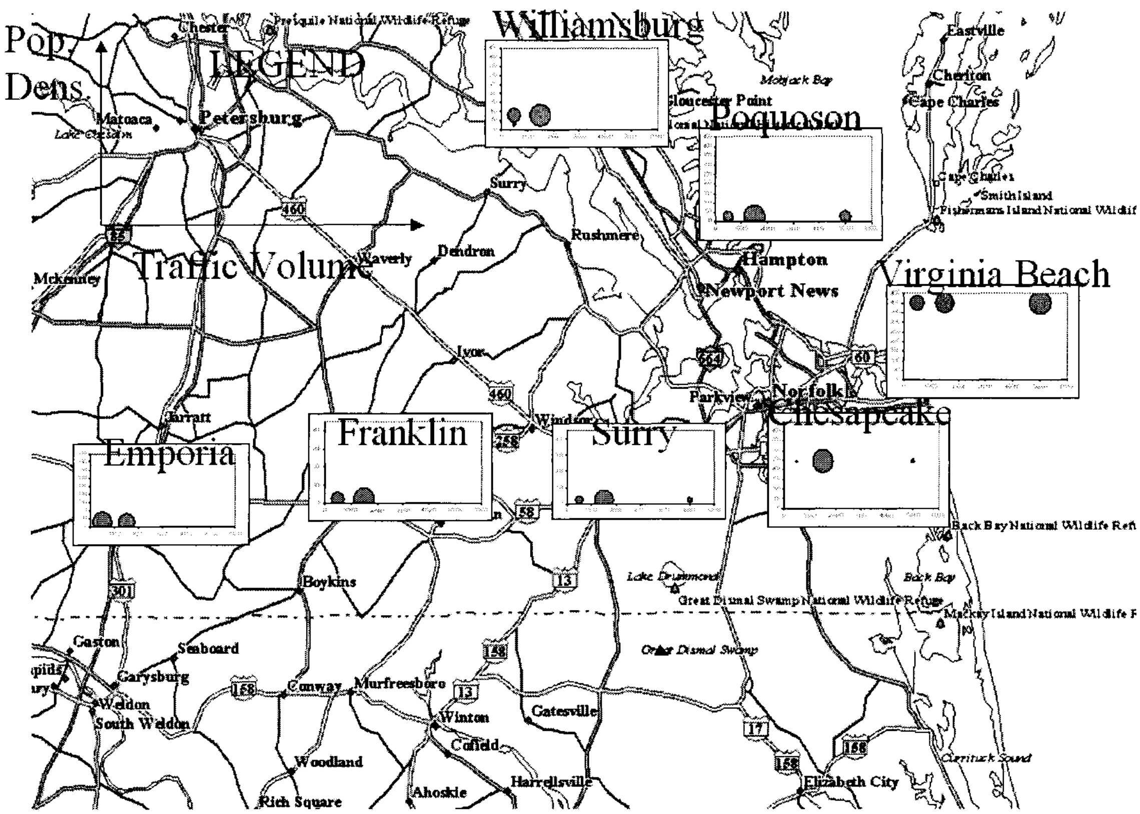

Figure 23. Map of Hampton Roads with multi-objective charts
for labeled cities/counties

Characterization of Preparedness and Recovery Alternatives

The enhancement of road systems can be performed through increasing robustness, redundancy and resilience. To determine which enhancement alternatives to implement, the characteristics of these alternatives are investigated. A framework is thus proposed to aid in the evaluation of enhancement alternatives. The framework is demonstrated using a case study.

When a hurricane strikes, the wind may knock out the signs along the streets. Enhancing signs usually requires new designs for posts and structures. There are two major factors related to the wind load that a sign is capable of withstanding. One is the size of the sign panel; the other is the design of the structural support for the sign. In order to increase the maximum wind speeds that shoulder-mounted signs can withstand by 20 miles per hour, increase in the size of the footing, the number of bolts, and the size of steel for a 30 to 40% greater structural resistance capacity are needed (Lambert et al. 1999). Enhancing the signs increases the robustness of the system but not the resilience and redundancy of the system. Another way to enhance the system is to store more signs in the warehouse so that VDOT can improve the redundancy of the system because VDOT will have signs to put back up after the storm is over. A third way to enhance signs is to make them detachable, thus increasing the resilience in the system but not the redundancy and the robustness of the system. All of these methods improve the time saved in recovery. Not all alternatives have cost savings mainly because man hours of preparation time may offset the time it would take to clean up the signs destroyed in the hurricane. The difficulty and cost of implementing the alternatives would also have to be considered. Table 20 shows the case study performed for the various ways to help enhance signs.

Table 20. A case study characterizing the enhancement of roadway signs. A filled circle represents a major impact while a half-filled circle represents a minor impact.

Alternatives:	Redundancy	Resilience	Robustness	Short term	Medium term	Long term	Short term	Medium term	Long term	Time savings	Cost savings	Lives saved	Economic impact	Environmental impact	Private property	Wind velocity	Storm surge	Traffic flow	Aids in evacuation
1. Strengthen signs			●			●				◓	◓					●			●
2. Store extra signs	●				●					●						●			
3. Detachable signs		●		●		●	●			◓	◓					●			●

Decision Trade-off Analysis on Recovery and Preparedness Alternatives

The sample alternative in Table 21 can be used indirectly with the enhancement tool. The user may decide to evaluate that sample alternative and thus utilize the tool to evaluate each individual road system within it.

Tradeoffs among the alternatives under the wind speed and storm surge scenarios can be performed using graphical representation. An example of such graph can be seen in Figure 24 where the ratio of repair to reconstruction cost is displayed for different levels of investment under the different wind speed scenarios. It should be noted that this view of investment versus consequences is limited by the quality of the alternatives. If all the alternatives entered are not cost-effective, then the curves will give a skewed picture of the tradeoffs. In this case, the curves could only be interpreted strictly as cost of alternative versus the ratio of repair to reconstruction cost. However, if the entered alternatives are some of the best ones, then the user can confidently interpret the curves as showing the tradeoffs between current investment and future consequence. The statements above are true for all the tradeoff curves in the tool. Step-by-step descriptions on how to use the enhancement alternatives comparison tool is found in Appendix D.

Table 21. Sample enhancement alternative

Equipment Category	Levels		
	Wind Velocity	Storm Surge	Traffic Flow
Signs, Signals and Lights			
Shoulder-mounted signs	w0	s0	t0
Cantilever signs	w0	s0	t0
Two-pole span signs	w0	s0	t0
Traffic signals systems	w0	s0	t0
High mast lighting structures	w0	s1	t0
Roadway lighting structures	w0	s1	t0
Bridges			
Beam Bridges	w1	s1	t3
Truss Bridges	w1	s1	t3
Tunnels			
Soft ground	w1	s1	t3
Sub aqueous	w1	s1	t3
Smart highway systems			
Motion detectors	w1	s1	t0
Alert signs	w1	s1	t0
Cameras	w1	s1	t0
Radar detectors	w1	s1	t0
Flood Mitigation			
Sand dunes	w1	s1	t0
Rocks	w1	s1	t0

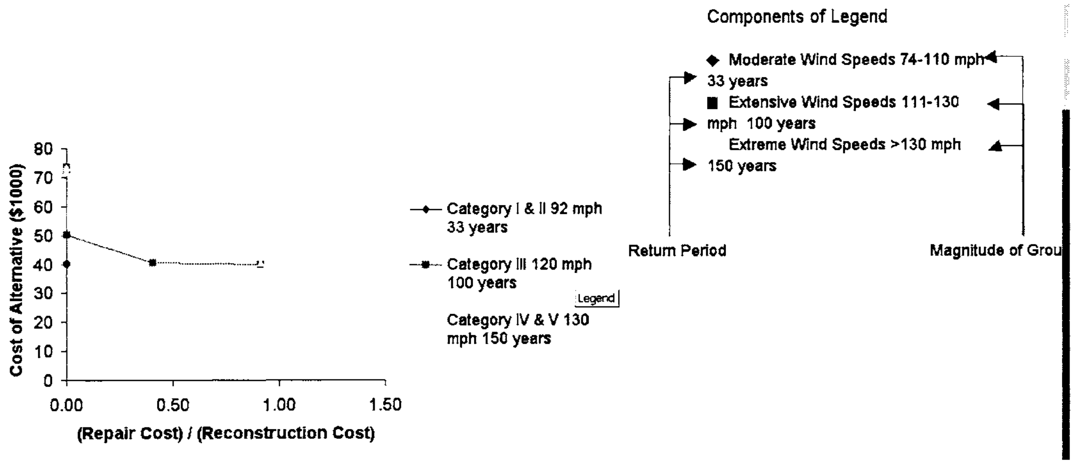

Figure 24. Tradeoff graph of the cost of the alternative versus the repair cost-to-reconstruction cost ratio

CONCLUSIONS

The hurricane preparedness and recovery efforts of a transportation agency can be improved through a number of methods.

First, a priority setting tool can be used to determine the area most in need of service during the aftermath of a disaster. Critical facilities need to be identified. With the model, a VDOT engineer can quickly make high level resource allocation decisions based on the criteria he feels are most important, and can change those criteria over the course of the recovery.

Second, a schedule analysis of the time-to-recovery efforts can also be conducted to determine the critical activities that need to be monitored closely to prevent and avoid unnecessary delays.

Third, using the methodology developed for analyzing dependency scenarios among agencies, dependency scenarios can be subjected to a categorical and comparative analysis, which can aid the state transportation agency's decision-making and subsequently reduce the overall time to recovery following a hurricane. The methodology, which is of great value to a state transportation agency because of the versatility it exhibits, can be applied to various geographical scales, types of disasters, and agencies.

Fourth, a method to systematically prioritize post-event activities in order to effectively aid in decisions concerning resource allocation for VDOT in the event of a natural disaster has been proposed. The developed tool utilizes multi-objective decision analysis in order to prioritize post-event activities based on available data.

Fifth, numerous alternatives that increase redundancy, robustness and resilience are available. It is therefore important to determine the impacts each alternative makes to cost, time savings, human life, economic, environment, and property. The proposed template for the characterization of alternatives enables the decision maker to make more knowledgeable decisions.

Sixth, the characterization of alternatives, a systematic approach to cost-benefit analysis of recovery and preparedness alternatives can be utilized. It is necessary to determine the tradeoffs among alternatives.

RECOMMENDATIONS

The recommendations of the effort are as follows:

Development of a Software Based Platform For Recovery Priorities

- Adopt a systematic approach to priority setting for recovery.
- Adopt the grids for priority setting.
- Use various grid-size resolutions (district, residency, smaller).
- Adopt the demonstrated metrics (populations, mileages, stakeholder facilities, etc.).
- Add a metric to represent the degree of recovery.
- Use the developed software and demonstrate with GIS divisions.
- Consult VDOT district staff to determine appropriate metrics to use.

Time-to-recovery Analysis

- Apply the methodology to actual data and post-hurricane processes.
- Examine the feasibility of dividing activities into sub-tasks that can be performed simultaneously.
- Examine the impacts of assigning more resources to the installation process.
- Examine various schedule configurations of activities and potential sub-activities.
- Investigate opportunities for further time and cost savings in the post-hurricane process.

Analysis of Schedule Dependencies among Agencies

- Perform a more extensive data collection possibly with an online surveying tool.
- Analyze individual scenarios collected using PERT, an activity network modeling tool, to identify potential opportunities for advancing the schedule in the post-hurricane process.
- Investigate the costs and benefits of pre-hurricane resource investments on the alternatives identified from the PERT models.

Development of Decision Support for Resource Allocation for Hurricane Recovery

- Adopt a systematic approach to resource allocation for recovery.
- Represent the variety of recovery projects across regions.
- Analyze the balance among all project impacts and costs.
- Use the approach to improve the allocation of resources to diverse projects.

- Project resource allocation needs from past storms to the estimate needs in future storms.

Characterization of Preparedness and Recovery Alternatives

- Generate more alternatives using the methodology given.
- Perform more case studies for different types of destructive forces.
- Extend to different types of disasters such as earthquakes, flooding, and snowstorms.

Decision Trade-off Analysis on Recovery and Preparedness Alternatives

- Expand upon the methodologies presented in this report by collecting data that will focus the approach analysis used.
- Adopt a systematic approach to cost-benefit analysis of recovery and preparedness.
- Expand the functionality of the tool to evaluate additional natural disasters such as earthquakes, tornadoes, snowstorms, floods due to rainfall, and any such event where the impacts can be lessened through mitigation.
- Expand the functionality of the tool to incorporate additional enhancement alternatives in addition to wind speed, storm surge, and traffic flow.
- Utilize the flexibility of the framework to maximize VDOT's understanding of their preparedness efforts.

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APPENDIX A. AGENCY CONTACT INFORMATION FOR COLLECTED DEPENDENCY SCENARIOS

The following spreadsheets contain the organization name, contact person and title, phone number, fax number, and email address of all state and local agencies contacted in Virginia, California, Florida, North Carolina, and South Carolina. The last column under the heading "Reply" on each spreadsheet states if the agency was successfully reached or not: if the agency was contacted, the word "yes" is shown, and if the agency did not respond, the word "no" is shown. If contact with the agency was not attempted, "n/a" is shown. If the agency reported a scenario used in the analysis, the number of the dependency scenario has been entered and the entire row is in italics. Also included is a sample letter that was sent by fax or email to the agencies.

Sample Letter to Agencies

I am performing research with the University of Virginia under contract with the Virginia Department of Transportation on hurricane preparedness and recovery. A goal of this effort is to speed the overall recovery from a natural disaster. One way to reach this goal is to determine what type of investments can be made in the preparation of a hurricane that could reduce the delay of particular activities, in the near, medium, and long terms of the recovery. I would appreciate your answers to some questions that I have of your organization.

If you would like to see a recent related project effort including Power Point slides, see http://www.virginia.edu/~risk/recovery. Please feel free to email me at cep4e@virginia.edu, and we can arrange a time to talk on the phone. You may reach me by fax at (804) 924-0865. I look forward to hearing from you.

The following questions could be answered in terms of a hurricane, flood, earthquake, or any other disaster. The phase of the recovery period could be in terms of days, weeks, months, and/or years. If you could answer some of these questions on the subject of preparedness as well, please do so, in terms the in the days leading up to an imminent event and/or the weeks before the start of the hurricane season.

1. What are the cases in which you were waiting on the Virginia Department of Transportation to be able to start a recovery activity? What are the cases in which VDOT was waiting on you? (materials, equipment, authorization, personnel, etc.)

2. If you haven't in the past, can you see yourself waiting on VDOT or VDOT waiting on you for a recovery activity in the future? Under what circumstances?

3. Do you have suggestions for improvement for VDOT? Is there anything they could have done to better minimize the delay of recovery?

4. Is there a particular system or geographic area with which you are concerned based on how it was recovered during a past disaster?

5. Would you suggest others within or outside your agency that I should contact? How else should I focus my concern on the interfaces of your agency with the VDOT in the prelude or aftermath of a hurricane?

Thank you,
Clare Patterson

Virginia Agencies and Organizations Contacted:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
COMMUNICATION:						
VA Amateur Radio Emerg. Services	Comm.	Tony Amato, Sec. Em. Coord.			sec@aresva.org	n/a
		VA Section Emerg. Coord.			mackeyf@aresva.org	n/a
VA Emerg. Communications Comm.	Comm.	Paxton Durham, Co-chair	(540) 989-8900	(540) 776-2727	jpd@vt.edu	n/a
EMERGENCY/RESCUE:						
Dept. of Emergency Services	Emerg.	T. Stewart Baker (ATTENDEE)	(804) 695-9506			no
		Jack Williamson, Coord.	(757) 269-2900	(757) 269-2905		yes
		Addison Slaughter, SERC				no
Fieldale-Collinsville Vol. Res. Squad	Emerg.	Daryl Hatcher, Captain	(540) 647-3232		jtclark@sitestar.net	n/a
Henry Co. Emerg. Manage. Services	Emerg.	General Information	(540) 634-4601			n/a
Newport News Emerg. Manage. Serv.	Emerg.	Jack Williamson, Coord.	(757) 269-2900	(757) 269-2905	ajwillia@ci.newport-news.va.us	no
		James Davis, Deputy Coord.	(804) 432-7920	(804) 432-7950	pittcoes@gamewood.net	no
Norfolk Emerg. Operations Center	Emerg.	James Talbot (ATTENDEE)	(757) 441-5600		Jtalbot@city.norfolk.va.us	no
Richmond Emerg. Manage. Services	Emerg.	Steve Batkins, Captain	(804) 646-6666		batkinsd@ci.richmond.va.us	no
VA Ass. Of Volunteer Rescue Squads	Emerg.	Wanda Morehead, President				no
		Kay Laws, District 2 VP				no
VA Dept. of Emergency Management	Emerg.	Mary Camp	(804) 879-6500	(804) 897-6526	mcamp@vdem.state.va.us	no
		Michael M. Cline	(804) 897-6501	(804) 897-6506		yes
VA Emergency Operations Center	Emerg.	General Information	(804) 674-2400	(804) 674-2419		no
ENVIRONMENT:						
Dept. of Conservation and Recreation	Environ.	Richard Dameron	(804) 371-6135		rodameron@dcr.state.va.us	yes
Floodplain Management Program	***Environ.***	***Corey Garyotis***	***(804) 786-8073***	***(804) 371-2630***	***cgaryotis@dcr.state.va.us***	***DS 9***
Department of Environmental Quality	Environ.	David Ormes	(804) 698-4263		dtormes@deq.state.va.us	n/a
Department of Forestry	Environ.	Lewis Southard	(804) 977-6555		southardl@dof.state.va.us	yes
Office of Sec. of Natural Resources	Environ.	Ronald Hamm, Dep. Sec.	(804) 786-0044	(804) 371-8333		n/a
FIRE:						
Bassett Volunteer Fire Department	Fire	Jimmy Craig, Chief	(540) 629-5323		lucky@sitestar.net	n/a
Department of Fire Programs	Fire	Larry McAndrews	(757) 727-4700	(757) 727-4704		yes
		Troy Lapetina, Exec. Director	(804) 371-0220	(804) 371-0217	vdfp@mail.com	no
Capital VA Area 1 Regional Office	Fire	Don Brown, Manager	(804) 371-0280	(804) 371-0265		n/a
Northern VA Area 2 Regional Office	Fire	Bert Roby, Manager	(540) 672-1277	(540) 672-1560		n/a
Southwest VA Area 3 Regional Office	Fire	Tom Lorton, Manager	(540) 783-1446	(540) 783-1842		n/a
Central VA Area 4 Regional Office	Fire	Don Hansen, Manager	(540) 857-7252	(540) 857-7100		n/a

Virginia Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
FIRE, continued:						
Dyers Store Volunteer Fire Dept.	Fire	Randy Smith, Chief	(540) 638-3184		chief.dsvfd@spotteddog.com	n/a
Fairfax Company Fire and Rescue	Fire	Edward Stinnette, Chief	(703) 246-2126		fireweb@co.fairfax.va.us	n/a
Operations	Fire	Chief			jbrown@co.fairfax.va.us	n/a
HazMat	Fire	General Information			ljohns@co.fairfax.va.us	n/a
Planning	Fire	General Information			ebeitz@co.fairfax.va.us	n/a
Henrico County Division of Fire	***Fire***	***R.C. Dawson***	***(804) 501-4905***		***daw71@co.henrico.va.us***	***DS1,2,3***
Horsepasture Volunteer Fire Dept.	Fire	Richard Reynolds, Chief	634-4660		bobnorris@kimbanet.com	n/a
Richmond Fire Department	Fire	Jack McElfish, Chief	(804) 646-6663		mcelfijk@ci.richmond.va.us	n/a
Resources Operations	Fire	John Hinant	(804) 646-5456		hinantje@ci.richmond.va.us	n/a
Public Information	Fire	Don Horton, Captain	(804) 646-1526		hortondj@ci.richmond.va.us	n/a
HazMat	Fire	Alan Brooke	(804) 646-6660		brookea@ci.richmond.va.us	n/a
State Fire Chiefs Ass. Of VA (SFCAV)	Fire	Robin Brannon, Exec. Director	(804) 762-4438	(804) 762-9889		no
		Edward Plaugher, President	(703) 228-3355	(703) 228-7097		no
Virginia Beach Fire	Fire	Timothy R. Berkimer	(757) 427-4228			no
Virginia Fire Marshal Academy	Fire	Russ Chandler, Manager	(804) 371-0220	(804) 371-0219	vafirelaw@aol.com	n/a
HEALTH:						
American Red Cross	Health	Rick Russell (ATTENDEE)	(757) 446-7745		Russellr@tidewater-redcross.org	yes
		Linda Hughes				no
Department of Health	Health	Judith Hayburn				no
Chesterfield Health Department	Health	General Information	(804) 748-1691	(804) 768-7708	svarney@vdh.state.va.us	n/a
Colonial Heights Health Department	Health	General Information	(804) 520-9380	(804) 520-9222		n/a
East Henrico Health Department	Health	General Information	(804) 652-3190	(804) 652-3188		n/a
Essex Co. Health Department	Health	General Information	(804) 443-3396	(804) 443-2377		n/a
Franklin City Health Department	Health	General Information	(757) 562-6109	(757) 562-2630		n/a
Gloucester Co. Health Department	Health	General Information	(804) 693-2445	(804) 693-1398		n/a
Goochland Health Department	Health	General Information	(804) 556-5343	(804) 556-3707		n/a
Hampton Center	Health	General Information	(757) 727-6422	(757) 727-3218		n/a
Hanover Health Department	Health	General Information	(804) 752-4313	(804) 752-4355		n/a
Hope Center	Health	General Information	(757) 825-4730	(757) 825-4727		n/a
Isle of Wight Co. Health Department	Health	General Information	(757) 357-4177	(757) 357-2838		n/a
King & Queen Co. Health Department	Health	General Information	(804) 785-6154	(804) 785-2601		n/a
King William Co. Health Department	Health	General Information	(804) 769-4988	(804) 769-2155		n/a
Lancaster Co. Health Department	Health	General Information	(804) 462-5197	(804) 462-6211		n/a
LaSalle Center	Health	General Information	(757) 727-1140	(757) 727-4881		n/a
Little Creek Clinic	Health	General Information	(757) 531-2100	(757) 531-2113		n/a

Virginia Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
HEALTH, continued:						
Mathews Co. Health Department	Health	General Information	(804) 725-7131	(804) 725-7466		n/a
Middlesex Co. Health Department	Health	General Information	(804) 758-2381	(804) 758-4828		n/a
New Kent Health Department	Health	General Information	(804) 966-9640	(804) 966-5210		n/a
Newport News City Health Department	Health	Daniel C. Warren, District Dir.	(757) 594-7305	(757) 594-7714		n/a
Norfolk Health Department	Health	Valerie Stallings	(757) 683-2756	(757) 683-2589	vstallings@vdh.state.va.us	n/a
Northhampton Co. Health Department	Health	General Information	(757) 442-6228	(757) 442-4307		n/a
Nothumberland Co. Health Department	Health	General Information	(804) 580-3731	(804) 580-2913		n/a
Pembroke Corp. Center	Health	General Information	(757) 518-2677	(757) 518-2640		n/a
Petersburg Health Department	Health	Headquarters	(804) 863-1652	(804) 862-6126		n/a
Portsmouth Health Department	Health	General Information	(757) 393-8585	(757) 393-8027		n/a
Powhatan Health Department	Health	General Information	(804) 794-9594	(804) 598-5688		n/a
Queen's Way Center	Health	General Information	(757) 825-4890	(757) 727-1040		n/a
Richmond City Health Department	Health	Headquarters	(804) 646-3134	(804) 646-3111		n/a
Richmond Co. Health Department	Health	General Information	(804) 333-4043	(804) 333-3447		n/a
South Hampton Co. Health Department	Health	General Information	(757) 653-3040	(757) 653-0834		n/a
South Norfolk Health Center	Health	General Information	(757) 382-2600	(757) 382-2607		n/a
Suffolk Health Department	Health	General Information	(757) 686-4900	(757) 925-2243		n/a
Three Rivers Health Department	Health	Headquarters	(804) 758-0029	(804) 758-4828		n/a
Victoria Center	Health	Martin Wheeler	(757) 727-1172	(757) 727-1185	mwheeler@vdh.state.va.us	n/a
West Henrico Health Department	Health	General Information	(804) 501-4522	(804) 501-4983		n/a
Westmoreland Co. Health Department	Health	General Information	(804) 493-1124	(804) 493-9352		n/a
Williamsburg Health Department	Health	General Information	(757) 253-4813	(757) 253-4285		n/a
Dept. of Medical Assistance Services	Health	General Information			mcloud@dmas.state.va.us	n/a
OBICI Hospital	***Health***	***Randy Vick (ATTENDEE)***	***(757) 934-4945***		***Rvick@obici.com***	***DS 4,5***
Office of Emergency Medical Services	***Health***	***Everette Vaughan***	***(804) 371-3500***	***(804) 371-3543***	***evaughan@vdh.state.va.us***	***DS6,7,8***
Sentara Hospitals	Health	Robert Bugg, (ATTENDEE)	(757) 668-3614		Rhbugg@sentara.com	no
MILITARY:						
Virginia Civil Air Patrol	Military	General Information	(804) 743-2220	(804) 743-2223	admin@vawg.cap.gov	n/a
Air National Guard	Military	Maj.Gen. Claude Williams	(804) 236-6505	(804) 236-6936		n/a
Army National Guard	Military	BG William Jones, Dep.Adj.Gen.	(804) 298-6102	(804) 298-6338		n/a
		CMSgt. Vickie Armes, Chief	(804) 236-6462	(804) 236-6936	vicki.armes@varich.ang.af.mil	n/a
Dept. of Military Affairs/National Guard	Military	Sgt. Major Parker, Emerg. Ctr	(804) 292-8627			no
National Guard Bureau	Military	LTC Tom Wilkinson			wilkinsont@va-arng.ngb.army.mil	yes

Virginia Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
POLICE:						
Capitol State Police	Police	Colonel George Mason	(804) 786-2568	(804) 371-8698		n/a
Chesterfield Sheriff's Office	Police	Clarence Williams, Sheriff	(804) 748-1261	(804) 748-5808	sheriff@ccso.net	n/a
Chesapeake Pol. Dept. , 1st Precinct	Police	General Information	(757) 382-6556	(757) 382-6821		no
Chester Police Department	Police	William T. Wand (ATTENDEE)	(757) 382-8527			no
Dept. of State Police, Ches., 5th Div.	Police	Lieut. Andrew Engemann (ATT)	(757) 424-6836	(757) 424-6732		yes
Fair Oaks District Station	Police	Stephen J. Lipovsky, Captain	(703) 591-0966		faocapt@co.fairfax.va.us	n/a
Fairfax County Police Department	Police	Col. Thomas Manger, Chief	(703) 246-2195		chief@co.fairfax.va.us	n/a
Fairfax County Sheriff's Office	Police	Maj. P. Maltagliati	(703) 246-3206	(703) 691-0510		n/a
Franconia District Station	Police	Frank J. Kitzerow, Captain	(703) 922-0889		fracapt@co.fairfax.va.us	n/a
Franklin Police Department	Police	Robert Eubanks (ATTENDEE)			Reubanks@ci.franklin.va.us	no
		R. Bruce Edwards (ATTENDEE)	(757) 562-8577			no
Giles County Sheriff's Office	Police	Larry Falls, Sheriff	(540) 921-3842	(540) 921-4976	gcso@i-plus.net	n/a
Henrico Police Department	Police	Colonel H.W.Stanley,Jr.	(804) 501-4839		police@co.henrico.va.us	n/a
Mason District Station	Police	Thomas Ryan, Captain	(703) 256-8035		mascapt@co.fairfax.va.us	n/a
McLean District Station	Police	Robert Callahan, Captain	(703) 556-7750		mclcapt@co.fairfax.va.us	n/a
Mount Vernon District Station	Police	Stephen L. Sellers, Captain	(703) 360-8400		mtvcapt@co.fairfax.va.us	n/a
Newport News Police Department	Police	Dennis Mook, Chief	(757) 926-8461	(757) 926-2374	chfoff@ci.newport-news.va.us	no
		Joseph St. John (ATTENDEE)	(757) 591-4978			no
North Precinct	Police	Thomas Bennett, Captain			tbennett@ci.newport-news.va.us	yes
South Precinct	Police	Susie Mowry, Captain			lmowry@ci.newport-news.va.us	no
Central Precinct	Police	Marvin Evans, Captain			hevans@ci.newport-news.va.us	no
Norfolk Pol. Dept., Spec. Enforce.Div.	Police	J.E.Robertson (ATTENDEE)	(757) 441-2211			no
Portsmouth Sheriff's Office	Police	Gary Waters, Sheriff	(757) 393-8210		pmso@pilot.infi.net	n/a
Reston District Station	Police	Edwin C. Roessler, Jr., Captain	(703) 478-0904		rescapt@co.fairfax.va.us	n/a
Richmond Police Department	Police	Colonel Jerry Oliver, Chief	(804) 646-6700		OliverJA@ci.richmond.va.us	n/a
Operations	Police	Teresa P. Gooch, Deputy Chief	(804) 646-6707		mqcollins@ci.richmond.va.us	n/a
Customer Service, East	Police	Daniel Goodall, Captain	(804) 646-4278	(804) 646-4152	goodallda@ci.richmond.va.us	n/a
Customer Service, West	Police	Paul Kiniry, Captain	(804) 646-1412	(804) 358-1093		n/a
Customer Service, South	Police	Carol Nicely, Captain	(804) 646-8092	(804) 646-8199		n/a
Customer Service, Central	Police	Albertina Carter, Captain	(804) 646-4105	(804) 646-4106		n/a
State Police Department	Police	Colonel Gerald Massengill	(804) 674-2000	(804) 674-2267	kscales@vsp.state.va.us	n/a
VA Beach Pol. Dept., Spec. Operations	Police	W.M.Summerell (ATTENDEE)	(757) 427-4045			no
		J.T. Vanderheiden (ATTENDEE)	(757) 426-5626			no
VCU Police Department	Police	Dan M. Dean, Jr., Chief	(804) 828-1210		dmdean@saturn.vcu.edu	n/a
West Springfield District Station	Police	Dorian B. Portee, Captain	(703) 644-7377		wspcapt@co.fairfax.va.us	n/a
Winchester Police Department	Police	Colonel Gary Reynolds	(540) 665-5647		jawpd@visuallink.com	n/a

Virginia Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
TRANSPORTATION:						
Department of Aviation	Transport.	Keith McCray	(804) 236-3625			yes
Dept. of Rail and Public Transportation	Transport.	Thomas Stewart (ATTENDEE)	(804) 786-1056		Stewart_tf@drpt.state.va.us	yes
Federal Highway Association	Transport.	Emily Lawton			Emily.Lawton@fhwa.dot.gov	n/a
		Claude Napier			Claude.Napier@fhwa.dot.gov	n/a
Franklin Residency, VDOT	Transport.	Randolph Cook			cook_rr@vdot.state.va.us	n/a
		J. D. Flythe			flythe_jd@vdot.state.va.us	n/a
VDOT - Environmental Affairs	Transport.	Ricky Woody			woody_rc@vdot.state.va.us	n/a
VDOT - Historical Review	Transport.	Tony Opperman	(804) 371-6749		opperman_af@vdot.state.va.us	n/a
VDOT - Location and Design	Transport.	David Legrande			legrande_dm@vdot.state.va.us	n/a
VDOT- Structures and Bridges	Transport.	Fred Dotson			Dotson_wf@vdot.state.va.us	n/a
UTILITY:						
Richmond Dept. of General Serv. Utility	Utility	Anne Paschke, Public Info. Off.	(804) 646-5276		paschkea@ci.richmond.va.us	n/a
		Sherry Crewe, Planning	(804) 646-8940		crews@ci.richmond.va.us	n/a
Administration	Utility	Johnel Bracey, Chief	(804) 646-5730		braceyj@ci.richmond.va.us	n/a
Financial Planning	Utility	Stacey Fayson, Manager	(804) 646-5244		sfayson@ci.richmond.va.us	n/a
Energy Services	Utility	William Galli, Deputy Director	(804) 646-5290		bgalli@ci.richmond.va.us	n/a
Gas and Water Service	Utility	Ricky Hicks, Tech. Supervisor	(804) 646-8412		hicksrs@ci.richmond.va.us	n/a
Virginia Power Company	Utility	Charles Taylor	(757) 857-2367	(757) 857-2677		yes
MISCELLANEOUS:						
Dept. of Agriculture and Consumer Serv.	Misc.	Richard Saunders	(804) 786-8899		risaunders@vdacs.state.va.us	no
Dept. of Business Assistance	Misc.	Rob Blackmore	(804) 371-8260		rblackmore@dba.state.va.us	yes
Chesapeake Bay Local Ass. Dept.	Misc.	Martha Little	(804) 225-3440		mlittle@cblad.state.va.us	yes
		Michael Clower			MCLOWER@cblad.state.va.us	yes
		Scott Crafton, Chief of Env. Eng.	(804) 371-7503		scrafton@cblad.state.va.us	yes
Commission on Local Government	Misc.	Adele MacLean	(804) 786-6508			yes
Department of General Services	Misc.	Elzy Williams, Building & Const.	(804) 371-7724		ewilliams@dgs.state.va.us	yes
		Demerst Smit, Deputy Director	(804) 371-7725		dsmit@dgs.state.va.us	no
Department of Historic Resources	Misc.	James Hill	(804) 367-2323		jhill@dhr.state.va.us	no
Dept. of Housing & Community Develop.	Misc.	Glenn Oder	(804) 371-7005		goder@dhcd.state.va.us	no
Department of Labor and Industry	Misc.	Edward Hegamyer	(804) 786-9875		edwardhegamyer@doli.state.va.us	yes
Dept. of Mines, Minerals and Energy	***Misc.***	***Cheryl Cashman***	***(804) 692-3213***		***cxc@mme.state.va.us***	***DS 10***
Dept. of Treasury, Div. Of Risk Manage.	Misc.	Don LeMond	(804) 225-4620		don.lemond@trs.state.va.us	no
Henry Co. Department of Public Safety		Steve Eanes, Director	(540) 634-4662		seanes@hcdps.com	n/a
Richmond Dept. of General Services	Misc.	Gregory Abdus-Salaam	(804) 646-5801		abdussgm@ci.richmond.va.us	n/a
Social Services	Misc.	Glenn Butler, Director	(804) 646-7430		butlerg@ci.richmond.va.us	n/a

Virginia Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
MISCELLANEOUS, continued:						
Small Business Development Center	Misc.	James T. Carroll, III, Director	(757) 664-2592	(757) 548-1835	jcarroll@hrccva.com	yes
VA Asso. of Planning District Comm.	Misc.	Robert de Voursney	(804) 982-5559	(804) 982-5536	vapdc@virginia.edu	n/a
Accomoack-Northampton Planning Dist. Comm.	Misc.	Paul F. Berge	(757) 787-2936	(757) 787-4221	anpdc@esva.net	n/a
Central Shenandoah Planning District Comm.	Misc.	Rebecca Joyce	(540) 885-5174	(540) 885-2687	Rebecca@cspdc.org	yes
Central Virginia Planning District Comm.	Misc.	C.W. Gillespie	(804) 845-3491	(804) 845-3493	cvpdc@usa.pipeline.com	n/a
Crater Planning District Comm.	Misc.	Dennis K. Morris	(804) 861-1666	(804) 732-8972	crater-pdc@worldnet.att.net	n/a
Cumberland Plateau Planning District Comm.	Misc.	Andrew Chafin	(540) 889-1778	(540) 889-5732	cppdc@naxs.net	n/a
Hampton Roads Planning District Comm.	Misc.	Gary Schuchardt	(757) 420-8300	(757) 523-4881	gschucha@hrpdc.org	yes
Lenowisco Planning District Comm.	Misc.	Ronald C. Flanary	(540) 431-2206	(540) 431-2208	rflanary@lenowisco.org	n/a
Lord Fairfax Planning District Comm.	Misc.	Stephen W. Kerr	(540) 636-8800	(540) 635-4147	lfpdc@shentel.net	n/a
Middle Peninsula Planning District Comm.	Misc.	Dan Kavanagh	(804) 758-2311	(804) 758-3221	mppdc@inna.net	n/a
Mount Rogers Planning District Comm.	Misc.	Thomas G. Taylor	(540) 783-5103	(540) 783-6949	staff@mrpdc.org	n/a
New River Valley Planning District Comm.	Misc.	David W. Rundgren	(540) 639-9313	(540) 831-6093	nrvpdc@nrvdc.org	n/a
Northern Neck Planning District Comm.	Misc.	Jerry W. Davis	(804) 333-1900	(804) 333-5274	nnpdc17@state.va.us	n/a
Northern Virginia Planning District Comm.	Misc.	G. Mark Gibb	(703) 642-0700	(703) 642-5077	gmg@novaregion.org	n/a
Piedmont Planning District Comm.	Misc.	Jack E. Houghton	(804) 392-6104	(804) 392-5933	JackH@tiger.hsc.edu	n/a
Rappahannock Planning District Comm.	Misc.	Stephen R. Manster	(540) 373-2890	(540) 899-4808	smanster@radco.state.va.us	n/a
Rappahannock Planning District Comm.	Misc.	Gary F. Christie	(540) 829-7450	(540) 829-7452	rrpdc@crosslink.net	n/a
Richmond Regional Planning District Comm.	Misc.	James R. Hassinger	(804) 358-3684	(804) 358-5386	richmondregional@richmondregional.org	n/a
Roanoke Valley Planning District Comm.	Misc.	Wayne G. Strickland	(540) 343-4417	(540) 343-4416	rvarc@rvarc.org	n/a
Southside Planning District Comm.	Misc.	Joyce I. French	(804) 447-7101	(804) 447-7104	pdc@buggs.net	n/a
Thomas Jefferson Planning District Comm.	Misc.	Nancy K. O'Brien	(804) 979-7310	(804) 979-1597	tjpdc@monticello.avenue.gen.va.us	n/a
West Piedmont Planning District Comm.	Misc.	Robert. W. Dowd	(540) 638-3987	(540) 638-8137	wppdc@kimbanet.com	n/a
Virginia Disaster Stress Intervention	Misc.	Steven Elsis, Info. Res. Manag.			elsissa@jmu.edu	n/a
VA Economic Development Partnership	Misc.	Bob Burnley			bburnley@yesvirginia.org	yes
VA Floodplain Manage. Association	Misc.	James Rakestraw, President	(540) 228-3655		president@vaflood.org	n/a
VA Housing Development Authority	Misc.	George R. Peterson	(804) 343-5753		george.Peterson@vhda.com	no
Virginia Marine Resources Comm.	Misc.	Col. Steven Bowman	(757) 247-2250			no
		Kale Wilford	(757) 247-2269	(757) 247-2020	wkale@mrc.state.va.us	n/a
Virginia Municipal League	Misc.	Greg Dickie	(804) 643-0274		gdickie@vml.org	yes
Virginia Port Authority	Misc.	Rick Napp, Hurricane Proc. Unit	(757) 440-7207			yes
		Donald Boyd (ATTENDEE)	(757) 683-2190		Dboyd@vpa.vit.org	yes
Virginia Resources Authority	Misc.	Mary Barnes	(804) 644-3117		mbarnes@vra.state.va.us	no

California Agencies and Organizations Contacted:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
COMMUNICATION:						
Bakersfield City Telecommunications	Comm.	General Information	(661) 326-3300		telecommunications@ci.bakersfield.ca.us	no
CA Amateur Radio Emergency Serv.	Comm.	Bruce Hilliard	(916) 445-5020		bhilliar@dhs.ca.gov	no
Berkeley	Comm.	John Remoy, Radio Officer			remoy@msn.com	no
Fairfield	Comm.	Dan Montandon, Radio Officer			dmontand@dhs.ca.gov	no
San Diego CARES	Comm.	Walt Davis, Rad. Officer	(760) 789-7954		wa6odq@arrl.net	yes
CA OES Aux. Communication Serv.	Comm.	Ben Green, Assistant Chief	(916) 262-1603		ben_green@oes.ca.gov	no
		Cary Mangum, State Officer	(916) 262-1670	(916) 262-1627	cary_mangum@oes.ca.gov	no
State Operations Communication Center	Comm.	Les Ballinger, Operations Off.	(916) 262-1675		les_ballinger@oes.ca.gov	no
Coastal	Comm.	Paul Carlin, Officer	(510) 286-6748		paul_carlin@oes.ca.gov	no
Inland	Comm.	Bill Pennington, Officer	(916) 262-1673		bill_pennington@oes.ca.gov	no
CA OES Emergency Alert System	Comm.	Cary Mangum, Plans Coord.	(916) 262-1670	(916) 262-1627	EAS_PM@oes.ca.gov	n/a
CA OES Em. Digital Information Serv.	Comm.	General Information			ron_rosenow@oes.ca.gov	no
Contra Costa County ARES	Comm.	Sam Lipson			ko6jr@arrl.net	no
Los Angeles County Dis. Comm. Serv.	Comm.	General Information	(323) 980-2246		disaster@artsci.net	no
		Mark Utley, Sher. Dept. Coord.			DCS@lasd.org	no
		Jim Bogdan, Chief Comm. Off.			Jbogdan@artsci.net	no
Marin County RACES	Comm.	Valerie Quigley			vquigley@marin.org	no
Orange County Amateur Rad. Emerg. S	Comm.	General Information				no
Placer County SAR Comm. Unit	Comm.	Eric Homa			ehoma@pacbell.net	no
Sacremento Valley ARES	Comm.	David Thorne, Emerg. Coord.			lazyt@cot.net	yes
		Bill Pennington, Emerg. Coord.			bill-pennington@oes.ca.gov	no
San Bernardino County ARES	Comm.	John Ransdell, Oper. Chief			kd6lxt@pacbell.net	no
San Diego County CARES	Comm.	Gerry Sandford, Chief			staff1@races.sandiego.ca.gov	yes
SF US Pub. Health Services Radio	Comm.	Eric Swanson, Officer	(415) 437-8045		eswanson@hrsa.gov	yes
San Luis Obispo Em. Comm. Council	Comm.	Robert Alberti, Director			w6ttx@arrl.net	yes
Santa Barbara Amat. Radio. Em. Serv.	Comm.	Jack Hunter, Emerg. Coord.			rjhunter@juno.com	yes
Santa Clara County ARES	Comm.	Anne Barrett, Emerg. Coord.			abarrett@usa.net	no
Sierra Del Mar Div. ARES	Comm.	Paul Cook, Comm. Coord.			n6rpf@yahoo.com	no
Sonoma County RACES	Comm.	General Information			acs@cds1.net	no
South County Amat. Radio. Em. Serv.	Comm.	Peter Liljequist, President	(650) 592-5663		kd6bxy@arrl.net	no

California Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
COMMUNICATION, continued:						
Southern Region Auxiliary Comm.	Comm.	John Hudson, Ass. Chief	(562) 795-2900		John_Hudson@oes.ca.gov	no
Tuolumne County ARES	Comm.	General Information			tcares@qsl.net	no
Ventura County ARES	Comm.	Bill Starkgraf, Emerg. Coord.			kd6uqb@arrl.net	no
EMERGENCY/RESCUE:						
Bakersfield City Fleet Service	Emerg.	Kirk Blair	(661) 326-3796		kblair@ci.bakersfield.ca.us	yes
CA Emergency Mobile Patrol	Emerg.	General Information	(818) 998-6791		admin@cemp.org	no
CA Emergency Serv. Association	Emerg.	General Information				no
CA Rescue Dog Association	Rescue	General Information	(916) 988-5542		100@carda.org	no
CA Explorer Search and Rescue	Rescue	General Information		(650) 618-1599	info@calesar.org	no
		Rich Sampson	(650) 340-4779		rich_sampson@calesar.org	yes
Inland Chapter	Emerg.	Ed Rutherford	(916) 774-5813		erutherford@roseville.ca.us	no
Southern Chapter	Emerg.	Wendy Milligan, Administrator	(805) 644-0899		scesamgr@aol.com	yes
CA Office of Emergency Services	Emerg.					
Disaster Assistance Branch	Emerg.	General Information	(916) 464-1024	(916) 464-0776		n/a
Hazardous Materials	Emerg.	General Information	(916) 464-3230	(916) 464-3205		n/a
Hazard Mitigation	Emerg.	Andrew Petrow	(626) 683-6720	(626) 683-6702	Andrew_Petrow@oes.ca.gov	yes
Planning / Tech. Hazards	Emerg.	General Information	(916) 464-3200	(916) 464-3208		n/a
Inland Region	Emerg.	General Information	(916) 262-1772	(916) 262-2869		n/a
Southern Region	Emerg.	General Information	(562) 795-2900	(562) 795-2877		n/a
Southern Region	Emerg.	General Information	(619) 525-4287	(619) 525-4943		n/a
Southern Region	Emerg.	General Information	(805) 568-1207	(805) 568-1211		n/a
Emergency & Disaster Management	Emerg.	General Information	(310) 284-3194	(310) 284-3195	info@emergency-management.net	no
Emergency Network Los Angeles	Emerg.	General Information	(213) 896-9190	(213) 627-2105		no
Kern County Off. of Emerg. Serv.	Emerg.	General Information	(661) 868-3000		connerc@co.kern.ca.us	no
Los Angeles HazMat Unit	Emerg.	General Information	(213) 847-2793	(213) 687-8341		no
Mountain View City Off. of Em. Serv.	Emerg.	General Information	(650) 903-6378		lynn.brown@ci.mtnview.ca.us	no
San Joaquin Off. of Emerg. Services	Emerg.	Ronald Baldwin, Dir. of Oper.	(209) 468-3968	(209) 944-9015		no
		General Information			sjcoes@co.san-joaquin.ca.us	no
San Jose Off. of Emerg. Services	Emerg.	General Information	(408) 277-4595	(408) 277-3345		no
San Luis Obispo County OES	Emerg.	George Brown			gbrown@co.slo.ca.us	yes

California Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
EMERGENCY/RESCUE, continued:						
Sierra Del Mar Emerg. Disaster Serv.	Emerg.	General Information	(619) 446-1262	(619) 446-0493		no
Yolo County off. of Emerg. Services	Emerg.	Dan McCanta, Em. Serv. Coord.	(530) 666-8930	(530) 666-8909	dan.mccanta@ccm.yolocounty.org	no
ENVIRONMENT:						
CA Bureau of Land Management	Environ.	Mike Pool, Director	(916) 978-4600	(916) 978-4620	castatedir@ca.blm.gov	no
Branch of Energy & Minerals	Environ.	Richard Grabowski, Director	(916) 978-4361	(916) 978-4389		no
Natural Resources	Environ.	David Mcilnay, Chief	(916) 978-4671	(916) 978-4657	dmcilnay@ca.blm.gov	no
Support Services	Environ.	Karen Barnette, Director	(916) 978-4501	(916) 978-4505	Karen_Barnette@ca.blm.gov	yes
Branch of Fire and Aviation	Environ.	Ed Wehking	(916) 978-4431	(916) 978-4438	ewehking@ca.blm.gov	no
Telecommunications Systems	Environ.	Don Black, Chief	(916) 978-4558	(916) 978-4580	dblack@ca.blm.gov	no
Information Resources Management	Environ.	Rob Cervantes, Chief	(916) 978-4544	(916) 978-4580	rcervant@ca.blm.gov	no
CA Conf. of Directors of Env. Health	Environ.	General Information	(916) 944-7315	(916) 944-2256		n/a
Department of Health Services	Environ.					
Environmental Management Branch	Environ.	Jack McGurk, Chief	(916) 323-3023		jmcgurk@dhs.ca.gov	no
Emergency Preparation Office	***Environ.***	***Dave Abbott, Coord.***	***(916) 323-3675***		***dabbott@dhs.ca.gov***	***DS 11***
Waste Management	Environ.	Darice Bailey, Chief	(916) 324-2209		dbailey@dhs.ca.gov	no
Environmental Health Services	Environ.	Glenn Takeoka, Chief	(916) 327-1053		gtakeoka@dhs.ca.gov	no
Department of Water Resources	Environ.					
Division of Flood Management	Environ.	Jay Punia, Chief	(916) 574-2611		jpunia@water.ca.gov	yes
		Ricardo Pineda	(916) 653-5440		rpineda@water.ca.gov	no
Division of Planning and Local Assistance	Environ.	Naser Bateni, Chief	(916) 327-1646		bateni@water.ca.gov	yes
Division of Operations and Maintenance	Environ.	Stephen Kashiwada	(916) 653-8583		slk@water.ca.gov	no
Emergency Preparedness	***Environ.***	***Sonny Fong, Manager***	***(916) 654-6135***	***(916) 653-5028***	***sonnyf@water.ca.gov***	***DS 16***
Environmental Services Office	Environ.	Barbara McDonnell, Chief	(916) 227-7531		bmcdonne@water.ca.gov	no
Division of Management Services	Environ.	Sandee Firch, Exec. Sec.	(916) 653-6943		sfirch@water.ca.gov	yes
Northern District	Environ.	Andrew Corry	(530) 529-7388		corrya@water.ca.gov	yes
Central District	Environ.	Ray Lee	(916) 227-7605	(916) 227-7600	ralee@water.ca.gov	yes
San Joaquin District	Environ.	Edward Perez	(559) 230-3317		evperez@water.ca.gov	no
Southern District	Environ.	William Elder	(818) 543-4646		elder@water.ca.gov	no

California Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
FIRE:						
Brisbane Fire Department	Fire	General Information	(415) 467-1216	(415) 467-8770	firechief@ci.brisbane.ca.us	no
Burlingame Fire Department	Fire	Bill Reilly, Chief	(650) 558-7600		breilly@burlingame.org	no
California Fire Safe Council	Fire	Jill Rushing			Jill.Rushing@mslpr.com	yes
CA State Firefighter's Association	Fire	Lynn Hall Shanon, Gen. Man.	(800) 451-2732	(916) 446-9889	Lshannon@csfa.net	n/a
Northern Branch	Fire	Neal Warner, Director			Nwarner@csfa.net	n/a
Central Branch	Fire	Michael Gill, Director			Mgill@csfa.net	n/a
Southern Branch	Fire	Ed Foster, Director			Efoster@csfa.net	n/a
Southern Branch	Fire	Peter Liebig, Director			Pliebig@csfa.net	n/a
CA Medical Task Force	Fire	Ric Schultz, Medical Coord.			RicSchultz@CATF5.org	n/a
CA Task Force - Search and Rescue	Fire	Marc Hawkins, Leader	(949) 581-4406	(949) 581-4649	MarcHawkins@CATF5.org	n/a
California City Fire Department	Fire	General Information	(760) 373-4841	(760) 373-1305	calcityfire@hotmail.com	no
El Cerrito Fire Department	Fire	Mark Scott, Chief	(510) 215-4450		fire@ci.el-cerrito.ca.us	no
Firescope Riverside	Fire	General Information	(909) 782-4174	(909) 782-4239		no
Healdsburg City Fire Department	Fire	General Information			fire@ci.healdsburg.ca.us	no
Kern County Fire Department	Fire	Geoff Wilford, Batt. Chief			geoffdw@lightspeed.net	no
Menlo Park Fire Prot. Dist.	Fire	Miles Julihn	(650) 688-8400		mpfd@menlofire.org	no
Millbrae Fire Department	Fire	General Information	(650) 259-2400		fire@ci.millbrae.ca.us	no
Orange County Fire Authority	Fire	Clerk of Authority	(714) 289-3725		nancyswanson@ocfa.org	no
Palo Alto Fire Department	Fire	Ruben Grijalva, Chief	(650) 329-2184	(650) 327-6951	fire@city.palo-alto.ca.us	no
Redwood City Fire Department	Fire	Edward Montez, Chief			emontez@redwoodcity.org	no
San Bruno Fire Department	Fire	William Graham, Chief	(650) 616-7096		scampos@ci.sanbruno.ca.us	no
San Luis Obispo Co. Fire Department	Fire	Dan Turner, Fire Chief	(805) 543-4244	(805) 543-4248		no
Selma City Fire Department	Fire	Roy Peak, Chief	(559) 896-2511	(559) 896-4300	RoyP@cityofselma.com	no
South County Fire Authority	Fire	General Information	(650) 802-4255	(650) 592-4714	info@scfa.dst.ca.us	no
Taft City Fire Department	Fire	General Information	(661) 765-4136		tcfdbran@lightspeed.net	no
		Roy Heimiller, Chief			rheimiller57@yahoo.com	no
Turlock City Fire Department	Fire	General Information	(209) 668-5580		fire@turlock.ca.us	no
Woodside Fire Protection District	Fire	Chief			mfuge@woodsidefire.org	no

California Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
HEALTH:						
Alameda County Ambulance Service	Health	General Information	(510) 535-6957	(510) 891-5700		no
Ctr for Pub. Health & Disaster Relief	Health	Steven Rottman	(310) 794-0864	(310) 794-0889	cphdr@ucla.edu	no
Department of Health Services	Health	General Information				n/a
Office of County Health Services	Health	General Information			ochsmail@dhs.ca.gov	no
Office of Public Affairs	Health	General Information	(916) 657-3064	(916) 657-0240		no
Emergency Medical Serv. Authority	Health	General Information		(916) 324-2875	llittle@emsa.ca.gov	no
DMS Division	Health	Jeff Runin, Division Chief			jrubin@emsa.ca.gov	no
		Laura Venegas, Specialist			lvenegas@emsa.ca.gov	no
		Anne Bybee, Specialist			abybee@emsa.ca.gov	yes
		Cheryl Starling, Specialist			cstarling@emsa.ca.gov	yes
		Derrick Green, Specialist			dgreen@emsa.ca.gov	no
EMS Division	Health	Maureen McNeil, Chief			mmcneil@emsa.ca.gov	no
Hall Ambulance Service	***Health***	***Louis Cox, Oper. Manager***	***(661) 322-8741***		***coxl@hallamb.com***	***DS 12***
		Ed Smith, Field Supervisor			smithe@hallamb.com	no
Orange County Dis. Med. Ass. Team	Health	Mike Steinkraus	(714) 480-5249	(949) 548-0646		no
		General Information			dmatca1@uwmc.com	no
San Bernardino Co. Dis. Med. Ass.	Health	Lee Fulton			gglee@eee.org	no
UCSD Dept. of Emerg. Medicine	Health	Kathy Richardson	(619) 543-6236	(619) 543-7598	kmrichardson@ucsd.edu	no
Local Emergency Medical Services:						
Alameda County Emerg. Medical Serv.	Health	Cindy Abbissinio, Admin.	(510) 628-5060	(510)465-5624	cabbissi@ph.mail.co.alameda.ca.us	yes
		James Pointer, Director	(510) 628-5060		jpointer@ph.mail.co.alameda.ca.us	no
		General Information			khelande@ph.mail.co.alameda.ca.us	no
Contra Costa County EMS	Health	Art Lathrop	(925) 646-4690	(925) 646-4379	alathrop@hsd.co.contra-costa.ca.us	yes
		Joe Barger, Director	(925) 646-4690		jbarger@ix.netcom.com	no
El Dorado Co. Emerg. Medical Serv.	Health	Jim Schneider, Aministrator	(530) 621-6500	(530) 621-2758	jschneider@co.el-dorado.ca.us	no
		Hugh Dame, Director	(530) 621-6500		hdame@innercite.com	no
Fresno County Emerg. Medical Serv.	Health	Dan Lynch, Aministrator	(559) 445-3387	(559) 445-3205	fkmems@fresno.ca.gov	no
		Jim Andrews, Director	(559) 445-3387		andrews@medisun.ucsfresno.edu	no
Imperial County Emerg. Medical Serv.	Health	John Pritting, Aministrator	(760) 339-4468	(760) 352-9933	johnpritting@imperialcounty.net	no
Kern County Emerg. Medical Serv.	Health	Russ Blind, Aministrator	(661) 861-3200	(661) 326-0951	blindr@co.kern.ca.us	no
		Vicki Bertholf, Coord.	(661) 868-5200	(661) 322-8453	bertholfv@co.kern.ca.us	no

California Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
HEALTH, continued:						
Los Angeles County EMS	Health	Virginia Hastings, Aministrator	(323) 890-7500	(323) 890-8528	vhastings@dhs.co.la.ca.us	no
		Sam Stratton, Director	(323) 890-7500		stratton@emedharbor.edu	no
Marin County Emerg. Medical Serv.	Health	Ardith Hamilton, Aministrator	(415) 499-6871	(415) 499-3747	ahamilton@marin.org	no
		Richard Carvolth, Director	(415) 499-6871		carvolth@soml.com	no
Mendocino Valley Em. Medical Serv.	Health	General Information	(707) 463-4590	(707) 467-2551		no
Merced County Emerg. Medical Serv.	Health	Chuck Baucom, Aministrator	(209) 381-1250	(209) 381-1259	he39@co.merced.ca.us	no
Monterey County Emerg. Medical Serv.	Health	Chris Le Venton, Aministrator	(831) 755-5013	(831) 455-0680	emsagency@co.monterey.ca.us	no
Mountain Valley Emerg. Medical Serv.	Health	Steve Andriese, Aministrator	(209) 529-5085	(209) 529-1496	andriesems@aol.com	no
		Ben Schifrin, Director	(209) 529-5085		benschif@sonnet.com	no
Napa Valley Emerg. Medical Serv.	Health	Bonny Martignoni	(707) 253-4341	(707) 259-8112	bmartign@co.napa.ca.us	no
North Coast Emerg. Medical Serv.	Health	Larry Karsteadt, Aministrator	(707) 445-2081	(707) 445-0443	execdir@nothcoast.com	no
		Kenneth Stiver, Director	(707) 445-2081		krs1147@aol.com	no
Northern CA Emerg. Medical Serv.	Health	Dan Spiess, Chief Officer	(530) 229-3975	(530) 229-3984	ncems@c-zone.net	no
		Harold Renollet, Director			75601.257@compuserve.com	no
Orange County Emerg. Medical Serv.	Health	Celia Waite, Aministrator	(714) 834-3500	(714) 834-3125	cwaite@hca.co.orange.ca.us	no
Riverside Co. Emerg. Medical Serv.	Health	Michael Osur, Aministrator	(909) 358-5029	(909)358-5160	hsa.health-1.mosur@co.riverside.ca.us	no
		Humberto Ochoa, Director	(909) 358-5029		hochoa8252@aol.com	no
Sacramento County EMS	Health	Bruce Wagner, Chief	(916)875-9753	(916) 875-9711	wagner@co.sacramento.ca.us	no
		Steven Tharratt, Director	(916)875-9753		rstharratt@ucdavis.edu	yes
San Benito Co. Emerg. Medical Serv.	Health	Peggy Earle, Aministrator	(831) 636-4169	(831) 636-4104		no
		Kent Benedict, Director	(831) 636-4168		skylax@cruzio.com	no
San Bernadino Emerg. Medical Serv.	Health	Diane Fisher, Aministrator	(909) 388-5823		dfisher@ph.co.san-bernardino.ca.us	no
San Diego Co. Emerg. Medical Serv.	Health	Jeri Bonesteele	(619) 285-6429	(619) 285-6531	jboneshe@co.san-diego.ca.us	yes
		Mel Ochs, Director	(619) 285-6429		melochs@aol.com	no
San Fran. Co. Emerg. Medical Serv.	Health	Michael Petrie, Aministrator	(415) 554-9963	(415) 241-0519	michael_petrie@dph.sf.ca.us	no
		John Brown, Director	(415) 554-9963		john_brown@dph.sf.ca.us	yes
San Joaquin County EMS	Health	Darrell Cramphorn, Amin.	(209) 468-6818	(209) 468-6725	sjemsa@co.san-joaquin.ca.us	no
		Richard Buys, Director	(209) 468-6818			n/a
San Luis Obispo County EMS	Health	Thomas Ronay, Director	(805) 546-8728	(805) 546-8736	sloemsa@fix.net	no
San Mateo Co. Emerg. Medical Serv.	Health	Barbara Pletz, Administrator	(650) 573-2564	(650) 573-2029	bpletz@mail.co.sanmateo.ca.us	no
		Karl Sporer, Director	(650) 573-2564		ksporer@co.sanmateo.ca.us	no

California Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
HEALTH, continued:						
Santa Barb. County EMS	Health	Nancy LaPolla, Administrator	(805) 681-5274	(805) 681-5142	jolmste@co.santa-barbara.ca.us	no
		Angelo Salvucci, Director	(805) 681-5274		salvucci@silcom.com	no
Santa Clara County EMS	Health	Pam West, Administrator	(408) 885-4250	(408) 885-3538	pam.west@hhs.co.santa-clara.ca.us	no
Santa Cruz Co. Emerg. Medical Serv.	Health	Vol Ranger, Administrator	(831) 454-4751	(831) 454-4488		no
Sierra-Sac. Valley EMS	Health	Leonard Inch, Administrator	(916) 625-1701		ssvagency@aol.com	no
		William Koenig, Director	(916) 625-1700		billkoen@aol.com	no
Solano County Emerg. Medical Serv.	Health	Michael Frenn, Administrator	(707)421-6685	(707) 421-6682	mfrenn@solanocounty.com	no
Sonoma Valley Emerg. Medical Serv.	Health	Sandy Covall-Alves, Coord.	(707) 565-6501	(707) 565-6510	scovall@sonoma-county.org	yes
Tulare County Emerg. Medical Serv.	Health	Patty Crawford	(559) 737-4660	(559) 737-4693		no
Tuolumne Co. Emerg. Medical Serv.	Health	Dan Burch, Administrator	(209) 536-0620	(209) 533-4761	TCEMS@mlode.com	no
Ventura County Emerg. Medical Serv.	Health	Barbara Brodfuehrer	(805) 677-5270	(805) 677-5290	Barbara.Brodfuehrer@mail.co.ventura.ca.us	yes
Local Red Cross:						
Arcadia Chapter Redcross	Health	David Stegner, Em. Serv. Dir.	(626) 447-2196		Stegner@arcadia-redcross.org	n/a
Carmel Area Chapter Red Cross	Health	General Information	(831) 624-6921	(831) 624-7014		n/a
Claremont Chapter Red Cross	Health	General Information			clmtarc@crossnet.org	no
Glendale-Crescenta Valley Chap. RC	***Health***	***Robert Reynoso, Em. Serv.***	***(818) 243-3121***	***(818) 240-2899***	***Robert@arcglendale.org***	***DS 13***
Greater Long Beach Chap. RC	Health	General Information	(562) 595-6341	(562) 424-2821	ncems@c-zone.net	no
High Desert Chapter Red Cross	Health	Sherril D'Espyne, Exec. Dir.	(760) 245-6511	(760) 245-3180	archighdesert@earthlink.net	no
Humboldt County Chapter Red Cross	Health	General Information	(707) 443-4521	(707) 443-2746	HCARC@Northcoast.com	no
LA Chapter Red Cross	Health	Sandra Shields, Dir. of Prep.	(213) 739-5211		Info@acrossla.org	yes
Mendocino Co. Chapter Red Cross	Health	General Information	(707) 463-0112	(707) 463-2715	arcmc@pacific.net	no
Merced-Mariposa Counties Chap. RC	Health	Samuel Ronveaux, Exec. Dir.	(209) 383-2150	(209) 383-0445	sammmarc@hotmail.com	yes
Monterey County Chapter Red Cross	Health	Cliff Thornburg, Dis. Serv.	(831) 242-6800	(831) 242-6808	Cliffthor@MontereyARC.org	no
Napa Chapter Red Cross	Health	General Information	(707) 257-2900	(707) 257-2902		no
Northern CA Chapter Red Cross	Health	General Information			fischera@usa.redcross.org	no
Rio Hondo Chapter Red Cross	Health	General Information	(562) 945-3944	(562) 945-6520	info@arcriohondo.org	no
Sacramento Sierra Chap. Red Cross	Health	Linda Lamphear	(916) 368-3220		lamphearl@sacramento-redcross.org	no
San Gabriel Valley Chap. Red Cross	Health	Barbara Pieper	(626) 799-0841	(626) 799-4802	pieper@sgvarc.org	yes
		Michael Amado	(626) 799-0841		amado@sgvarc.org	yes

California Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
HEALTH, continued:						
Santa Barbara Chapter Red Cross	Health	General Information			chapter@sbaco-redcross.org	no
Santa Clara Valley Chap. Red Cross	Health	Karen Borgstrom	(408) 577-2010	(408) 577-2030	borgstromk@usa.redcross.org	yes
Santa Cruz Co. Chapter Red Cross	Health	General Information	(831) 462-2881	(831) 462-5996		no
Santa Monica Chapter Red Cross	Health	Stephanie Jensen	(310) 394-3773	(310) 451-3226	pubafrs@redcrossofsantamonica.org	yes
Silverado Chapter Red Cross	Health	General Information	(707) 963-2717		silvrado@fcs.net	no
Sonoma Co. Chapter Red Cross	Health	Sandy Stoddard, Dis. Serv. Dir.	(707) 577-7609		sonomarc@crossnet.org	yes
Stanislaus Co. Chapter Red Cross	Health	Charles Gibson, Dis. Team	(209) 523-6451	(209) 523-3735		no
Ventura Co. Chapter Red Cross	Health	Clark Hodges, Dis. Team	(805) 339-2234		chodges@arcventura.org	no
Western Nevada Co. Chap. RC	Health	General Information	(530) 272-3265		redcross@wncarc.org	no
Yolo Co. Chapter Red Cross	Health	Disaster Services	(530) 662-4669		emerdir@yc-arc.org	no
MILITARY:						
Armed Forces - RedCross	Military	General Information			arcmc@pacific.net	no
California Air National Guard	Military	SMSgt. Jack Gruber	(916) 854-3784		Jack.Gruber@ca.ang.af.mil	n/a
		LtCol Philip Kincaid	(916) 569-2225		Philip.Kincaid@camoff.ang.af.mil	n/a
		Thomas Field			Thomas.Field@camoff.ang.af.mil	n/a
		MSgt Tracie Gunson	(805) 986-7431		Tracie.Gunson@cachan.ang.af.mil	n/a
		Public Affairs			pa.129rqw@camoff.ang.af.mil	n/a
		CofS	(916) 854-3490	(916) 854-3084		n/a
		POMSO	(916) 854-3440	(916) 854-3475		n/a
		POTO	(916) 843-3207	(916) 854-3069		n/a
		AG	(916) 854-3500	(916) 854-3671		n/a
		HRO	(916) 854-3401	(916) 854-3439		n/a
		SPMS	(916) 854-3412	(916) 854-3439		n/a
		AGR MGR	(916) 854-3403	(916) 854-3439		n/a
CA Army National Guard	***Military***	Karen Ouimet			karen.ouimet@ca.ngb.army.mil	n/a
		Maj. Terry Edinboro, Chf. of Op	***(916) 854-3485***		***terry.edinboro@js.ca.ngb.army.mil***	***DS 14***
CA National Guard	Military					
Information Management	Military	Col. James Chapman			James.Chapman@ca.ngb.army.mil	n/a
Construction and Facility Management	Military	General Information			Glenn.Barrows@ca.ngb.army.mil	n/a
State Military Department	Military	Colonel Benny Steagall	(916) 854-3580	(916) 854-3597		n/a

California Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
POLICE:						
Alameda Police Department	Police	General Information	(510) 748-4508	(510) 523-5322	COPPS@ci.alameda.ca.us	no
Alhambra Police Department	Police	Lawrence Lewis, Chief			alhcop@ix.netcom.com	no
Arcadia Police Department	Police	David Hinig, Chief	(626) 574-5150	(626) 447-6581	dhinig@ci.arcadia.ca.us	no
Arroyo Grande Police Department	Police	Richard Checansky, Officer	(805) 473-5100		chet@thegrid.net	no
Atascadero Police Department	Police	General Information	(805) 461-5051		jcouch@Atascadero.org	no
Atwater Police Department	Police	Jerry Moore, Chief	(209) 357-6396		jmoore@data.co.merced.ca.us	no
Bakersfield City Police Department	Police	General Information	(661) 327-7111		police@ci.bakersfield.ca.us	no
Brea City Police Department	Police	William Lentini, Chief	(714) 990-7633		Chief@ci.brea.ca.us	no
Buena Park Police Department	Police	Gary Hicken, Op. Div. Captain	(714) 562-3901		Gary_Hicken@ci.buena-park.ca.us	no
Burlingame Police Department	Police	General Information	(650) 692-8440	(650) 697-8130		no
Calexico Police Department	Police	Tommy Tunson, Chief			tchief@thegrid.net	no
Ceres City Police Department	Police	Art de Werk, Chief	(209) 538-5726		adewerk@ci.ceres.ca.us	no
Chowchilla City Police Department	Police	John Robinson, Chief	(559) 665-8600		policechief@softhome.net	no
Clayton Police Department	Police	General Information	(925) 673-7350	(925) 672-1429		no
Cloverdale Police Department	Police	Robert Dailey, Chief	(707) 894-2150		police@cloverdale.net	no
Corcoran Police Department	Police	Reuben Shortnacy, Chief	(559) 992-5151		CPD@mail.com	no
Corona City Police Department	Police	Richard Gonzales, Chief	(909) 736-2330	(909) 279-3579	chiefg@ci.corona.ca.us	no
Corte Madera Police Department	Police	Phillip Green, Chief	(415) 927-5150	(415) 927-5167		no
CSU Police Department	Police	John Carpenter, Chief	(619) 594-6905	(619) 594-6653	john.carpenter@sdsu.edu	no
CSU San Diego Police Department	Police	General Information	(619) 594-6905		john.carpenter@sdsu.edu	no
Desert Hot Springs Police Dept.	Police	Paul Stotesbury, Chief	(760) 329-6411	(760) 251-3523	info@deserthotsprings.com	no
Dinuba Police Department	Police	General Information	(559) 591-5911	(559) 591-5920	dinubapd@psnw.com	no
Downey Police Department	Police	General Information	(562) 861-0771		downeypd@instanet.com	no
El Centro Police Department	Police	Raymond Loera, Chief	(760) 337-4528		rloera@ecpd.org	no
El Cerrito Police Department	Police	Scott Kirkland	(510) 215-4410		police@ci.el-cerrito.ca.us	no
Eureka Police Department	Police	David Douglas, Chief	(707) 441-4060	(707) 441-4334		no
Folsom Police Department	Police	Joseph Williams, Chief	(916) 355-7230	(916) 985-7643	policedept@folsom.ca.us	no
Fortuna Police Department	Police	Kent Bradshaw, Chief	(707) 725-7550	(707) 725-7574		no
Fountain Valley	Police	Elvin Miali, Chief	593-4456		el.miali@fountainvalley.org	no
Fresno Co. Sherrif's Department	Police	Donald Burk, Captain			dburk@fresno.ca.gov	no
		Roger Greening, Captain			rgreening@fresno.ca.gov	no

California Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
POLICE, continued:						
Half Moon Bay City Police Department	Police	Dennis Wick, Chief	(650) 726-8288		cop@coastside.net	no
Hawthorne Police Department	Police	General Information	(310) 970-7976	(310) 676-3856	patrol@hawthornepolice.com	no
Hayward Police Department	Police	Craig Calhoun, Chief	(510) 293-7272	(510) 293-7183		no
Healdsburg City Police Department	Police	General Information			police@ci.healdsburg.ca.us	no
Hemet City Police Department	Police	Pete Hewitt, Chief	(909) 765-2400	(909) 765-2412	tpalmer@ci.hemet.ca.us	yes
Hercules Police Department	Police	Michael Tye, Chief	(510) 799-8260	(510) 799-8281		no
Hollister Police Department	Police	Bill Pierpoint, Chief			bpierpoint@police.hollister.ca.us	yes
Huntington Beach Police Department	Police	R. Lowenberg, Chief			lowenber@surfcity-hb.org	no
Indio Police Department	Police	George Rawson, Chief			rawson@indiopd.org	no
King City Police Department	Police	Richard Metcalf, Chief			pdchief@kingcity.com	no
Lemoore Police Department	Police	Kimberly Morrell, Chief	(559) 924-9574	(559) 924-3116	kmorrell@co.kings.ca.us	no
Long Beach Police Department	Police	General Information	(562) 570-7301	(562) 570-7114		no
Los Angeles Police Department	Police	Sgt. Ron Spicer, Emerg. Op.			ronspicer@hotmail.com	yes
Air Support Division	Police	Officer Charles Perriguey	(213) 485-2011	(213) 485-2073		yes
Operations - Central	Police	Deputy Chief	(213) 485-3101	(213) 485-6623		no
Operations - Valley	Police	Deputy Chief	(818) 756-8303	(818) 756-8298		no
Operations - West	Police	Deputy Chief	(213) 473-0277	(213) 473-0285		no
Lompoc Police Department	Police	William Brown, Chief	875-8107		j_chastain@ci.lompoc.ca.us	no
		Jim Thomas, Sheriff			sheriff@sbsheriff.org	no
Los Banos Police Department	Police	Michael Hughes	(209) 827-7070	(209) 827-7006	policea@data.co.merced.ca.us	no
Madera County Sherrif's Department	Police	John Anderson, Sheriff	(559) 675-7770	(559) 675-8413	sheriff@thegrid.net	no
		Sgt. Chuck Reiring			sgtchuck@psnw.com	no
Madera Police Department	Police	Jerry Noblett, Chief	(559) 674-5611		jnoblett@madnet.net	no
Maywood Police Department	Police	Rick Lopez, Chief	(213) 562-5005		chief@cityofmaywood.com	no
Menlo Park Police Department	Police	Scott Vermeer, Chief	(650) 858-3325	(650) 327-4314	policechief@menloparkpolice.org	no
Mill Valley City Police Department	Police	Robert Ritter, Dir. of Pol. Serv.	(415) 389-4100		police@cityofmillvalley.org	no
Modesto Police Department	Police	David Funk	(209) 572-9657	(209) 572-9669	FunkD@modestopd.com	yes
Monterey Police Department	Police	Phil Penko, Sergeant	(831) 646-3830		penko@ci.monterey.ca.us	no
Moraga Police Department	Police	Barry Kalar, Chief	376-2515	376-2850	police@moraga.ca.us	no
Moutain View City Police Department	Police	Richard Elias, Sergeant	(650) 903-6707		rich.elias@ci.mtnview.ca.us	no
Mt. Shasta Police Department	Police	General Information	(530) 926-7540	(530) 926-3601	p-mspd@inreach.com	no

California Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
POLICE, continued:						
Napa City Police Department	Police	General Information	(707) 257-9550		dmonez@cityofnapa.org	yes
Oceanside Police Department	Police	General Information			police@ci.oceanside.ca.us	no
Orange Police Department	Police	Andy Romero, Chief	(714) 744-7301	(714) 744-7428	aromero@orangepd.org	no
Oxnard Police Department	Police	Art Lopez, Chief		(805) 483-8408	chief@oxnardpd.org	no
Palm Springs Police Department	Police	Lee Weigel, Chief	(760) 323-8126		ReneeM@ci.palm-springs.ca.us	yes
Palo Alto Police Department	Police	Pat Dwyer, Chief	(650) 329-2406	(650) 617-3120	pd@city.palo-alto.ca.us	no
Petaluma Police Department	Police	Pat Parks, Chief	(707) 778-4372	(707) 778-4476	police@ci.petaluma.ca.us	no
Pinole Police Department	Police	John Miner, Chief	(510) 724-8955		police@ci.pinole.ca.us	no
Pismo Beach Police Department	Police	General Information	(805) 773-2208	(805) 773-3505		no
Placerville Police Department	Police	General Information	(530) 624-5210	(530) 642-5215	admin@HangtownCops.org	no
Red Bluff Police Department	Police	Mace McIntosh, Chief	(530) 527-3134	(530) 529-4768	mmcintosh@rbpd.org	no
Redding Police Department	Police	Steve Davidson, Captain	(530) 225-4223	(530) 225-4553	rpdweb@ci.redding.ca.us	no
Redlands City Police Department	Police	Jim Bueermann, Chief			rdlpolice@eee.org	no
Reedley Police Department	Police	Joe Garza, Sgt.	(559) 637-4250	(559) 638-7218	joe.garza@reedley.com	no
Rialto Police Department	Police	Arthur Burgess, Captain	(909) 820-2572		Aburgess@Rialtopd.com	no
Ridgecrest Police Department	Police	Michael Avery, Lieutenant	(760) 371-3711		mavery@ci.ridgecrest.ca.us	no
Ripon City Police Department	Police	Richard Bull, Chief	(209) 599-2102	(209) 599-4034	rip-pdlt@thevision.net	no
Riverside Police Department	Police	Emergency Serv. Coord.	(909) 351-6099		CNIEVES@ci.riverside.ca.us	no
Sacramento Police Department	Police	Arturo Venegas, Chief			spdcau@mail2.quiknet.com	no
Salinas Police Department	Police	Sassie McSorley, Captain	(831) 758-7090		cassiem@ci.salina.ca.us	no
San Bruno Police Department	Police	Brad Schimek, Field Officer	(650) 616-7100	(650) 871-6734	bschimek@ci.sanbruno.ca.us	no
San Carlos Police Department	Police	Jim Branucci, Chief	(650) 802-4223		jim.granucci@ci.san-carlos.ca.us	no
San Fernando Police Department	Police	Dominick Rivett, Chief	(818) 898-1200		info@ci.san-fernando.ca.us	no
San Gabriel Police Department	Police	David A. Lawton, Chief			chief@sgpd.com	no
San Leandro Police Department	Police	Joe Kitchen, Chief	(510) 577-3251		jkitchen@ci.san-leandro.ca.us	no
San Manteo Police Department	Police	Susan Manheimer, Chief	(650) 522-7710		police@ci.sanmateo.ca.us	no
Santa Barbara OES	Police	D. Gonzales, Chief	(805) 897-2473	(805) 897-2473	dgonzales@sbpd.com	yes
Santa Clara Police Department	Police	Charles Arolla, Chief	(408) 615-4890		police@ci.santa-clara.ca.us	no
Santa Fe Springs Police Department	Police	Fernando Tarin, Director	(562) 409-1850	(562) 409-1854	FernandoTarin@santafesprings.org	no
Santa Maria Police Department	Police	David Stern	(805) 928-3781	(805) 922-0877	dstern@ci.santa-maria.ca.us	yes
Santa Monica Police Department	Police	James T. Butts, Chief	(310) 458-8407		Chief@santamonicapd.org	no

California Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
POLICE, continued:						
Sausalito Police Department	Police	Earnest Clements, Chief	(415) 289-4181		eclements@ci.sausalito.ca.us	no
Selma City Police Department	Police	Tom Whiteside, Chief	(559) 896-2525	(559) 896-8839	ThomasW@cityofselma.com	no
South Pasadena Police Department	Police	Michael Berkow, Chief	(626) 799-1121		mberkow@ci.south-pasadena.ca.us	yes
South San Fran. Police Department	Police	Mark Raffaelli, Chief	(650) 877-8900	(650) 877-5982		no
St. Helena Police Department	Police	Bert Johansson, Chief	(707) 967-2850	(707) 963-8043		no
Stockton Police Department	Police	Edward Chavex, Chief	(209) 937-8377		police@ci.stockton.ca.us	no
Sunnyvale Police Department	Police	General Information	(408) 730-7100	(408) 749-0166	pubsfty@ci.sunnyvale.ca.us	yes
Tracy Police Department	Police	General Information	(209-831-4550)		PoliceDept@ci.tracy.ca.us	no
Turlock Pol. Services	Police	General Information	(209) 668-5550	(209) 667-5226		no
UC Irvine Police Department	Police	Kathy Hooven, Chief	(949) 824-7797		krstanle@uci.edu	no
Upland Police Department	Police	Martin Thouvenell, Chief	(909) 946-7624		mthouvenell@uplandpd.org	no
Vallejo Police Department	Police	Robert Nichelini, Chief	(707) 648-4553	(707) 648-4490		no
Walnut Creek Police Department	Police	Tom Soberanes, Chief	(925) 943-5894		soberanes@ci.walnut-creek.ca.us	no
Whittier Police Department	Police	Charles Hoover, Chief	(562) 945-8252		chief@whittierpd.org	no
TRANSPORTATION:						
CalTrans (CA State DOT)	Trans.	Tony Harris, Chief Dep. Dir.			Tony_Harris@dot.ca.gov	no
		Jim Varney, Dis. Coord.	(916) 654-3523		Jim_Varney@dot.ca.gov	yes
Environmental Programs	Trans.	Gary Winters			Gary _Winters@dot.ca.gov	yes
Equipment Service	Trans.	Mike Brown, Director			Mike_Brown@dot.ca.gov	no
Information Systems	Trans.	Gil Tafoya, Director			Gilbert_Tafoya@dot.ca.gov	no
Maintenance and Operations	Trans.	John Cottier			John_Cottier@dot.ca.gov	yes
Operations	Trans.	Kim Nystrom			Kim_Nystrom@dot.ca.gov	no
Planning	Trans.	Brian Smith, Dep. Director			Brian_Smith@dot.ca.gov	yes
Transportation System Information	Trans.	Martha Tate Glass			Martha_Tate_Glass@dot.ca.gov	no
District 1	Trans.	Rick Knapp, Director			Rick_Knapp@dot.ca.gov	no
District 10	Trans.	Mark Leja, Director			Mark_Leja@dot.ca.gov	no
District 11	Trans.	Gary Gallegos, Director			Gary_Gallegos@dot.ca.gov	no
District 12	Trans.	Ken Nelson, Director			Ken_Nelson@dot.ca.gov	no
District 2	Trans.	Thom Niesen, Director			Thom_Niesen@dot.ca.gov	no
District 3	Trans.	Irene Itamura, Director			Irene_Itamura@dot.ca.gov	yes

California Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
TRANSPORTATION, continued:						
CalTrans, continued:						
District 4	Trans.	Harry Yahata, Director			Harry_Yahata@dot.ca.gov	no
District 5	Trans.	Jay Walter, Director			Jay_Walter@dot.ca.gov	no
District 6	Trans.	Bart Bohn, Director			Bart_Bohn@dot.ca.gov	no
District 8	Trans.	Anne Mayer			Anne_Mayer@dot.ca.gov	no
District 9	Trans.	Tom Hallenbeck, Director			Tom_Hallenbeck@dot.ca.gov	yes
Amtrak California	Trans.	General Information			rail.program@dot.ca.gov	yes
California City Municipal Airport	Trans.	Tom Weil, Airport Manager	(760) 373-4867	(760) 373-4869	weilt@ccis.com	no
Cloverdale Transit	Trans.	General Information			mitch@netdex.com	no
David City UniTrans	Trans.	General Information			initrans@ucdavis.edu	no
Humboldth Transit Authority	Trans.	General Information			hta@hta.org	no
Los Angeles DOT	Trans.	Dave Roseman	(323) 224-6556		droseman@dot.lacity.org	yes
Metrolink	Trans.	Francisco Oaxaca	(213) 347-2800	(213) 452-0429	OAXACAF@scrra.net	yes
Redding Area Bus Authority	Trans.	General Information			rabastaff@ci.redding.ca.us	yes
Roseville Transit	***Trans.***	***Mike Wixon, Trans. Manage.***	***(916) 774-5480***	***(916) 774-5195***	***mwixon@roseville.ca.us***	***DS 15***
Sacramento Int. Airport	Trans.	General Information	(916) 929-5411	(916) 874-0636	market@smf.co.sacramento.ca.us	no
Sacramento Transport. Authority	Trans.	Norman Hom	(916) 323-0080	(916) 323-0850	sta@sta.sacramento.ca.us	yes
Solano Transport. Authority	Trans.	General Information			staplan@hotmail.com	no
Yolo County Transport. Dist.	Trans.	General Information	(530) 661-0816	(530) 661-1732		no
UTILITY:						
Bakersfield City Water	Utility	General Information	(661) 326-3715		water@ci.bakersfield.ca.us	no
CA Energy Commission	Utility	Bob Aldrich	(916) 654-4989	(916) 654-4420	energia@energy.ca.gov	yes
CA Water Commission	Utility	Douglas Priest	(916) 653-5958	(916) 653-9745	priestd@water.ca.gov	yes
Energy Emerg. Response Office	Utility	Tom Glaviano	(916) 654-4996			no
Healdsburg City Elec. Utility	Utility	General Information			electric@ci.healdsburg.ca.us	no
Sacremento County Air Quality	Utility	General Information			sacaqmd@pacbell.net	no

California Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name & Title of Contact	Phone Num.	Fax Number	Email	Reply
MISCELLANEOUS:						
Bakersfield City General Services	Misc.	General Information	(661) 326-3781		general_services@ci.bakersfield.ca.us	no
Marin InterAgency Disaster Coal.	Misc.	Hank Waschow, Proj. Coord.	(415) 491-8915	(415) 479-9722		no
Nat. Fld Insur. Prog. Contractors	Misc.	Edie Lohmann, Reg. Manager	(916) 780-7889	(916) 780-7905	Edie.Lohmann@worldnet.att.net	yes
Small Business Association	Misc.	General Information			disaster.assistance@sba.gov	no
Southern CA Earthquake Center	Misc.	Mark Benthien	(213) 740-0323	(213) 740-0011	benthien@usc.edu	yes

North Carolina Agencies and Organizations Contacted:

Name of Agency/Organization	Type	Name and Title of Contact	Phone Num.	Fax Number	Email	Reply
COMMUNICATION:						
Agency for Public Telecommunications	Comm.	Bill Ramsey, Operations Manager	(919) 733-6341	(919) 715-3569	bill.ramsey@ncmail.net	yes
BellSouth	Comm.	Clifton Metcalf, Dir. Ext. Affairs	(704) 417-8741		Clifton.Metcalf@bellsouth.com	yes
NC Amateur Radio Emerg Service	***Comm.***	***David Fleming, Emerg. Coord.***	***(336) 766-8667***		***ke4jhj@arrl.net***	***DS 19***
Ral.-Wake Emerg. Communications	Comm.	John Davis	(919) 890-3537		johnjdavis@sprintmail.com	no
		W. Brent Boyin	(919) 890-3537		bboykin@mindspring.com	no
SCANA Communications	***Comm.***	***George Crouch***			***gcrouch@scana.com***	***DS 17***
EMERGENCY:						
Catawba County Emerg. Services	Emerg.	General Information	(828) 465-8200	(828) 465-8392		no
Charlotte Emerg. Management	Emerg.	Wayne Broome	(704) 336-2810			n/a
Dare County Emergency Services	Emerg.	William Sawyer, Public Safety Dir,	(252) 473-1101		wsawyer@co.dare.nc.us	no
		Sandy Sanderson			darecoem@co.dare.nc.us	yes
Dept. of Emergency Management	Emerg.	Emergency Services	(919) 733-3867	(919) 733-2503		no
Dept. of Health & Hum. Serv.'s SERT	Emerg.	Charles Alley	(919) 857-4095		Charles.Alley@Dma.dhhs.ncmail.net	yes
		Rick Brown, Head	(919) 733-1665		rick.brown@ncmail.net	yes
Dept. of Environ. Heath's SERT	Emerg.	Wayne Munden	(919) 715-3237			yes
Durham HazMat. Regional Response	Emerg.	Karen Trimberger, Team Leader			trimb001@mc.duke.edu	no
		Michael Chapman, Team Leader			Michael_Chapman@ncair.net	no
		Michael Pirrello, Team Leader			pirre001@acpub.duke.edu	no
		Jim Chang, Team Leader			jcc11472@glaxowellcome.com	no
Forsyth County Emerg. Services	Emerg.	General Information	(336) 767-6161	(336) 727-2200	wsfcoem@ci.winston-salem.nc.us	no
		Terry Slaughter, Em. Man. Coord.			terrells@main.nc.us	no
Greensboro County Emerg. Serv.	Emerg.	Marilyn Braun, Coordinator			mbraun@mindspring.com	no
Guilford County Emergency Services	Emerg.	Charles Porter, Dir. of Em. Serv.	(336) 373-7565	(336) 333-6538		n/a
New Hanover County Emerg. Serv.	Emerg.	General Information	(910) 341-4300	(910) 341-4299		n/a
NC Emergency Management Ass.	Emerg.	General Information			kranthony@hci.net	no
NC Emergency Response Comm., (EPCRA)	Emerg.	General Information			nc-sara@ncem.org	no
		Richard Berman, HazMat. Prog.	(919) 733-1361	(919) 733-2860	rberman@ncem.org	yes
		Lynn Pittman, Reg. Resp. Coord.	(919) 715-0465	(919) 733-2860	lpittman@ncem.org	no
Onslow County Emergency Services	Emerg.	General Information			oceman@co.onslow.nc.us	no
Orange County Emergency Services	Emerg.	General Information	(919) 968-2050	(919) 968-4066	OCEM@co.orange.nc.us	no
Pamlico County Emergency Services	Emerg.	General Information	(252) 745-4131		emc@pamlico-nc.com	no

North Carolina Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name and Title of Contact	Phone Num.	Fax Number	Email	Reply
EMERGENCY, continued:						
Rowen County Emergency Services	Emerg.	General Information	(704) 638-0911	(704) 633-7503		n/a
		Wayne Ashworth, Dir. of Em. Serv.			ashworthw@co.rowan.nc.us	no
Scotland County Emergency Serv.	Emerg.	Roylin Hammond	(910) 277-2416		roylin@scotland.dss.dhr.state.nc.us	no
Wake County Emergency Services	Emerg.	General Information	(919) 856-6480	(919) 856-7046		no
		Martin L. Chriscoe, Director			mchriscoe@co.wake.nc.us	yes
Wayne County Emergency Services	Emerg.					
Patetown	Emerg.	General Information	(919) 731-1416		patetownvfd@yahoo.com	no
Thoroughfare	Emerg.	General Information			thoroughfare@goldsboro.net	no
Wilmington Emergency Manage. Div.	Emerg.	Nancy Watkins	(910) 251-4945		nancy.r.watkins@usace.army.mil	no
Wilson County Emergency Services	Emerg.	Gordon Deno	(252) 399-2830	(252) 399-0904	gdeno@wilson-co.com	yes
ENVIRONMENT:						
Dept.of Environ. & Natural Resources	Environ.	Craig Deal, Coord. with NCDOT				yes
Disaster & Emergency Response	***Environ.***	***Mike Kelly, Director***	***(919) 715-3644***			***DS 27***
Asheville Region	Environ.	General Information	(828) 251-6208	(828) 251-6452		no
Fayetteville Region	Environ.	Paul Rawls	(910) 486-1541	(910) 486-0707	Paul.Rawls@ncmail.net	yes
Mooresville Region	Environ.	General Information	(704) 663-1699	(704) 663-6040		no
Raleigh Region	Environ.	General Information	(919) 571-4700	(919) 571-4718		no
Washington Region	Environ.	General Information	(252) 946-6481	(252) 975-3716		no
Wilmington Region	Environ.	Eric Imhof	(910) 395-3900	(910) 350-2004	ericimhof@p2pays.org	yes
Winston-Salem Region	Environ.	General Information	(336) 771-4600	(336) 771-4631		no
Groudwater and Air Quality	Environ.	General Information		(336) 771-4632		no
Division of Coastal Management	Environ.	Donna Moffitt, Director	(919) 733-2293	(919) 733-1495	Donna.Moffitt@ncmail.net	yes
Eliz. City District	***Environ.***	***Ted Sampson, Manager***	***(252) 264-3901***	***(252) 264-3723***	***Ted.Sampson@ncmail.net***	***DS20,21***
Wash. District	Environ.	Terry Moore, Manager			Terry.Moore@ncmail.net	yes
Morehead District	Environ.	Ted Tyndall, Manager			Ted.Tyndall@ncmail.net	no
Wilmington District	***Environ.***	***Bob Stroud, Manager***	***(910) 395-3900***	***(910) 350-2004***	***Bob.Stroud@ncmail.net***	***DS 22***
Division of Environmental Health	Environ.	Linda Sewall	(919) 715-2870		Linda.Sewall@ncmail.net	yes
		General Information			deh.service@ncmail.net	no
Division of Forest Resources						
District 1, Region III	Environ.	Keith Jenkins, Forester	(828) 667-5211	(828) 665-0331	pat.fuhr@ncmail.net	yes
Districts 2 and 6, Region III	Environ.	Hunter Birckhead, Forester	(828) 757-5611	(828) 757-5614	hunter.birckhead@ncmail.net	yes

North Carolina Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name and Title of Contact	Phone Num.	Fax Number	Email	Reply
ENVIRONMENT, continued:						
Division of Forest Resources, cont.:						
District 9, Region III	Environ.	Gerald McCall, Forester	(828) 586-4007	(828) 586-4008	gerald.mccall@ncmail.net	yes
District 12, Region III	Environ.	Howard Williams, Forester	(704) 827-7576	(704) 827-4345		no
District 3, Region II	Environ.	Dave Andres, Forester	(910) 997-9220	(910) 997-9224	dave.andres@ncmail.net	yes
District 5, Region II	Environ.	Reid Hildreth, Forester	(252) 442-1626	(252) 442-1651	reid.hildreth@ncmail.net	no
District 10, Region II	***Environ.***	***Vic Owen, Forester***	***(336) 956-2111***		***vic.owen@ncmail.net***	***DS 18***
District 11, Region II	Environ.	Jim Ellis, Forester	(919) 732-8105	(919) 732-4005	kathy.knight@ncmail.net	no
District 4, Region I	Environ.	Ralph M. Cullom, Forester	(252) 514-4764	(252) 514-4768	ralph.cullom@ncmail.net	yes
District 7, Region I	Environ.	David Lane, Forester	(252) 331-4781	(252) 331-4817	david.lane@ncmail.net	no
District 8, Region I	Environ.	Bob Houseman, Forester	(910) 642-5093	(910) 642-7195	bob.houseman@ncmail.net	yes
District 13, Region I	Environ.	Roger Stallard, Forester	(252) 926-3041	(252) 926-1931	roger.stallard@ncmail.net	yes
Division of Land Resources	Environ.	Charles Gardner, Director			Charles.Gardner@ncmail.net	no
Division of Waste Management	Environ.	Jill Pafford, Section Chief	(919) 733-4996		jill.burton@ncmail.net	yes
		Linda Culpepper, Env. Supervisor	(919) 733-4996		linda.culpepper@ncmail.net	yes
Field Operations	Environ.	Phil Prete	(919) 733-4996		phil.prete@ncmail.net	no
Western Region	Environ.	Brent Rockett, Supervisor	(336) 771-4600		brent.rockett@ncmail.net	no
East Field Unit	Environ.	Mark Fry, Supervisor	(910) 486-1541		mark.fry@ncmail.net	yes
Facility Management	Environ.	Pete Doorn, Head	(919) 733-4996		peterdoorn@ncmail.net	no
Division of Water Quality	Environ.	Coleen Sullins, Section Chief			coleen.sullins@ncmail.net	no
Information Management	Environ.	Susan Massengale			Susan.Massengale@ncmail.net	yes
Planning Branch	Environ.	Boyd Devane			Boyd.Devane@ncmail.net	yes
Division of Water Resources	Environ.	General Information	(919) 733-4064	(919) 733-3555		no
		John Morris	(919) 715-5422		john.morris@ncmail.net	yes
Water Supply Planning	Environ.	Tony Young, Chief	(919) 715-0390			n/a
Water Allocation	Environ.	Tom Fransen, Chief	(919) 715-0381			n/a
FIRE:						
Apex Fire Department	Fire	General Information			APEX4001@aol.com	no
Arrington Volunteer Fire Department	Fire	Randy Rogers	(919) 736-4310		Firewind1@hotmail.com	no
Asheville Fire Department	Fire	Robert Griffin	(828) 259-5636	(828) 259-5429	RobertG@mail.ci.asheville.nc.us	yes
Black Mountain Fire Department	Fire	Craig Bannerman	(828) 669-8074	(828) 669-8143	cbannerman@worldnet.att.net	no
Charlotte Fire Department	Fire	Jeff Dulin	(704) 336-2578	(704) 336-4170	JDULIN@ci.charlotte.nc.us	no

North Carolina Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name and Title of Contact	Phone Num.	Fax Number	Email	Reply
FIRE, continued:						
Coats-Grove Fire Department	Fire	General Information	(910) 897-7575		district6@surrealnet.net	no
Currituck Vol. Fire Department	Fire	General Information			info@lcvfd.org	no
Durham County Fire Department	Fire	Jeffrey L. Batten	(919) 560-0660	(919) 560-0670	firemarshal@co.durham.nc.us	no
Kill Devil Hills Fire Department	Fire	General Information	(252) 480-4060	(252) 480-4069	MARIE@kdh-nc.com	no
Moriah Volunteer Fire & Rescue Dept.	Fire	General Information	(336) 364-7620		mvfd300@aol.com	no
Newell Volunteer Fire Department	Fire	General Information			newellvfd@mindspring.com	no
NC Fire and EMS Resources	Fire	General Information			info@nc-fire-ems.com	no
NC State Fire Association	Fire	Paul F. Miller	(252) 753-2626	(252) 753-3335	ncsfa@interpath.com	yes
Ranlo Fire and Rescue Department	Fire	General Information	(704) 824-4086		RANLOCHIEF@aol.com	no
Rowen Fire Department	Fire	Arthur Delaney, Fire Marshal			delaneya@co.rowan.nc.us	no
Troutman Fire and Rescue Dept.	Fire	General Information	(704) 525-4576		tfd@statesville.net	no
Winston-Salem Fire Department	Fire	General Information	(336) 773-7900	(336) 773-7974		no
Station 1	Fire	General Information			Statio1@ci.winston-salem.nc.us	no
Station 10	Fire	General Information			Statio10@ci.winston-salem.nc.us	no
Station 11	Fire	General Information			Statio11@ci.winston-salem.nc.us	no
Station 12	Fire	General Information			Statio12@ci.winston-salem.nc.us	no
Station 13	Fire	General Information			Statio13@ci.winston-salem.nc.us	no
Station 14	Fire	General Information			Statio14@ci.winston-salem.nc.us	no
Station 15	Fire	General Information			Statio15@ci.winston-salem.nc.us	no
Station 16	Fire	General Information			Statio16@ci.winston-salem.nc.us	no
Station 17	Fire	General Information			Statio17@ci.winston-salem.nc.us	no
Station 18	Fire	General Information			Statio18@ci.winston-salem.nc.us	no
Station 2	Fire	General Information			Statio2@ci.winston-salem.nc.us	no
Station 3	Fire	General Information			Statio3@ci.winston-salem.nc.us	no
Station 4	Fire	General Information			Statio4@ci.winston-salem.nc.us	no
Station 5	Fire	General Information			Statio5@ci.winston-salem.nc.us	no
Station 6	Fire	General Information			Statio6@ci.winston-salem.nc.us	no
Station 7	Fire	General Information			Statio7@ci.winston-salem.nc.us	no
Station 8	Fire	General Information			Statio8@ci.winston-salem.nc.us	no
Station 9	Fire	General Information			Statio9@ci.winston-salem.nc.us	no

North Carolina Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name and Title of Contact	Phone Num.	Fax Number	Email	Reply
HEALTH:						
Alexander County Emerg. Med. Serv.	Health	Trevor Craig, Medical Director			tcriag@abts.net	no
American Red Cross, VOAD	Health	Beverly Cooper	(366) 854-0408	(336) 854-0408	bcoope@earthlink.net	yes
Ash-Rand Rescue and Emergency Medical Services	Health	General Information	(336) 625-3354	(336) 625-0213	arrescue@asheboro.com,	no
		Larry Pugh			ljpugh@asheboro.com	no
Avery County Emerg. Med. Services	Health	Shelburne Wilson, Medical Dir.			docwilson@aol.com	no
Buncombe County Emerg. Med. Serv.	Health	Stace Horine, Medical Director			sehorine@pol.net	no
Catawba County Emerg. Med. Serv.	Health	David Weldon, Manager			ccems@mail.co.catawba.nc.us	no
Cherokee County Emerg. Med. Serv.	Health	Alyce Garrity, Medical Director			AlyceMD@aol.com	no
Cleveland County Emerg. Med. Serv.	Health	Kevin O'Dell, Medical Director			EMRGNCDOC@aol.com	no
Craven County Emerg. Med. Services	Health	Anthony Frank, Medical Director			Afrank@coastalnet.com	no
Cumberland Emerg. Medical Serv.	Health	Keith Henderson, Medical Director			KhendersonDOFACEP@msn.com	no
Currituck Emerg. Medical Services	Health	Francis Watson, Medical Director			fewatson@ibm.net	no
Dare County Emerg. Medical Serv.	Health	General Information	(252) 441-1551	(252) 441-6464		no
Dept. of Health & Human Services	Health	H.David Bruton, Office of Secretary	(919) 715-4534	(919) 715-4645		yes
Facility Services	Health	Lynda D. McDaniel, Director	(919) 733-2342	(919) 733-2757	Lynda.McDaniel@ncmail.net	yes
		Drexdal R. Pratt, Chief of OEMS	(919) 733-2285	(919) 733-7021		no
Information Resource Management	Health	Bill Cox, Director	(919) 733-8900	(919) 733-8871		yes
Medical Assistance	Health	Paul R. Perruzzi, Director	(919) 857-4011	(919) 733-6608		yes
		Linda Connelly, Assistant Director	(919) 857-4186	(919) 715-9566	Linda.Connelly@ncmail.net	yes
Public Health	Health	Dr. A. Dennis McBride, Director	(919) 733-4392			yes
Social Services	Health	Chip Modlin, Director			Chip.Modlin@ncmail.net	no
		Sherry Bradsher, Chief			Sherry.Bradsher@ncmail.net	no
		Hank Bowers, Planning and Info.			Hank.Bowers@ncmail.net	no
Durham County Emerg. Medical Serv.	Health	Richard Serra, Medical Director			Serra001@mc.duke.edu	no
Forsyth County Emerg. Med. Serv.	Health	Anthony Lynn			ALynn911@aol.com	yes
		Roy Alson, Medical Director			ralson@wfubmc.edu	no
Fort Run Volun. Fire and EMS Dept.	Health	General Information	(252) 747-4434		Fortrun1@aol.com	no
Greene County Emerg. Medical Serv.	Health	Aaron Cotton, Medical Director			Acotten@ibm.net	no
Guildord County Emerg. Medical Serv.	Health	Norman Mayer, Medical Director			norman.mayer@mosescone.com	no
Haywood County Emerg. Med. Serv.	Health	Mark Jaben, Medical Director			jabenm@aol.com	no
Mecklenbug Emerg. Medical Serv.	Health	Tom Blackwell, Medical Director			tblackwell@carolinas.org	no

North Carolina Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name and Title of Contact	Phone Num.	Fax Number	Email	Reply
HEALTH, continued:						
Montgomery Emerg. Medical Serv.	Health	David Garces, Medical Director			dgarces@hotmail.com	no
Nat. Assoc. of Rescue and EMS	Health	General Information	(919) 736-0506	(919) 736-7759	ncarems@esn.net	no
		Henry Sermons, Commander	(252) 447-5660		hpsermons@havelocknc.net	no
Area 1	Health	Durwood Evans	(252) 357-1394		gatesemc@albemarlenet.com	no
Area 3	Health	Benny Greene	(910) 590-2976		pammer@intrstar.net	no
Area 4	Health	Ricky Davis	(252) 237-0789			n/a
Area 5	Health	Charles Whitman	(910) 892-1211		drschief@aol.com	no
Area 6	***Health***	***Angie Callihan***	***(919) 496-5005***		***apce100@gloryroad.net***	***DS 24***
Area 7	Health	Harold James	(704) 624-5398		hlj800@alltel.net	no
Area 8	Health	Bill Henderson	(336) 570-5601		wch23nc@juno.com	yes
Area 9	Health	Joe Blevins	(704) 878-3573		jblevins@abts.net	yes
New Hanover Emerg. Medical Serv.	Health	Ted Winneberger, Medical Director			twinneberg@aol.com	no
Nine Mile Volun. Rescue and EMS	Health	General Information	(910) 347-6000		nmvrs@gibralter.net	no
NC Office of Emeg. Medical Services	Health	Stephen Acai, Trans. Specialist			Stephen.Acai@ncmail.net	n/a
		Ed Seagroves, Disaster Coord.			Ed.Seagroves@ncmail.net	n/a
Orange County Emerg. Medical Serv.	Health	Marshall McCoy, Medical Director			McCoy@med.unc.edu	no
Pernder County Emerg. Medical Serv.	Health	Ed San Miguel, Medical Director			apachemd@aol.com	no
Person Emerg. Medical Serv.	Health	Kimmie Yarborough, Medical Dir.			yarbo@person.net	no
Rockingham Emerg. Medical Serv.	Health	Lawrence Fusco, Medical Director			ljfusco@pol.net	no
Rowan County Emerg. Medical Serv.	Health	Steven Isaacs, Medical Director			flysgi@mindspring.com	no
Scotland County Emerg. Medical Serv.	Health	Robert Zottie, Medical Director			paradocbob@aol.com	no
Shine Fire and Emerg. Medical Serv.	Health	Richard Chase	(252) 747-7416		rogue006@earthlink.net	no
Stanly County Emerg. Medical Serv.	Health	Mark DuFine, Medical Director			drmarkjd@aol.com	no
Surry County Emerg. Medical Serv.	Health	Monty Spangler, Medical Director			monty.spangler@ibm.net	no
Union County Emerg. Medical Serv.	Health	John Cattie, Medical Director			jvcmsa@aol.com	no
Wake County Emerg. Medical Serv.	Health	Donald Vaughn, Medical Director			devmder@mindspring.com	no
Watauga County Emerg. Medical Serv.	Health	Allen Brandon, Medical Director			BrandonHA@Boone.Net	no
Wilson County Emerg. Medical Serv.	Health	Thomas Hooper, Medical Director			thooper@wilson-co.com	no

North Carolina Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name and Title of Contact	Phone Num.	Fax Number	Email	Reply
MILITARY:						
Civil Air Patrol	Military	Colonel A W (Woody) Solloway			wsulloway@nc-cap.org	yes
		Donald Beckett, Johnston Co. Sq.	(919) 989-7696			n/a
NC National Guard	Military	General Information	(704) 391-4141	(704) 398-4776		n/a
		1st Lt. Allan Cecil			allan.cecil@ncchar.ang.af.mil	yes
		MSgt Brian Keith			brian.keith@ncchar.ang.af.mil	no
		SrA Kevin B. Collins			kevin.collins@ncchar.ang.af.mil	no
POLICE:						
Charlotte-Mechlenburg Police Dept.	Police	General Information			kbridges@cmpd.ci.charlotte.nc.us	no
Charlotte Police Department	Police	Darrel Stephens, Police Chief	(704) 336-2337			no
Dept. of Human Res. Police Dept.	Police	General Information	(828) 686-3996	(828) 686-3479		no
Durham Police Department.	Police	General Information	(919) 560-4322	(919) 560-4971		no
Fayetteville Police Department	Police	Ron Hansen	(910) 433-1819	(910) 433-1820		no
Kill Devil Hills Police Department	Police	General Information, Public Services	(252) 480-4080	(252) 441-6136	cathy@kdh-nc.com	no
Kitty Hawk Police Department	Police	Robert K. Morris, Chief	(252) 261-3895		rkmorris@co.dare.nc.us	yes
Manteo Police Department	Police	General Information			cops@townofmanteo.com	no
NC Special Police Department	Police	General Information	(919) 832-8908		AdminServ@NCSP.org	no
Raleigh Police Department	Police	M.W.Brown, Chief of Police	(919) 890-3385		scaringellim@ralieigh-nc.org	no
Southern Shores Police Department	Police	General Information	(252) 261-3331	(252) 261-4851	sspd161@southernshores.org	no
State Capitol Police Department	Police	Sara Keen	(919) 733-4646	(919) 733-2974	sara.keen@ncmail.net	yes
State Highway Patrol	Police	Administration	(919) 733-7952	(919) 733-1189		no
Operations	Police	Lieutenant Gary Brown	(919) 733-4030	(919) 733-2161	Gbrown@ncshp.org	yes
Information Management	Police	General Information	(919) 662-4440	(919) 662-4444		no
Troop A	Police	Headquarters	(252) 758-5300	(252) 752-6157		no
		Communications	(252) 792-4101	(252) 792-6740		no
Troop B	Police	Headquarters	(910) 486-1058	(910) 483-1761		no
		Communications	(910) 862-3133	(910) 862-6287		no
Troop C	Police	Headquarters	(919) 733-3911	(919) 733-6868		no
		Communications	(919) 733-3861	(919) 733-8134		no
Troop D	Police	Headquarters	(336) 334-5621	(336) 334-3289		no
		Communications	(336) 334-5500	(336) 334-5103		no

North Carolina Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name and Title of Contact	Phone Num.	Fax Number	Email	Reply
POLICE, continued:						
State Highway Patrol, continued:						
Troop E	Police	Headquarters	(704) 639-7595	(704) 855-1720		no
		Communications	(704) 637-0207	(704) 855-2295		no
Troop F	Police	Headquarters	(828) 466-5504	(828) 466-5506		no
		Communications	(828) 466-5500	(828) 466-5558		no
Troop G	Police	Headquarters	(828) 298-4253	(828) 299-4626		no
		Communications	(828) 298-4252			no
Troop H	Police	Headquarters	(704) 283-8559	(704) 289-4224		no
		Communications	(704) 292-1539			no
Wilmington Police Department	Police	John H. Cease, Chief	(910) 343-3610			n/a
Winston-Salem Police Department	Police	Linda Davis, Chief	(336) 773-7700		chiefdavis@wspd.org	yes
TRANSPORTATION:						
Charlotte Aviation Department		Jerry Orr, Director	(704) 359-4000			yes
Department of Transportation						
Equipment and Inventory Control	Trans.	Jean Wilkins, Sec. to Director	(919) 733-2220	(919) 733-1192	jwilkins@dot.state.nc.us	no
	Trans.	Henry Gibbs, Fleet Management	"	"	hgibbs@dot.state.nc.us	no
	Trans.	Jihad Shawwa, Fleet Management	"	"	jshawwa@dot.state.nc.us	yes
	Trans.	Charles Jones, Equip. Super.	(919) 733-3535	"	cjones1@dot.state.nc.us	no
	Trans.	John Stallings, Fleet Support	(919) 733-2220	"	jstallings@dot.state.nc.us	no
	Trans.	Bevin Elliot, Equipment Engineer	"	"	belliott@dot.state.nc.us	no
	Trans.	Dave Vanpelt, Material Manager	"	"	dvanpelt@dot.state.nc.us	no
	Trans.	Chris Lyon, Inven. Cont. Manager	"	"	clyon@dot.state.nc.us	yes
	Trans.	John Strickland, Inventory Systems A	"	"	jstrickland@state.nc.us	no
Operations	Trans.	J.D. Goins, Chief Engineer	(919) 733-7621	(919) 733-4141	Jgoins@dot.state.nc.us	yes
Planning and Environment	Trans.	Janet D'Ignazio, Chief	(919) 733-2520	(919) 733-9150	jdignazio@dot.state.nc.us	yes
State Construction and Materials Branch	Trans.	Robert Canales	"	"	rcanales@dot.state.nc.us	no
		Kelly Hutchinson	"	"	khutchinson@dot.state.nc.us	yes
Roadside Environmental Unit	Trans.	Bill Johnson	(919) 733-2920	(919) 733-9810	wdjohnson@dot.state.nc.us	no
Roadside Operations	Trans.	W. Cliff McNeill, Jr.	"	"	cmcneill@dot.state.nc.us	yes
State Maintenance and Equipment Branch	Trans.	Steve Varnedoe, State Maint.	(919) 715-5662	(919) 715-2858	svarnedoe@dot.state.nc.us	no
Statewide Planning Branch	Trans.	Mike Bruff, Manager	(919) 733-4705	(919) 733-2417	bruff@dot.state.nc.us	yes

North Carolina Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name and Title of Contact	Phone Num.	Fax Number	Email	Reply
RESCUE:						
Brevard Rescue	Rescue	General Information	(828) 884-4950		operations@brevardrescue.com	no
Burke County Search and Rescue	Rescue	General Information	(828) 437-1911	(828) 438-1841	bceoc@hci.net	no
Coastline Rescue	Rescue	Keith Sawyer	(910) 842-2266	(910) 846-2251		n/a
Down East Search and Rescue	Rescue	Benny Davis	(252) 946-2591		swamprat@beaufortco.com	yes
Gates County Rescue Squad	Rescue	General Information	(252) 357-0141		gatescountyrescue@hotmail.com	no
Hickory Rescue Squad	Rescue	General Information	(828) 327-5466		resq433@aol.com	no
Newton-Conover Rescue Squad	Rescue	Tony Moore, Chief EMT			tlmoore@charter.net	no
NC Search and Rescue	Rescue	Gordon Deno, Central Unit	(252) 399-2820	(252) 399-0904	gdeno@wilson-co.com	yes
Pinetops Rescue Squad	Rescue	General Information	(252) 827-4801		emsnc1@worldspy.net	no
Polk County Rescue Squad	Rescue	General Information	(828) 894-3067		polkfirstresponders@hotmail.com	no
Robeson County Search and Rescue	Rescue	David Carter	(910) 671-3150	(910) 737-5079	dcarter@intrstar.net	no
Rutherford County Search and Res.	Rescue	Randy Webb	(828) 245-4819	(828) 245-9688	rutherfordrescue@hotmail.com	no
Sandhills Overland Search and Res.	Rescue	Kim Hyre	(910) 692-0984		khyre@mindspring.com	no
Snow Camp Search and Rescue	Rescue	Roger Williams	(336) 376-3442	(336) 376-3442	RWILLI185@aol.com	no
South Point LifeSaving Crew	Rescue	General Information	(704) 825-3743		southpointrescue@hotmail.com	no
State Animal Response Team	Rescue	Mary Ann T. McBride, SAR Head			mcbride3@bellsouth.net	yes
Field Operations	Rescue	Jimmy Tickel, Head			jimmy.tickel@ncmail.net	no
Operations	Rescue	C. Fred Kirkland, Head	(919) 733-7601		fred.kirkland@ncmail.net	yes
Stokes County Mountain Rescue	Rescue	General Information	(336) 985-5036		jring@triad.rr.com	n/a
Wake Canine Search and Rescue	Rescue	Mike Guzzo	(919) 310-1743	(919) 715-9763		yes
Walstonburg Fire-Rescue-EMS	Rescue	General Information	(252) 753-6006		FutzUnit1@aol.com	no
UTILITY:						
Duke Energy	Utility	Randy Wheeless, Environment	(704) 382-8379		crwheele@duke-energy.com	no
Duke Power	Utility	Guynn Savage, Power Distribution	(704) 382-8350		ghsavage@duke-energy.com	no
		Joe Maher, Electric Operations	(704) 382-8323		jmaher@duke-energy.com	no
Haywood EMC (Energy)	Utility	General Information			HEMC@haywoodemc.com	no
Operations	Utility	Tom Batchelor, Manager			tom.batchelor@haywoordemc.com	no
Waynesville	Utility	General Information	(828) 452-2281	(828) 456-8803		no
Lake Toxaway	Utility	General Information	(828) 966-4215	(828) 883-3874		no

North Carolina Agencies and Organizations Contacted, continued:

Name of Agency/Organization	Type	Name and Title of Contact	Phone Num.	Fax Number	Email	Reply
UTILITY, continued:						
Nantahala Power and Light	Utility	Barbara McRae			bamcrae@duke-energy.com	yes
		Fred Alexander	(828) 369-4534		afalexan@duke-energy.com	no
Public Water Supply	Utility	Jessica Miles, Section Chief	(919) 715-3232		Jessica.Miles@ncmail.net	no
Protection and Enforcement	Utility	Robert Midgette	(919) 715-3224		Robert.Midgette@ncmail.net	no
SRF Branch	Utility	Sid Harrell, Environ. Engineer	(919) 715-3216		Sid.Harrell@ncmail.net	yes
MISCELLANEOUS:						
NC Department of Commerce	Misc.	Ray Denny, Director	(919) 733-7979		rdenny@mail.commerce.state.nc.us	no
Housing & Bus. Redevelopement	Misc.	Gene Byrd	(919) 715-5747		gbyrd@nccommerce.com	no
		Linda Ray, Information Officer	(919) 715-2881		lray@nccommerce.com	yes
Small Business Assistance Program	Misc.	Tony Pendola	(877) 623-6748	(919) 715-7468	tony_pendola@p2pays.org	no
NC Cooperative Extension Service	***Misc.***	***W. Simmons***	***(252) 448-9621***	***(252) 448-1243***	***WG_Simmons@ncsu.edu***	***DS 25***
		Norman Harrell, Agricultural Agent			nharrell@wilson.ces.ncsu.edu	yes
		Ann Ward			award@dare.ces.ncsu.edu	yes

APPENDIX B. RECOVERY SOFTWARE USER'S GUIDE

This write-up gives an introduction and step-by-step instructions on how to use the hurricane recovery software. It will also provide several useful examples to walk the user through the tool and some helpful hints and suggestions that will make the software easier to use and the output more meaningful. It should be very simple to learn how to create your own models after this brief tutorial. Detailed instructions are also provided in the software in the "Instructions" tab. Note that in the spreadsheet the user should only make entries into cells shaded yellow.

Step 1: "Facilities" Tab

Since the model being implemented uses facilities, the user must go to the facilities tab and enter which facilities to include in the model. Look for the eight yellow boxes in a column on the left, each one corresponding to a facility category. To include that category of facilities, enter a "1". To not include that category, enter a "0". Then proceed to the "Roads" tab.

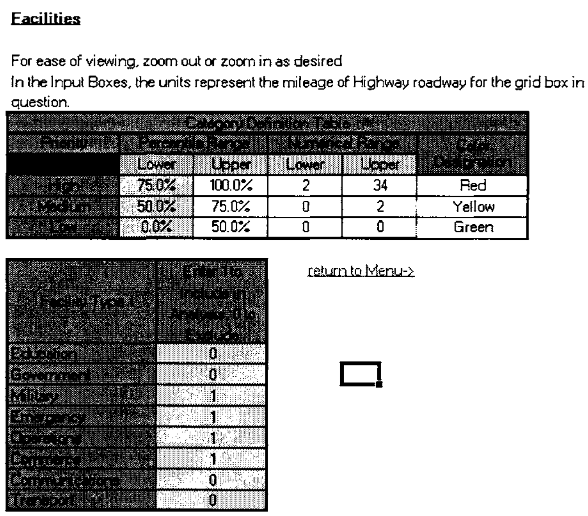


Figure B.1 Entering facilities into the model

Step 2: "Roads" Tab

The next step, inputting the type of roads to include in the mileage calculations, is pretty much the exact same thing. Go to the "Roads" tab and look for the four yellow cells in the upper left, each corresponding to a different road type. Again, enter a "1" to include interstate and a "0" to not include US Highway, Primary route, and Secondary Routes. Anything other than a one or a zero is an error, and in this case more than one "1" is also an error. Then proceed onto the "Summary" tab.

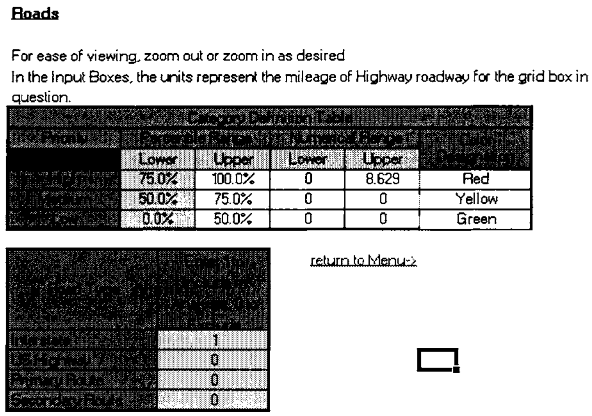


Figure B.2 Entering roads in the model

Step 3: "Summary" Tab

The final step to completing this model is in the "Summary" tab. All that is required here is to enter the numerator and denominator into the model and it will be done. The model from above contains facilities and population in the numerator of the equation, and the road mileage is in the denominator. None of the user inputs are used. Looking at the upper left of this screen, look for the yellow blocks two rows high and six columns wide. The six columns are for the six data types (critical facilities, population, road mileage, and user inputs #1, #2, and #3). The two rows are for the numerator and the denominator. If the model calls for the data type in the numerator, put a "1" in the top box and a "0" in the bottom. Likewise, if the model calls for a data type in the denominator, put a "0" in the top box and a "1" in the bottom. If the model does not use the data type, then a "0" should be placed in both boxes. So for Facilities and Population enter a "1" on top and a "0" down below, for Roads put a "0" on top and a "1" below, and for User Input #1, #2, and #3 put "0" in both spaces.

Note that if a data type is placed in the numerator, than a higher value in that data leads to a higher priority. If the data were placed in the denominator, a higher value in the data would receive a lower priority.

Summary

For ease of viewing, zoom out or zoom in as desired

Category Definition Table					
Priority	Percentile Range		Numerical Range		Cell Color
	Lower	Upper	Lower	Upper	
High	80.0%	100.0%	146.30168	13438	Red
Medium	20.0%	80.0%	16.374691	146.30168	Yellow
Low	0.0%	20.0%	0.1808954	16.374691	Green

return to Menu->

Enter a 1 in the below table to include that factor in the prioritization score, otherwise leave it blank or enter a 0 for the factors that aren't needed in the final

	Facilities	Population	Roads	User Input #1	User Input #2	User Input #3
Numerator	1	1	0	0	0	0
Denominator	0	0	1	0	0	0

The formula is as follows:

$$\frac{\text{Facilities}}{1} \times \frac{\text{Population}}{1} \times \frac{1}{\text{Roads}} \times \frac{1}{1} \times \frac{1}{1} \times \frac{1}{1}$$

*Note: If numerator or denominator is left empty, then the resultant fraction will be one by default

Figure B.3 Summary worksheet

The output, shown in Figure B.4, gives priorities for this model. Most of the cells are white because of no data in those cells – meaning there are no Interstate highways passing through those cells. Of the cells that do have data, we see high priorities in Red (darkest shade), medium in yellow (moderate shade), and low in green (lightest shade). In this setup, the top 20% of cells with data get red, the bottom 20% get green, and the middle 60% get yellow. Looking back at Figure B.3 shows how to change those distributions. Look to the upper left, and remember to only change cells shaded yellow. You can adjust the lower bounds (bottom always stays at 0.0%) to change how the output is perceived. The right side shows the numbers from the left with the map in the background. The colors do not show through but the numbers can still be examined and it really helps to locate the roads beneath the numbers.

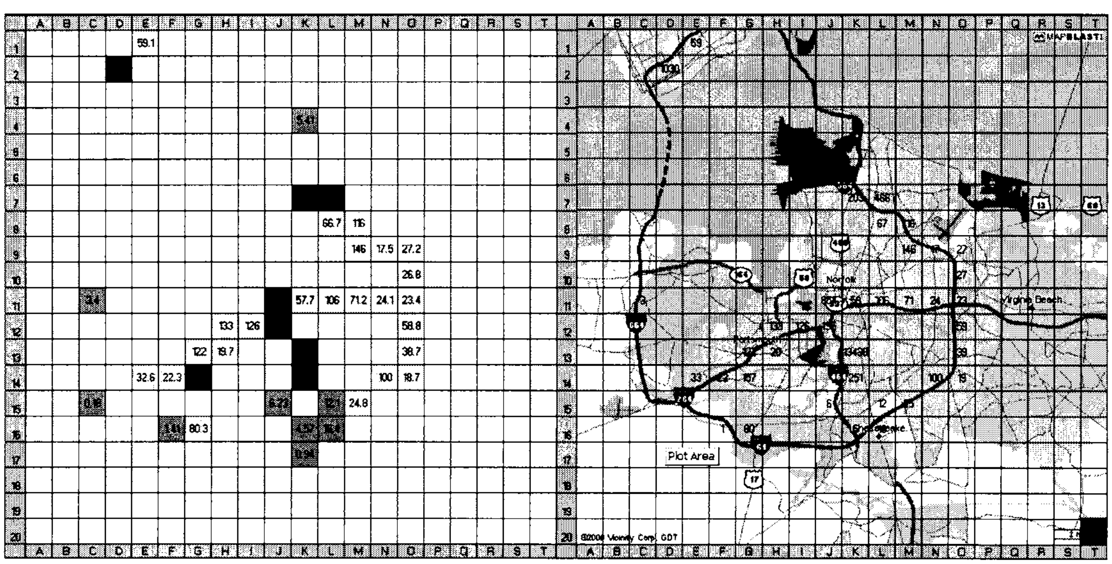


Figure B.4 Output of the sample prioritization model

To get a good feeling of what this model can do, the user needs to run many, many different models and examine the outputs. The user should experiment with combinations that might not originally make sense. The user really wants to know what spots are continually hot spots and what spots rarely if ever are high on the priority lists. If certain cells continually stay as vitally important then the model is producing a robust answer, but if it changes all the time then the model is not a robust solution.

Sample Models

There are literally thousands of different combinations of models that could be used as criteria for the prioritization. There are various combinations of facilities, road types, and whether or not to include population and the various user inputs, which could be anything. One of the objectives for this project is to prioritize disaster recovery on a short, medium, and long-term basis. The table below contains several suggestions for short-term, medium-term and long-term recovery models.

Table B.1 Sample models

Time domain	Example priority setting model
Short-term	1) Emergency facilities * population / interstate mile 2) (Ops. + Trans. + Mil.) / primary route mile 3) Schools (Evac. Shelters) * population / interstate mile
Medium-term	1) Schools * population / US highway mile 2) (Comm. + Trans.) * population / primary route mile 3) (Emerg. + Ops. + Mil.) * User Input [damage indicator]
Long-term	1) Commercial * population / primary route mile 2) (All facilities) * population / User Input [recovery cost] 3) (All facilities) * population / secondary mile

The models shown in Table B.1 are only samples, though they are all practical models. The point of Table B.1 is to show examples of how the user can go about creating models and also how many possible models exist.

APPENDIX C. DEPENDENCY SCENARIOS

The complete list of researched dependency scenarios is shown in Table C.1. Following it are descriptions of scenarios 1 through 25 were taken from the interview responses (the contact name and agency are included), and scenarios 26 through 48 were taken from NC DOT's report of lessons learned from Hurricane Floyd and from an interview with one if its authors, Kelly Hutchinson. The scenario descriptions are listed chronologically by their associated dependency scenario number, which can be found in the first column of Table C.1. Their "names", which correspond to the entries in the second column of Table C.1 ("Dependency Scenario Name"), are indicated in bold.

Table C.2 contains each dependency scenario, and the primary organizational function of the state DOT that was involved along with a secondary function associated with the scenario.

Table C.1 Categorization of collected dependency scenarios according to the associated organizational function involved within VA, CA, SC, and NC state DOTs. Each row represents a different dependency scenario.

Dependency Scenario #	Dependency Scenario Name	State	Agency Name	Agency Type	Level of Agency	Pre/Post Disaster	Time Horizon	Administration	Environ., Regulatory Affairs	Equipment	Finance	Information Management	Legal / Authorization	Materials	Operations	Personnel	Structure and Bridge
DS1	Sandbag Requests	VA	Henrico Co. Div. Of Fire	Fire	Local	Post	ST							x			
DS2	Barricade Requests	VA	Henrico Co. Div. Of Fire	Fire	Local	Post	ST			x							
DS3	On-call Personnel	VA	Henrico Co. Div. Of Fire	Fire	Local	Post	ST									x	
DS4	Updated Road Status Info.	VA	Obici Hospital	Health	Local	Post	ST					x					
DS5	Inaccurate Road Information	VA	Obici Hospital	Health	Local	Post	ST					x					
DS6	Bridge Failure	VA	Office of Emerg. Med. Serv.	Health	State	Post	MT										x
DS7	Available Road Status Info.	VA	Office of Emerg. Med. Serv.	Health	State	Post	ST					x					
DS8	Inaccurate Road Information	VA	Office of Emerg. Med. Serv.	Health	State	Post	ST					x					
DS9	Road Access	VA	Dept. of Conserv. and Rec.	Envir.	State	Post	MT										x
DS10	Geological Information	VA	Dept. of Mines,Min.,Energy	Envir.	State	Post	LT					x					
DS11	Road Access	CA	Dept. of Health Services	Health	State	Post	ST								x		
DS12	Long Term Road Access	CA	Hall Ambulances	Health	Local	Post	LT										x
DS13	Road Access & Authorization	CA	Glen.-Cres.Vall. Redcross	Health	Local	Post	ST								x		
DS14	Convoy Use	CA	CA National Guard	Military	State	Post	ST								x		
DS15	Road Repairs	CA	Roseville Transit	Trans.	Local	Post	LT										x
DS16	Road Access and Information	CA	Dept. of Water Resources	Envir.	State	Post	ST								x		
DS17	Transmitter Sites	SC	SCANA Communications	Comm.	State	Post	ST								x		
DS18	Crawler Tractor Use	NC	Div. Of Forest Resources	Envir.	Region.	Post	ST						x				
DS19	Road, Bridge, and Flood Info.	NC	Amat. Radio Emerg. Serv.	Comm.	Region.	Post	ST					x					
DS20	Obtaining Environ. Permits	NC	Div. Of Coastal Manage.	Envir.	State	Post	LT						x				
DS21	Sandbag Debris	NC	Div. Of Coastal Manage.	Envir.	State	Post	LT								x		
DS22	Coastal Inlet Stabilization	NC	Div. Of Coastal Manage.	Envir.	State	Post	MT		x								
DS23	Environmental Violations	NC	Div. Of Coastal Manage.	Envir.	State	Post	MT					x					
DS24	Resource Depletion	NC	Franklin Co. Emerg. Manage	Emerg.	Local	Post	ST									x	
DS25	Deadstock Removal	NC	NC Extension Service	Volun.	State	Post	MT								x		

Table C.1 (continued). Categorization of collected dependency scenarios according to the associated organizational function involved within VA, CA, SC, and NC state DOTs. Each row represents a different dependency scenario.

Dependency Scenario #	Dependency Scenaio Name	State	Agency Name	Agency Type	Level of Agency	Pre/Post Disaster	Time Horizon	Administration	Environ., Regulatory Affairs	Equipment	Finance	Information Management	Legal / Authorization	Materials	Operations	Personnel	Structure and Bridge
DS26	Detour Information	NC	Local Emergency Services	Emerg.	State	Post	ST					x					
DS27	Chainsaw Crews	NC	Dept. of Natural Resources	Envir.	State	Post	ST								x		
DS28	Conflicting Road Information	NC	NC State Highway Patrol	Police	State	Post	ST					x					
DS29	Fund Reimbursements	NC	FEMA	Emerg.	State	Post	LT				x						
DS30	Ineffective Equipment	NC	NC DOT	Trans.	State	Post	ST			x							
DS31	Relocated Personnel	NC	NC DOT	Trans.	State	Post	ST									x	
DS32	Equipment Distribution	NC	NC DOT	Trans.	State	Post	ST			x							
DS33	Undefined Roles	NC	NC DOT	Trans.	State	Post	ST	x									
DS34	Excessive Workloads	NC	NC DOT	Trans.	State	Post	LT	x									
DS35	Structure Repairs	NC	NC DOT	Trans.	State	Post	MT								x		
DS36	Insufficient Traffic Manage.	NC	NC DOT	Trans.	State	Post	ST					x					
DS37	Fuel Confusion	NC	NC DOT	Trans.	State	Post	ST					x					
DS38	Conference Calls	NC	NC DOT	Trans.	State	Post	MT	x									
DS39	Email Communication	NC	NC DOT	Trans.	State	Post	MT					x					
DS40	Unconfirmed Equipment	NC	NC DOT	Trans.	State	Post	ST					x					
DS41	Road Closure Reports	NC	NC DOT	Trans.	State	Post	ST								x		
DS42	Restricted Access	NC	NC DOT	Trans.	State	Post	ST		x								
DS43	Inconsistent Barricades	NC	NC DOT	Trans.	State	Post	ST			x							
DS44	Refueling	NC	NC DOT	Trans.	State	Post	ST							x			
DS45	Restricted Communication	NC	NC DOT	Trans.	State	Post	ST					x					
DS46	HazMat Information	NC	NC DOT	Trans.	State	Post	ST					x					
DS47	Disposal Sites	NC	NC DOT	Trans.	State	Post	MT								x		
DS48	Processing Reimbursements	NC	NC DOT	Trans.	State	Post	LT				x						

Descriptions of Scenarios

Virginia

DS1. Sandbag Requests-- A potential delay could take place between the time when the Henrico County Division of Fire requests materials over the phone from VDOT such as sand bags and the time when they actually receive it. (R. C. Dawson, Jr., Deputy Fire Chief, Henrico County Division of Fire)

DS2. Barricade Requests-- A potential delay could take place between the time when the Henrico County Division of Fire requests equipment over the phone from VDOT such as traffic barricades and the time when they actually receive it. (R. C. Dawson, Jr., Deputy Fire Chief, Henrico County Division of Fire)

DS3. On-call personnel-- A potential delay could take place between Henrico County Division of Fire if there are an inadequate number of on-call personnel at VDOT during emergency response. (R. C. Dawson, Jr., Deputy Fire Chief, Henrico County Division of Fire)

DS4. Updated Road Status Information-- Obici Hospital had to wait on VDOT for the availability to current, updated road status and closure information following Hurricane Floyd. (Randy Vick, Obici Hospital)

DS5. Inaccurate Road Status Information-- Obici Hospital experienced delays following Hurricane Floyd because the road status information that was provided by VDOT was inaccurate. (Randy Vick, Obici Hospital)

DS6. Bridge Failure-- The response of the Office of Emergency Medical Services in the future to an isolated area could be delayed if there is a road or bridge failure that is waiting to be repaired by VDOT. (C. Everette Vaughan, Jr., Director of Emergency Operations at the Office of Emergency Medical Services)

DS7. Available Road Status Information-- The Office of Emergency Medical Services had to wait on VDOT for the availability of current, updated road status information following Hurricane Floyd. (C. Everette Vaughan, Jr., Director of Emergency Operations at the Office of Emergency Medical Services)

DS8. Inaccurate Road Status Information-- The Office of Emergency Medical Services' response to Franklin, VA following Hurricane Floyd was delayed because the road status and closure information provided by VDOT was inaccurate. (C. Everette Vaughan, Jr., Director of Emergency Operations at the Office of Emergency Medical Service)

DS9. Road Access-- The Department of Conservation and Recreation could potentially be waiting on VDOT in the future to make a bridge or road passable. (Corey Garyotis, Senior Floodplain Engineer, Department of Conservation and Recreation)

DS10. Geological Information-- VDOT could potentially be waiting on the Department of Mines, Minerals, and Energy in the future to provide geological information or information on where road building materials can be found. (Cheryl Cashman, Department of Mines, Minerals, and Energy)

California

DS11. Road Access-- The California Department of Health Services medical response could potentially be delayed if roads are impassable. (Dave Abbott, CA Department of Health Services)

DS12. Long Term Road Access-- The Hall Ambulance Service, Inc. of Bakersfield is still experiencing delays from closed and almost non- accessible roads due to flooding 2 years ago. (Louis Cox, Hall Ambulance Service, Inc.)

DS13. Road Access and Authorization-- The Glendale-Crescenta Valley Chapter of the Redcross has waited on CalTrans to clear roads and to give them authorization for use in order to provide equipment and supplies where necessary. (Robert Reynoso, Glendale-Crescenta Valley Chapter, Redcross)

DS14. Convoy Use-- The California National Guard could potentially be waiting on CalTrans in the future, because their convoys cannot be used until the roads are passable. (Maj Terry Edinboro, CA National Guard)

DS15. Road Repairs-- Roseville Transit has waited on CalTrans for highway repairs and openings of overcrossings. (Michael Wixon, Roseville Transit)

DS16. Road Access and Status Information-- The Department of Water Resources has experienced delays due to blocked roads, and a lack of communication and information regarding road status. (Sonny Fong, Department of Water Resources)

North Carolina and South Carolina

DS17. Transmitter Sites-- When trying to access transmitter sites in order to provide two-way communication for government and utility officials, SCANA Communications waited on the SC DOT to clear roads. (George Crouch, SCANA Communications)

DS18. Crawler Tractor Use-- During major snow disasters, the Division of Forest Resources has waited on NC DOT for a request before bringing out their crawler tractors. (Vic Owen, Division of Forest Resources)

DS19. Road, Bridge, and Flood Status Info.-- When directing relief radio operators to affected areas in order to provide backup communication, the ARES has waited on NC DOT for information on road closures, damaged bridges, and flooded highways. (David Fleming, Amateur Radio Emergency Service)

DS20. Obtaining Environmental Permits-- NC DOT has waited on the Division of Coastal Management to provide permits. There is potential for the delay to increase since the DCM must meet legislated requirements for public notification and comment. If the proposed new development for recovery is thought to cause significant negative environmental impacts, NC DOT experiences further delays. (Ted Sampson, Division of Coastal Management)

DS21. Sandbag Debris-- The DCM is currently still waiting on NC DOT to remove sandbag debris from the coast. (Ted Sampson, Division of Coastal Management)

DS22. Coastal Inlet Stabilization-- The DCM waited on NC DOT following Hurricane Fran to stabilize and close a storm generated inlet under SR 1568. (Bob Stroud, Division of Coastal Management)

DS23. Environmental Violations-- The environmental unit has waited on the Division of Coastal Management for information regarding what recovery activities violate coastal development restrictions. Various repairs were delayed due to a lack of information regarding new environmental requirements. Some repairs were made before NC DOT was aware of the requirement changes. (NC DOT report, 2000)

DS24. Resource Depletion-- Franklin County Emergency Management experienced delays when they were left with few equipment and personnel after NC DOT requested that they aid another larger county. (Angie Callihan, Franklin County Emergency Management)

DS25. Deadstock Removal-- The NC Extension Service was delayed in delivering feed and removing deadstock due to blocked roads. (W. Simmons, NC Extension Service)

DS26. Detour Information-- Local emergency service providers experienced travel delays because they were not informed that a certain route had become a detour, and subsequently they unexpectedly faced added volumes of traffic. (NC DOT report, 2000)

DS27. Chainsaw Crews-- The Department of Natural Resources were delayed in evaluating environmental hazards and distribute chain saw crews due to a lack of accessible ground routes and information from NC DOT. Specifically, NC DOT lacked updated information regarding floodplain locations. (Mike Kelly, Department of Natural Resources)

DS28. Conflicting Road Information-- Widespread delays occurred during the height of the flooding due to conflicting road condition information from NC DOT and the NC State Highway Patrol. (NC DOT report, 2000)

DS29. Fund Reimbursements-- Finance unit had to wait and is still waiting on FEMA and FHWA for fund reimbursements. (NC DOT report, 2000)

Intra-Agency, NC DOT

The following intra-agency dependency scenarios concern North Carolina's Department of Transportation efforts following Hurricane Floyd.

DS30. Ineffective Equipment-- Field operations experienced a delay repairing roads and bridges, because the equipment provided were ineffective due to the water impacts. (NC DOT report, 2000)

DS31. Relocated Personnel-- Areas needing assistance waited on personnel, because many of the reinforcement workforce coming from the western, less affected area of the state were initially sent to the wrong location, only to be relocated to another. (NC DOT report, 2000)

DS32. Equipment Distribution-- Because of the large transfer of equipment between districts, there were delays in the distribution of supplies, i.e. in getting the right supplies to the right people. (NC DOT report, 2000)

DS33. Undefined Roles-- Widespread delays occurred with fields units' tasks such as debris removal, EOC staffing, and signs and signals because internal miscommunication resulted in the field force lacking a clearly defined role. (NC DOT report, 2000)

DS34. Excessive Workloads-- In the months following Hurricane Floyd, the responsibilities of the field units increased to include not only routine tasks and recovery efforts, but special reporting as well. Various duties performed by the field units were subsequently delayed in the long term because of their excessive workload. (NC DOT report, 2000)

DS35. Structure Repairs-- The repairs of structures were delayed because the loss control unit did not effectively communicate needs to the structure units. (NC DOT report, 2000)

DS36. Insufficient Traffic Management-- Evacuation was delayed from insufficient traffic management resources, a lack of real-time road condition information, and a lack of communication among surrounding states regarding traffic information. In particular, lane closures for work zones were reopened later than planned due to miscommunication. (NC DOT report, 2000)

DS37. Fuel Confusion-- A lack of communication resulted in field units refueling their vehicles only when their tanks approached empty. They were not informed that they were authorized to refuel at any time, regardless of the amount in their tank. This could have caused unnecessary setbacks due to vehicles running out of fuel. (NC DOT report, 2000)

DS38. Conference Calls-- Communication among administration units and officials was delayed due to conference call participants waiting on each other to assemble for the call. (NC DOT report, 2000)

DS39. Email Communication-- Communication among units was delayed when using email. (NC DOT report, 2000)

DS40. Unconfirmed Equipment-- Equipment units experienced unnecessary setbacks because they filled equipment requests from other state agencies that were not verified first, causing supplies to be sent that were not needed. (NC DOT report, 2000)

DS41. Road Closure Reports-- Road repairs by field units were delayed because they were spending too much time reporting road closures. (NC DOT report, 2000)

DS42. Restricted Access-- Personnel delays occurred because the DOT emergency staff's ID badges only gave them access to NC DOT facilities during limited hours. (NC DOT report, 2000)

DS43. Inconsistent Barricades-- Field units had to wait on the equipment unit for reinforcement barricades because suppliers sent barricade parts that were not standardized. (NC DOT report, 2000)

DS44. Refueling-- Poor road conditions forced field units to wait for fuel. The field units could be delayed further in the future if fuel resources are too low. (NC DOT report, 2000)

DS45. Restricted Communication-- The central office experienced delays obtaining various information from field units because communication lines were frequently all tied up. (NC DOT report, 2000)

DS46. HazMat Information-- NC DOT's administrative officials waited on commercial entities to provide accurate locations of hazardous materials within the proximity of areas needing repair. Field units were subsequently delayed waiting for authorization on these locations. (NC DOT report, 2000)

DS47. Disposal Sites-- Because landfills and disposal sites had limited access and hours of operation, field units experienced delays with debris removal. (NC DOT report, 2000)

DS48. Processing Reimbursements-- The finance unit experienced delays for reimbursement even before submission to FEMA due to the extensive manual work involved with compiling the necessary documents. (NC DOT report, 2000)

Table C.2 Categorization of collected dependency scenarios according to the associated *pair* of organizational functions involved within VA, CA, SC, and NC state DOTs. Each row represents a different dependency scenario. A letter 'P' indicates the primary function involved while a letter 'S indicates the secondary function.

Dependency Scenario #	Dependency Scenario Name	State	Agency Name	Agency Type	Level of Agency	Pre/Post Disaster	Time Horizon	Administration	Environ., Regulatory Affairs	Equipment	Finance	Information Management	Legal / Authorization	Materials	Operations	Personnel	Structure and Bridge
DS1	Sandbag Requests	VA	Henrico Co. Div. Of Fire	Fire	Local	Post	ST					S		P			
DS2	Barricade Requests	VA	Henrico Co. Div. Of Fire	Fire	Local	Post	ST			P		S					
DS3	On-call Personnel	VA	Henrico Co. Div. Of Fire	Fire	Local	Post	ST	S								P	
DS4	Updated Road Status Info.	VA	Obici Hospital	Health	Local	Post	ST					P			S		
DS5	Inaccurate Road Information	VA	Obici Hospital	Health	Local	Post	ST					P			S		
DS6	Bridge Failure	VA	Office of Emerg. Med. Serv.	Health	State	Post	MT								S		P
DS7	Available Road Status Info.	VA	Office of Emerg. Med. Serv.	Health	State	Post	ST					P			S		
DS8	Inaccurate Road Information	VA	Office of Emerg. Med. Serv.	Health	State	Post	ST					P			S		
DS9	Road Access	VA	Dept. of Conserv. and Rec.	Envir.	State	Post	MT								S		P
DS10	Geological Information	VA	Dept. of Mines,Min.,Energy	Envir.	State	Post	LT					P		S			
DS11	Road Access	CA	Dept. of Health Services	Health	State	Post	ST								P		S
DS12	Long Term Road Access	CA	Hall Ambulances	Health	Local	Post	LT								S		P
DS13	Road Access & Authorization	CA	Glen.-Cres.Vall. Redcross	Health	Local	Post	ST						S		P		
DS14	Convoy Use	CA	CA National Guard	Military	State	Post	ST								P		S
DS15	Road Repairs	CA	Roseville Transit	Trans.	Local	Post	LT								S		P
DS16	Road Access and Information	CA	Dept. of Water Resources	Envir.	State	Post	ST					S			P		
DS17	Transmitter Sites	SC	SCANA Communications	Comm.	State	Post	ST								P		S
DS18	Crawler Tractor Use	NC	Div. Of Forest Resources	Envir.	Region.	Post	ST			S			P				
DS19	Road, Bridge, and Flood Info.	NC	Amat. Radio Emerg. Serv.	Comm.	Region.	Post	ST					P			S		
DS20	Obtaining Environ. Permits	NC	Div. Of Coastal Manage.	Envir.	State	Post	LT		S				P				
DS21	Sandbag Debris	NC	Div. Of Coastal Manage.	Envir.	State	Post	LT		S						P		
DS22	Coastal Inlet Stabilization	NC	Div. Of Coastal Manage.	Envir.	State	Post	MT		P						S		
DS23	Environmental Violations	NC	Div. Of Coastal Manage.	Envir.	State	Post	MT		S			P					
DS24	Resource Depletion	NC	Franklin Co. Emerg. Manage	Emerg.	Local	Post	ST	S								P	
DS25	Deadstock Removal	NC	NC Extension Service	Volun.	State	Post	MT								P		S

Table C.2 (continued). Categorization of collected dependency scenarios according to the associated *pair* of organizational functions involved within VA, CA, SC, and NC state DOTs. Each row represents a different dependency scenario. A letter ‘P’ indicates the primary function involved while a letter ‘S’ indicates the secondary function.

Dependency Scenario #	Dependency Scenaio Name	State	Agency Name	Agency Type	Level of Agency	Pre/Post Disaster	Time Horizon	Administration	Environ., Regulatory Affairs	Equipment	Finance	Information Management	Legal / Authorization	Materials	Operations	Personnel	Structure and Bridge
DS26	Detour Information	NC	Local Emergency Services	Emerg.	State	Post	ST					P			S		
DS27	Chainsaw Crews	NC	Dept. of Natural Resources	Envir.	State	Post	ST					S			P		
DS28	Conflicting Road Information	NC	NC State Highway Patrol	Police	State	Post	ST					P			S		
DS29	Fund Reimbursements	NC	FEMA	Emerg.	State	Post	LT	S			P						
DS30	Ineffective Equipment	NC	NC DOT	Trans.	State	Post	ST		S	P							
DS31	Relocated Personnel	NC	NC DOT	Trans.	State	Post	ST		S							P	
DS32	Equipment Distribution	NC	NC DOT	Trans.	State	Post	ST			P		S					
DS33	Undefined Roles	NC	NC DOT	Trans.	State	Post	ST	P				S					
DS34	Excessive Workloads	NC	NC DOT	Trans.	State	Post	LT	P							S		
DS35	Structure Repairs	NC	NC DOT	Trans.	State	Post	MT								P		S
DS36	Insufficient Traffic Manage.	NC	NC DOT	Trans.	State	Post	ST					P			S		
DS37	Fuel Confusion	NC	NC DOT	Trans.	State	Post	ST					P			S		
DS38	Conference Calls	NC	NC DOT	Trans.	State	Post	MT	P				S					
DS39	Email Communication	NC	NC DOT	Trans.	State	Post	MT		S			P					
DS40	Unconfirmed Equipment	NC	NC DOT	Trans.	State	Post	ST			S		P					
DS41	Road Closure Reports	NC	NC DOT	Trans.	State	Post	ST								P	S	
DS42	Restricted Access	NC	NC DOT	Trans.	State	Post	ST		P							S	
DS43	Inconsistent Barricades	NC	NC DOT	Trans.	State	Post	ST		S	P							
DS44	Refueling	NC	NC DOT	Trans.	State	Post	ST							P	S		
DS45	Restricted Communication	NC	NC DOT	Trans.	State	Post	ST		S			P					
DS46	HazMat Information	NC	NC DOT	Trans.	State	Post	ST					P	S				
DS47	Disposal Sites	NC	NC DOT	Trans.	State	Post	MT		S						P		
DS48	Processing Reimbursements	NC	NC DOT	Trans.	State	Post	LT	S			P						

APPENDIX D. ENHANCEMENT COMPARISON TOOL

This section describes the components of the spreadsheet program for evaluating enhancement alternatives. The beginning of the spreadsheet program contains a welcome page followed by the individual worksheets. The "Welcome Page" is shown in Figure D.1.

The main methodology that this model follows involves comparing the enhancement of a single road system to different levels with respect to wind speed, storm surge and traffic wear. This model cannot compare the costs and benefits of multiple road systems against a different array of alternatives. It is limited to analyzing the enhancement capabilities of one road system at a time. For example, the sample alternative that was given in the previous section, in Table D.3, can be used indirectly with this tool. The user may decide to evaluate that sample alternative and thus utilize this tool to evaluate each individual road system within it. This tool has the flexibility to analyze any road system with respect to any enhancement option. VDOT may consider using additional options other than wind speed, storm surge, and traffic flow. The tradeoff analyses, at the end of the tool, can provide VDOT with important information about the costs, risks, and benefits of enhancing a road system.

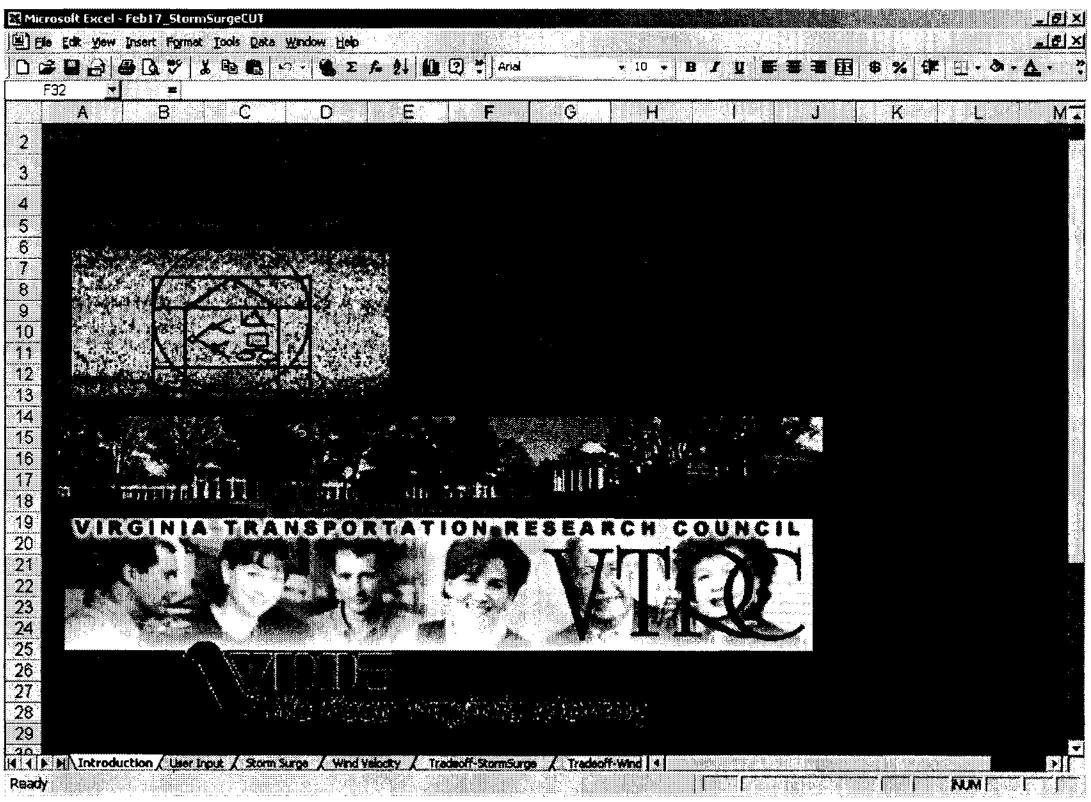


Figure D.1 Welcome page of the Cost, Risk, and Benefit Decision Tool

The spreadsheet software is partitioned into three electronic worksheets that take input from the user and another two worksheets that display results. The sequence of analysis is clearly identified in the worksheets. This section will use a step-by-step approach to describe each step of the spreadsheet, its functionality, and the results.

If the width of the screen is not big enough or the text is too small for the screen, click on View from the menu bar and select Zoom. Enter a zoom value that is appropriate for the screen.

Wind Speed

The first worksheet is **User Input,** which takes the majority of the input required from the user to begin the analysis. The main input to this worksheet is the type of road system to consider. Figure D.2 shows the very first portion of the worksheet. Shown in the figure is the introduction, which provides an area to enter the type of road system to consider (Step 1). When entering the type of road system, the user can input any road system. The other worksheets are automatically titled with the respective road system.

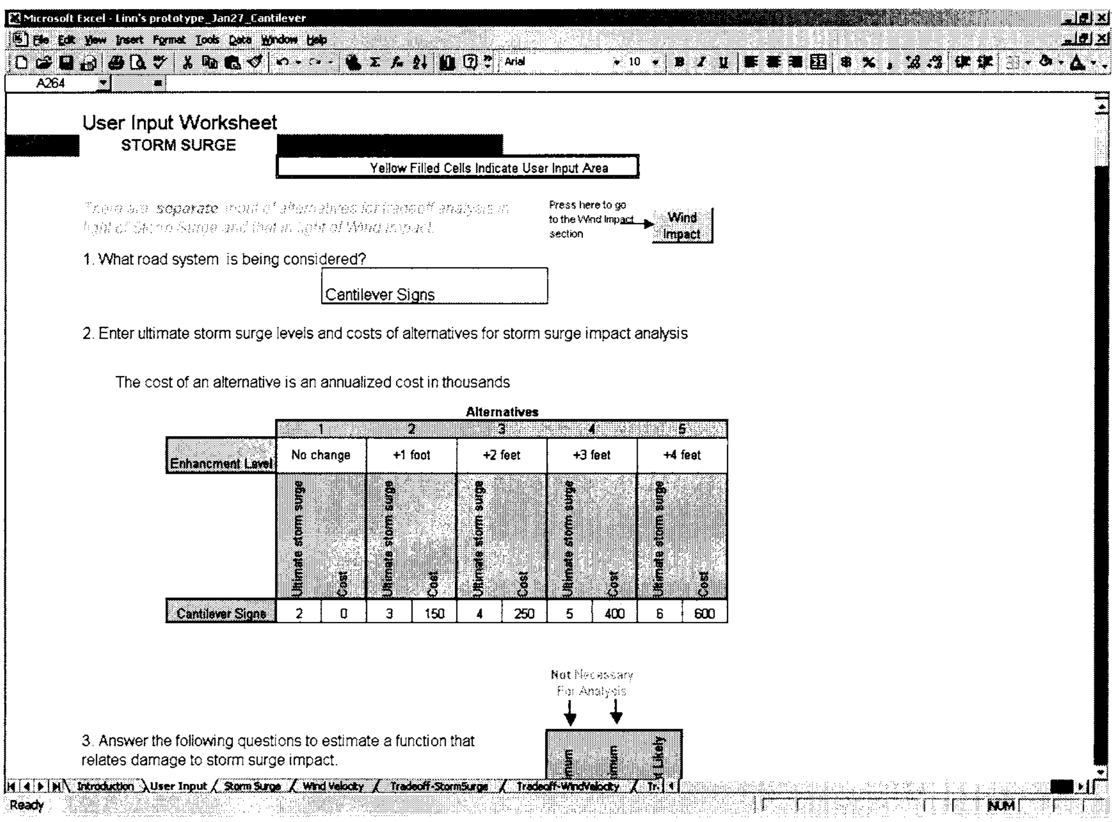


Figure D.2 The top of the **User Input** worksheet

Figure D.3 shows the Wind Impact portion of the worksheet, which includes Step 2 completely and part of Step 3. Step 2 involves entering the design alternatives. For each design alternative, the user supplies the name, the cost of reconstruction, and the design load, which is the wind speed in miles per hour that the road system is designed to withstand without having significant damage. In Step 3, the user answers questions in order to assess the relationship between wind speed and damage. The questions are:

1. What is the greatest wind speed that results in no damage cost?
2. What is the repair cost of VDOT equipment for a wind speed equal to the design load?
3. What is the lowest wind speed that results in total reconstruction cost?

The answers to these questions give three points on a graph of (repair cost) / (reconstruction cost) versus (impact force) / (design load) as shown in Figure D.4. The user answers the first and third questions in terms of percentages of design load. The answer to the second question is in terms of a percentage of reconstruction cost. With respect to Figure D.4, the answer to the first question gives a point on the horizontal axis from where the function begins to increase linearly. The next question locates a point where the horizontal coordinate is 1 because the wind speed is equal to the design load. The answer to the question gives the value for the vertical component of the point. Answering the third question locates a point where the vertical component is always 1 but the horizontal component depends on the answer. An assumption, which is stated below the questions in the spreadsheet underlying the assessed relationship, is that the non-dimensional relationship assessed in Step 3 is applicable to all of the relevant alternatives.

The questions ask for minimum, most likely, and maximum numerical estimates. Supplying the three types of answers characterizes the uncertainty of the assessment. However, it is not absolutely necessary to enter minimum and maximum estimates as they are only used to make the graph shown in Figure D.5. Only the most-likely estimates are used in the mathematical model for calculating damage, which is expressed as the ratio of repair cost to reconstruction cost.

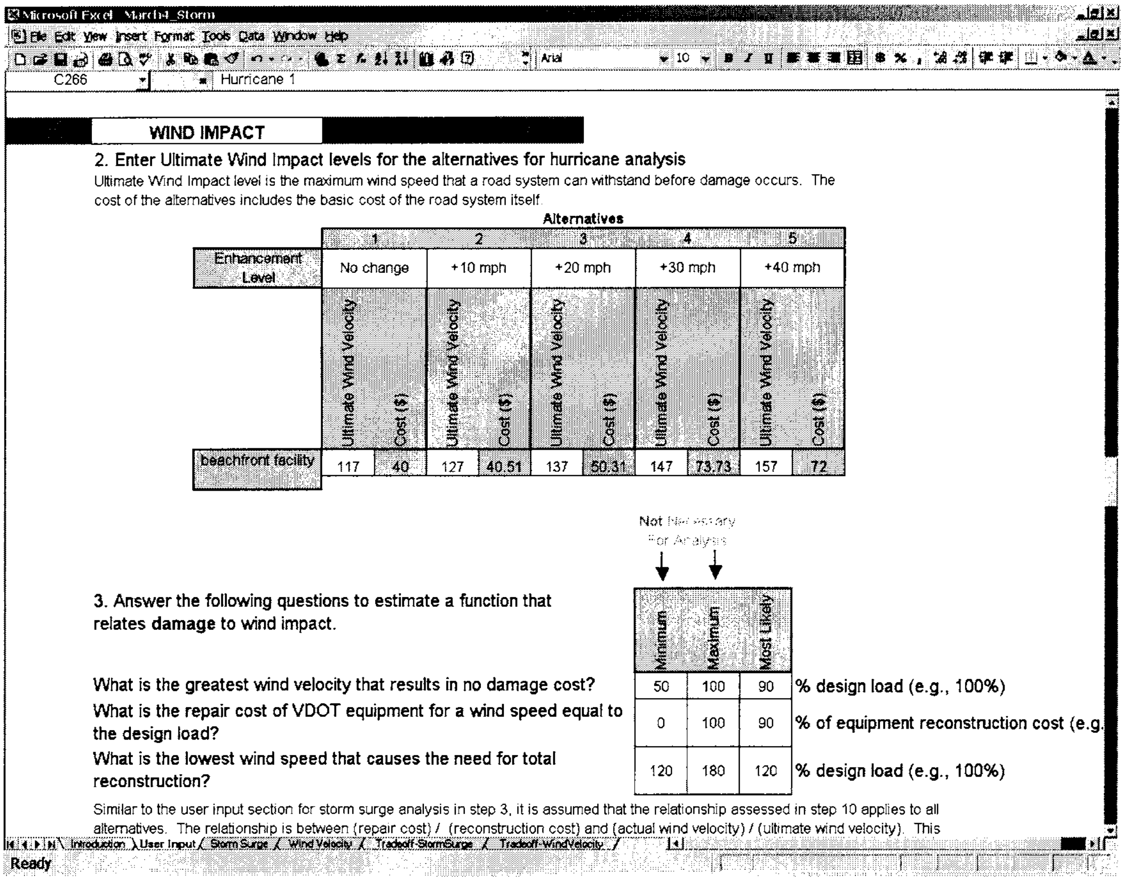
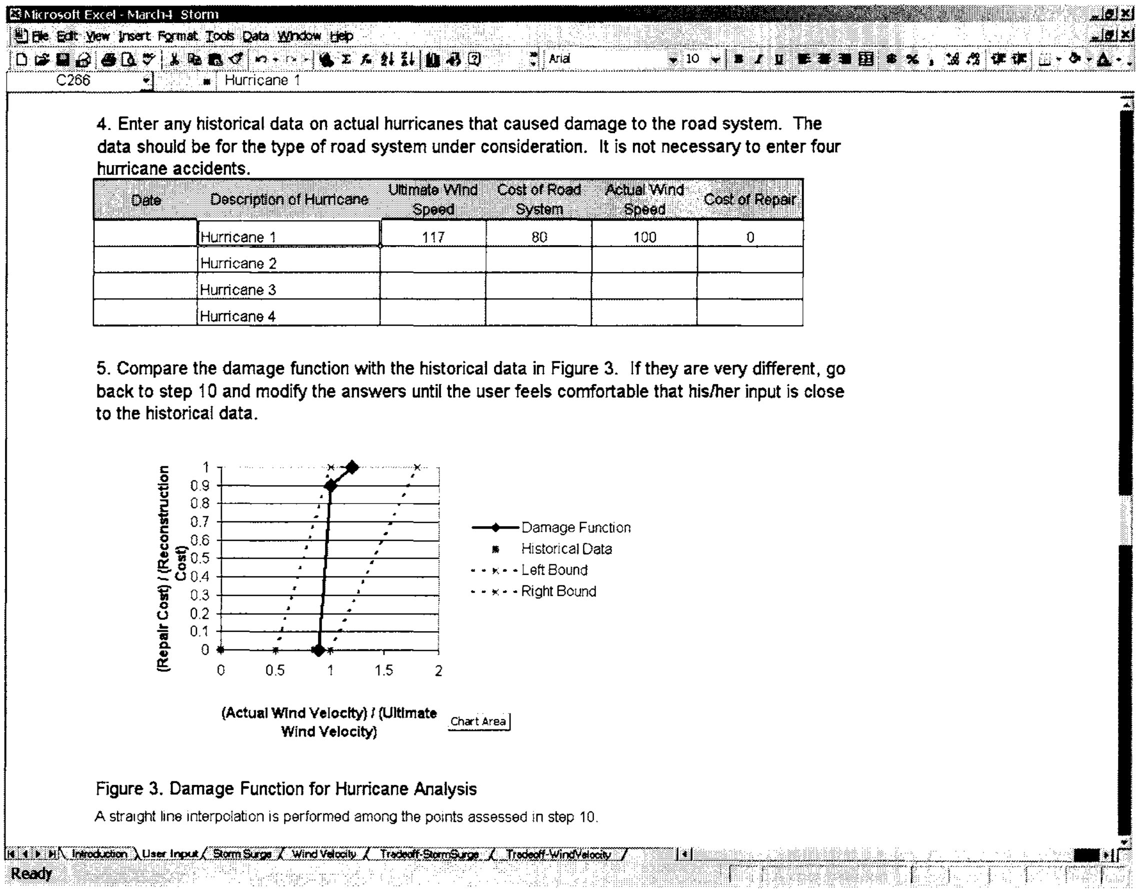


Figure D.3 Input areas for design alternatives and questions to support calculating damage due to wind speeds.

Step 4 shown in Figure D.4 asks the user to enter any historical data on actual wind speed-related incidents. As indicated in Step 4, the data should be relevant to impacts on the road system of concern because impacts on other road systems might not have the same repair cost. The historical data is then plotted along with the relationship assessed in Step 3. From the plot, the user can assess how close his/her estimated relationship is to the historical data. Step 5, the next step, is to compare the estimated relationship, which is called the damage function, to the historical data, and to modify the answers in Step 3 if they are too different. The historical data is not used to calculate damage directly; it helps in the modeling only as a basis for comparison with the estimated relationship. It is assumed that a straight-line interpolation of the points assessed in Step 3 is sufficiently accurate to describe the relationship. The minimum and maximum estimates are also plotted in the graph. See Figure D.5 for a more detailed look at the graph. If the historical data are mostly lying outside of the left and right bounds, then the user may decide to reconsider the answers to the questions in Step 3. However, the historical data may actually not be very close to the real relationship when there is little relevant data on actual wind speed impacts. This is the case for the example seen in Figure 3 of Figure D.4.



Microsoft Excel - March4 Storm

File Edit View Insert Format Tools Data Window Help

C266 Hurricane 1

4. Enter any historical data on actual hurricanes that caused damage to the road system. The data should be for the type of road system under consideration. It is not necessary to enter four hurricane accidents.

Date	Description of Hurricane	Ultimate Wind Speed	Cost of Road System	Actual Wind Speed	Cost of Repair
	Hurricane 1	117	80	100	0
	Hurricane 2				
	Hurricane 3				
	Hurricane 4				

5. Compare the damage function with the historical data in Figure 3. If they are very different, go back to step 10 and modify the answers until the user feels comfortable that his/her input is close to the historical data.

Figure 3. Damage Function for Hurricane Analysis

A straight line interpolation is performed among the points assessed in step 10.

Introduction User Input Storm Surge Wind Velocity Tradeoff-StormSurge Tradeoff-WindVelocity

Ready

Figure D.4 Historical data and comparison with assessed relationship

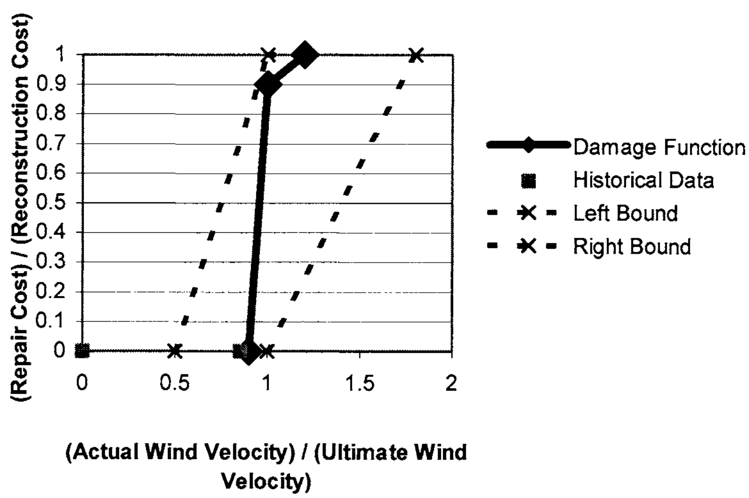


Figure D.5 Damage function plotted along with historical data for user to modify the estimates entered in Step 3 accordingly if necessary

In Step 6 the user is asked several questions in order to assess the relationship between wind speed and time to recover. *Time to recover* is the time it takes to repair the road system so that it is functional and operable. In Step 7, there is the opportunity to enter any historical data on the time to recover after wind speed impacts (up to four accidents). Figure D.6 shows Steps 6 and Step 7.

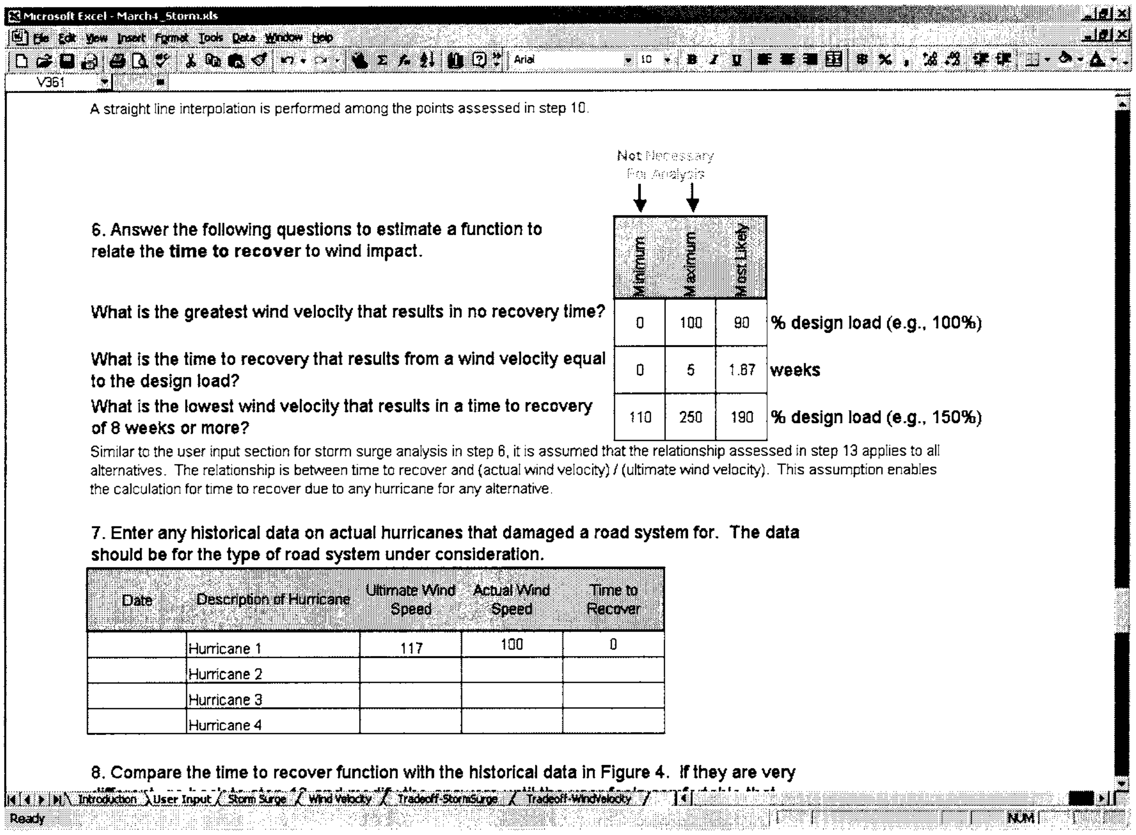


Figure D.6 Assessment questions for time to recover and historical data

In Step 8, a plot is displayed for the user to check whether his/her input in Step 6 is close to the historical data (see Figure D.7). Similar to the damage function, a straight-line assumption is made on the points assessed previously. The historical data is then plotted along with the relationship assessed in Step 6. From the plot, the user can assess how close his/her estimated relationship is to the historical data. Step 8, the next step, is to compare the estimated relationship, which is called the damage function, to the historical data, and to modify the answers in Step 6 if they are too different. The historical data is not used to calculate damage directly; it helps in the modeling only as a basis for comparison with the estimated relationship. It is assumed that a straight-line interpolation of the points assessed in Step 6 is sufficiently accurate to describe the relationship. The minimum and maximum estimates are also plotted in the graph. If the historical data are mostly lying outside of the left and right bounds, then the user may decide to reconsider the answers to the questions in Step 6. However, the historical data may actually not be very close to the real relationship when there is little relevant data on actual wind speed impacts. There is no difference between how this plot is used and how the damage function is used except that the value to calculate here is *time to recover* (plotted on the vertical axis).

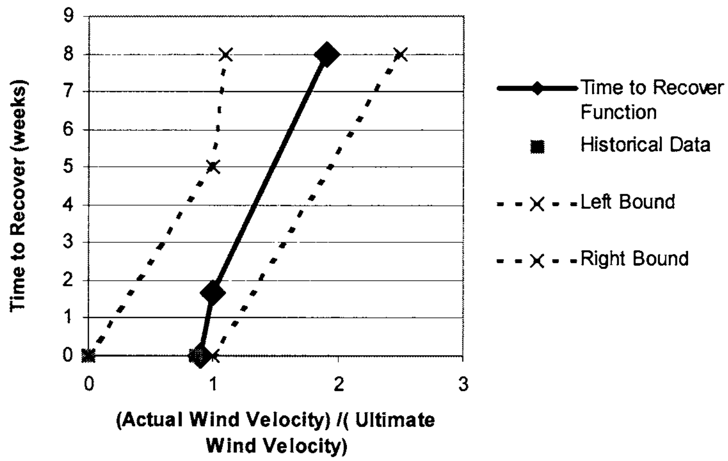
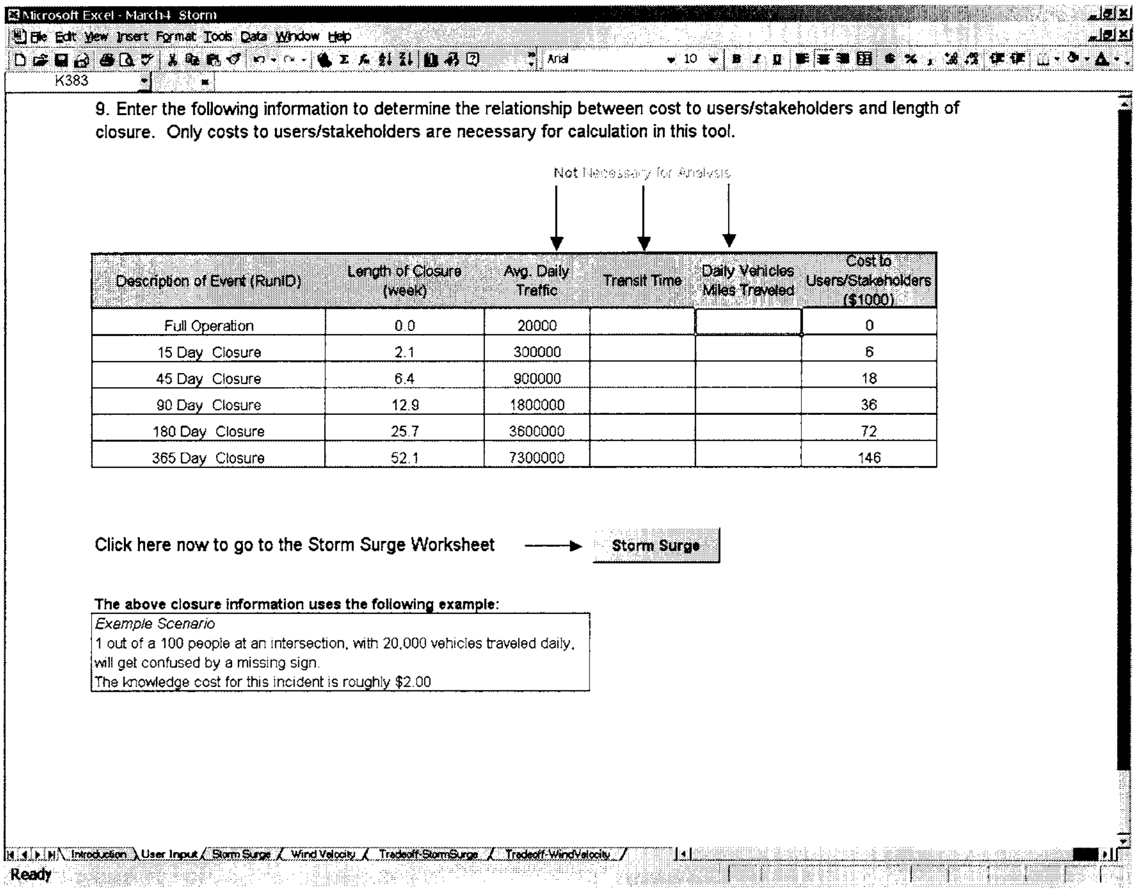


Figure D.7 Plot of *time to recover* versus *wind impact* for historical data and estimated relationship

Figure D.7 shows the last major step on this worksheet, which is to enter information about closure costs. For different lengths of closure of the road system, the user needs to enter an estimate of the cost to industry. The data available in Figure D.7 was created from an example that was derived in order to show the user this closure analysis capability. After completing this step, the user should click on the button on the screen to open the next worksheet, which is called Storm Surge.



9. Enter the following information to determine the relationship between cost to users/stakeholders and length of closure. Only costs to users/stakeholders are necessary for calculation in this tool.

Not Necessary for Analysis

Description of Event (RunID)	Length of Closure (week)	Avg. Daily Traffic	Transit Time	Daily Vehicles Miles Traveled	Cost to Users/Stakeholders ($1000)
Full Operation	0.0	20000			0
15 Day Closure	2.1	300000			6
45 Day Closure	6.4	900000			18
90 Day Closure	12.9	1800000			36
180 Day Closure	25.7	3600000			72
365 Day Closure	52.1	7300000			146

Click here now to go to the Storm Surge Worksheet → Storm Surge

The above closure information uses the following example:

Example Scenario
1 out of a 100 people at an intersection, with 20,000 vehicles traveled daily, will get confused by a missing sign.
The knowledge cost for this incident is roughly $2.00

Figure D.8 Closure cost entry table

Shown in Figure D.9, the **Wind Impact** worksheet displays the values that are calculated from the input on the **User Input** worksheet. These values are the costs of reconstruction of the alternatives and various risk metrics. The reconstruction cost is plotted on the vertical axis, while a risk metric is plotted on the horizontal. In this way, the user could see the present investment and the risk of a wind speed accident. There are four risk metrics that describe the consequences of a wind speed impact. They are:

1. Repair Cost / Reconstruction Cost
2. Repair Cost
3. Time to Recover
4. Cost to Industry

In Step 9, the user enters three scenarios of wind speed under which to evaluate the alternatives. For each scenario, the hurricane magnitudes and the return period of the event are pre-set as hurricane categories [I to II], [III], and [IV to V]. Information pertaining to the return periods is provided below in Figure D.10.

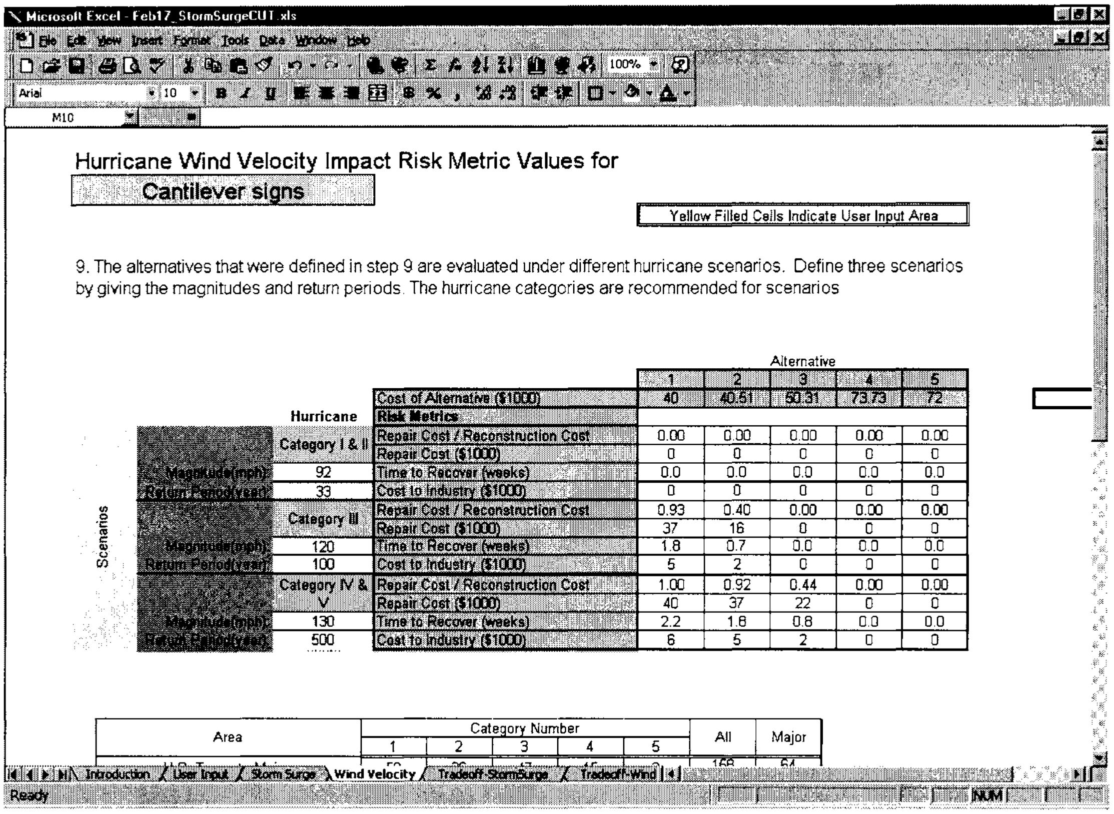


Figure D.9 Top of **Wind Impact** worksheet with scenario entry boxes

Figure D.10 shows the table providing information on the return periods of various hurricane categories in different states.

Area	Category Number 1	2	3	4	5	All	Major
U.S. Texas to Maine	58	36	47	15	2	158	64
Texas	12	9	9	6	0	36	15
Louisiana	8	5	8	3	1	25	12
Mississippi	1	1	5	0	0	8	6
Alabama	4	1	5	0	1	10	5
Florida	17	16	17	6	0	57	24
Georgia	1	4	0	0	0	5	0
South Carolina	6	4	2	2	0	14	4
North Carolina	10	4	10	1	0	25	11
Virginia	2	1	1	0	0	4	1
Maryland	0	1	0	0	0	1	0
Delaware	0	0	0	0	0	0	0
New Jeresey	1	0	0	0	0	1	0
New York	3	1	5	0	0	9	5
Connecticut	2	3	3	0	0	8	3
Rhode Island	0	2	3	0	0	5	3
Massaschusetts	2	2	2	0	0	6	2
New Hampshire	1	1	0	0	0	2	0
Maine	5	0	0	0	0	5	0

Figure D.10 U.S. Mainland Hurricane Strikes by States, 1900 - 1996 (NHC, 1999)

Tradeoff Analysis for Wind Speed

The next worksheet, **Tradeoff – Wind Velocity,** contains graphs that show the tradeoffs between the alternatives under the wind speed scenarios. Figure D.11 shows the first graph: cost of alternative versus *(repair cost)* / *(reconstruction cost)*. A key on the right hand side of the screen describes the components of the legend that accompany each graph. The way to interpret the curves in the graphs is to view the cost of an alternative on the vertical axis as the present investment for that alternative and the value on the horizontal axis as a consequence of a wind speed-related incident provided that the alternative was chosen. The consequence can be any of the risk metrics such as (repair cost) / (reconstruction cost), repair cost, time to recover, or cost to industry. The three curves are associated with the three scenarios entered previously in Step 9. These three scenarios are three probable wind speed incidents that have different probabilities of occurrence, and therefore different return periods. For example, referring to the graph in Figure D.11, the user can tell what the ratio of repair to reconstruction cost is for different levels of investment under the different wind speed scenarios. It should be noted that this view of investment versus consequences is limited by the quality of the alternatives. If all the alternatives entered are not cost-effective, then the curves will give a skewed picture of the tradeoffs. In this case, the curves could only be interpreted strictly as cost of alternative versus the ratio of repair to reconstruction cost. However, if the entered alternatives are some of the best ones, then the user can confidently interpret the curves as showing the tradeoffs between current investment and future consequence. The statements above are true for all the tradeoff curves in the tool.

Again referring to the graph in Figure D.11, the user could see that if an extensive wind speed impact occurred (see the middle curve), investing $45,100 instead of $53,100 would mean having a ratio of repair cost to reconstruction cost of 0.4 instead of 0. In other words, a potential damage in the future equal to 40% of the reconstruction cost is traded off for a cost saving of $8,000 in the present. Also, the user could notice that for the moderate wind speed impact case (curve on the left), investing more than $45,100 does not lessen the repair cost. For example, if the user is only concerned about moderate wind speed impacts because the more severe cases have insignificant probabilities of occurrence in the design life span of the road system and possible wind destruction is not a concern, then the user will probably choose an alternative that does not exceed $45,100. If the user has reason to believe that an extensive or even extreme wind speed impact would occur during the road system's life span, it may make sense to invest over $45,100. The user should look at the tradeoffs involving these two scenarios. Consider the moderate wind speed impact scenario, there is a reduction in expected repair cost for investing more than $45,100. The final choice of a design is based on the user's best judgment after looking at the tradeoffs under the different scenarios. This decision is usually not fully determined by the tool. There may be "softer" factors that cannot be measured which affect the decision. For example, a user or stakeholder of the industry might not choose any enhancement that has even a small-expected downtime because of the "dread" of tedious work involved. This dread of work is hard to measure.

This analysis assumes that any damage however minor will be repaired. If the assumption is not true, then repeated occurrences of a certain type of event such as a moderate wind speed impact could cause greater consequences than the model in the tool predicts. The model assumes that the road system is in undamaged condition before an event occurs.

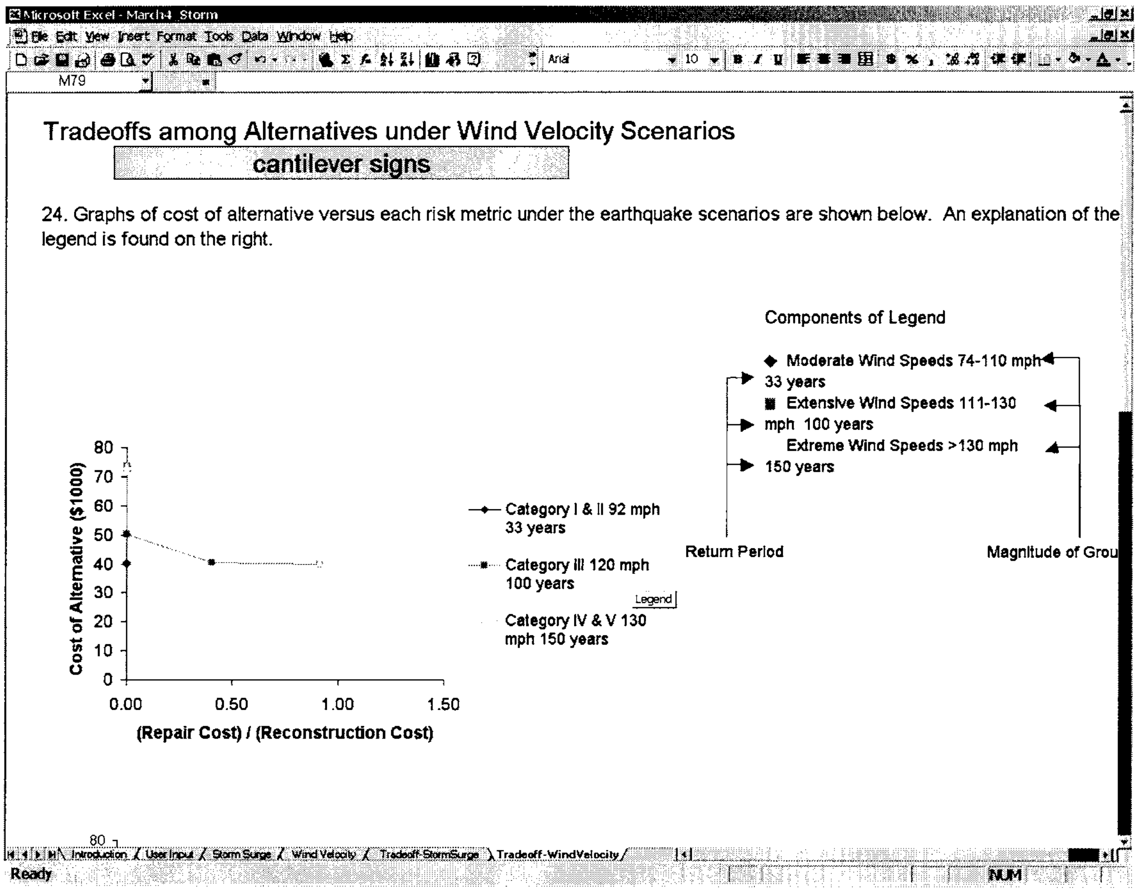


Figure D.11 Tradeoff graph of the cost of the alternative versus the repair cost, reconstruction cost ratio.

Storm Surge

The following section describes the storm surge portion of the tool. This tool has the flexibility to evaluate the enhancement effects of a variety of options on a single road system. For example, the user may wish to see the impacts that both wind speed and storm surge have on traffic signal systems – a task that is easily achieved with this tool. VDOT may also consider additional options such as sustainable traffic flow.

The first worksheet is **User Input,** which takes the majority of the input required from the user to begin the analysis. The main input to this worksheet is the type of road system to consider. Figure D.12 shows the very first portion of the worksheet. Shown in the figure is the introduction, which provides an area to enter the type of road system to consider (Step 1). For this scenario, a beachfront facility was used to be evaluated. The other worksheets are automatically titled with the respective road system.

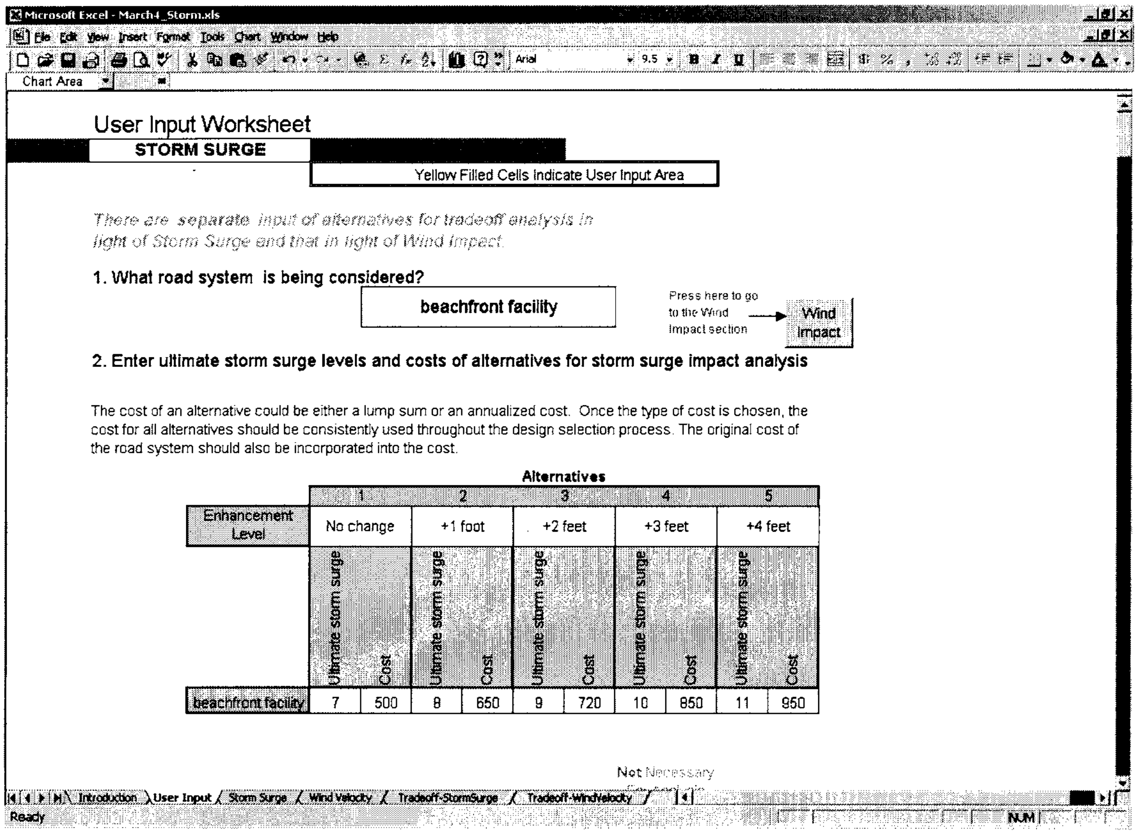


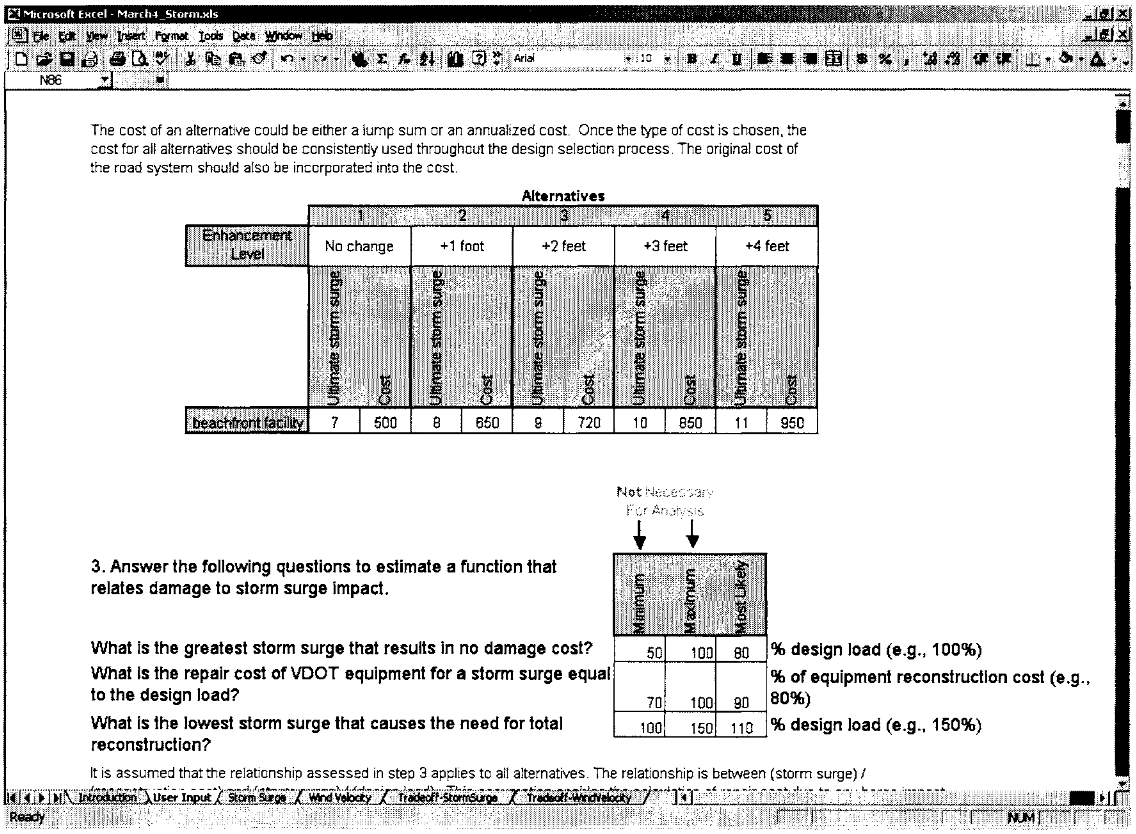
Figure D.12 The top of the **User Input** worksheet

Figure D.13 shows the storm surge portion of the worksheet, which includes Step 2 completely and part of Step 3. Step 2 involves entering the design alternatives. For each design alternative, the user supplies the name, the cost of reconstruction, and the design load, which is the storm surge in feet that the road system is designed to withstand without having significant damage. In Step 3, the user answers questions in order to assess the relationship between wind speed and damage. The questions are:

1. What is the greatest storm surge that results in no damage cost?
2. What is the repair cost of VDOT equipment for a storm surge equal to the design load?
3. What is the lowest storm surge that results in total reconstruction cost?

The answers to these questions give three points on a graph of (repair cost) / (reconstruction cost) versus (impact force) / (design load) as shown in Figure D.14. The user answers the first and third questions in terms of percentages of design load. The answer to the second question is in terms of a percentage of reconstruction cost. With respect to Figure D.14, the answer to the first question gives a point on the horizontal axis from where the function begins to increase linearly. The next question locates a point where the horizontal coordinate is 1 because the storm surge is equal to the design load. The answer to the question gives the value for the vertical component of the point. Answering the third question locates a point where the vertical component is always 1 but the horizontal component depends on the answer. An assumption, which is stated below the questions in the spreadsheet underlying the assessed relationship, is that the non-dimensional relationship assessed in Step 3 is applicable to all of the relevant alternatives.

The questions ask for minimum, most likely, and maximum numerical estimates. Supplying the three types of answers characterizes the uncertainty of the assessment. However, it is not absolutely necessary to enter minimum and maximum estimates as they are only used to make the graph shown in Figure D.15. Only the most-likely estimates are used in the mathematical model for calculating damage, which is expressed as the ratio of repair cost to reconstruction cost.


Microsoft Excel - March4_Storm.xls

The cost of an alternative could be either a lump sum or an annualized cost. Once the type of cost is chosen, the cost for all alternatives should be consistently used throughout the design selection process. The original cost of the road system should also be incorporated into the cost.

	Alternatives 1		2		3		4		5	
Enhancement Level	No change		+1 foot		+2 feet		+3 feet		+4 feet	
	Ultimate storm surge	Cost	Ultimate storm surge	Cost	Ultimate storm surge	Cost	Ultimate storm surge	Cost	Ultimate storm surge	Cost
beachfront facility	7	500	8	650	9	720	10	850	11	950

3. Answer the following questions to estimate a function that relates damage to storm surge impact.

	Minimum	Maximum	Most Likely	
What is the greatest storm surge that results in no damage cost?	50	100	80	% design load (e.g., 100%)
What is the repair cost of VDOT equipment for a storm surge equal to the design load?	70	100	90	% of equipment reconstruction cost (e.g., 80%)
What is the lowest storm surge that causes the need for total reconstruction?	100	150	110	% design load (e.g., 150%)

Not Necessary For Analysis (Minimum, Maximum)

It is assumed that the relationship assessed in step 3 applies to all alternatives. The relationship is between (storm surge) /

Introduction | User Input | Storm Surge | Wind Velocity | Tradeoff-StormSurge | Tradeoff-WindVelocity

Ready

Figure D.13 Input areas for design alternatives and questions to support calculating damage due to wind speeds

Step 4 shown in Figure D.14 asks the user to enter any historical data on actual storm surge-related incidents. As indicated in Step 4, the data should be relevant to impacts on the road system of concern because impacts on other road systems might not have the same repair cost. The historical data is then plotted along with the relationship assessed in Step 3. From the plot, the user can assess how close his/her estimated relationship is to the historical data. Step 5, the next step, is to compare the estimated relationship, which is called the damage function, to the historical data, and to modify the answers in Step 3 if they are too different. The historical data is not used to calculate damage directly; it helps in the modeling only as a basis for comparison with the estimated relationship. It is assumed that a straight-line interpolation of the points assessed in Step 3 is sufficiently accurate to describe the relationship. The minimum and maximum estimates are also plotted in the graph. See Figure D.15 for a more detailed look at the graph. If the historical data are mostly lying outside of the left and right bounds, then the user may decide to reconsider the answers to the questions in Step 3. However, the historical data may actually not be very close to the real relationship when there is little relevant data on actual storm surge impacts.

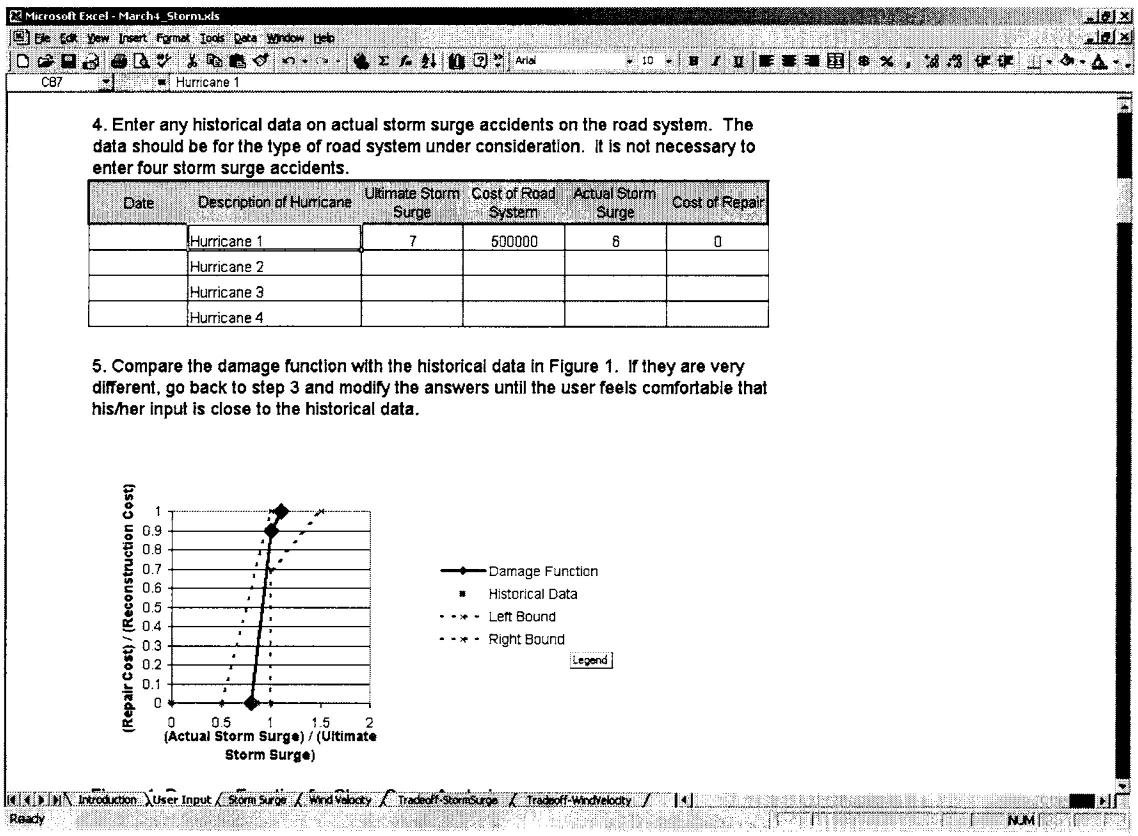


Figure D.14 Historical data and comparison with assessed relationship

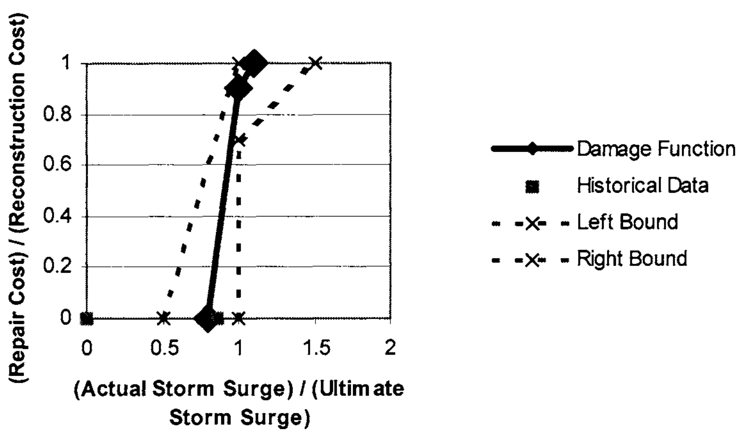


Figure D.15 Damage function plotted along with historical data for user to modify the estimates entered in Step 3 accordingly if necessary

In Step 6 the user is asked several questions in order to assess the relationship between storm surge and time to recover. *Time to recover* is the time it takes to repair the road system so that it is functional and operable. In Step 7, there is the opportunity to enter any historical data on the time to recover after storm surge impacts (up to four accidents). Figure D.16 shows Steps 6 and Step 7.

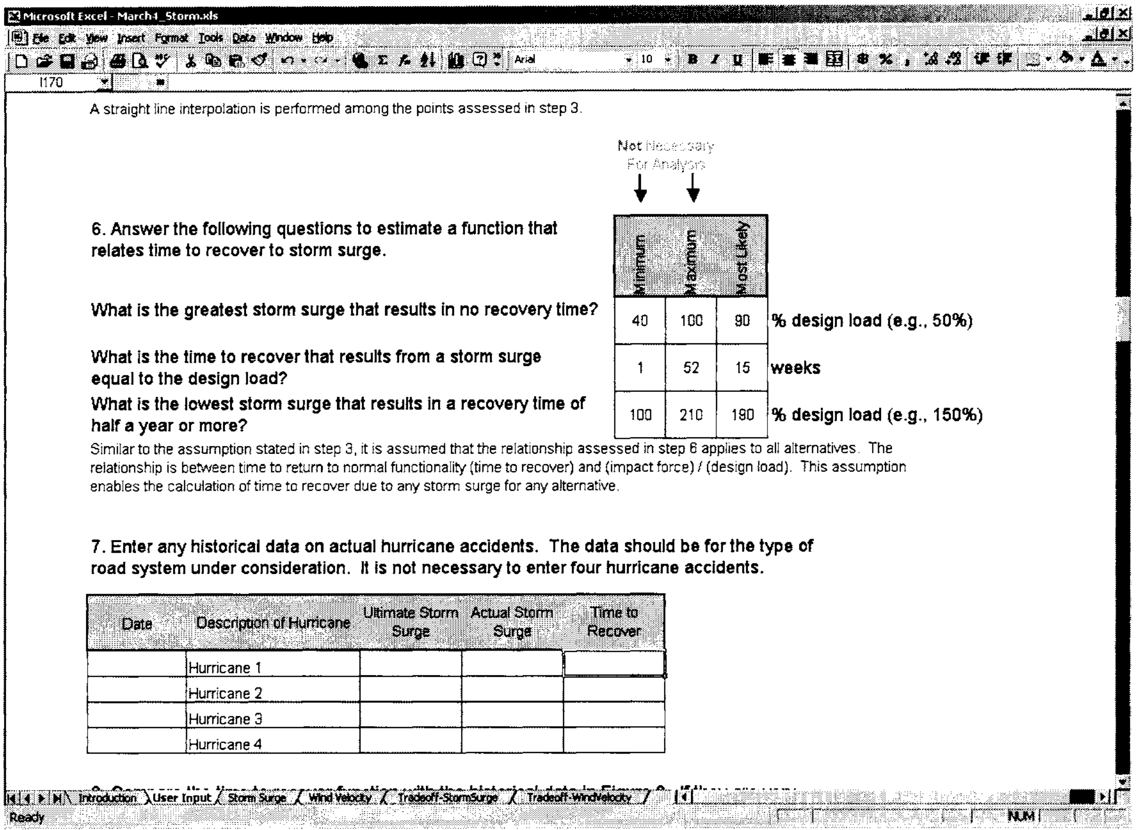


Figure D.16 Assessment questions for time to recover and historical data

In Step 8, a plot is displayed for the user to check whether his/her input in Step 6 is close to the historical data (see Figure D.17). Similar to the damage function, a straight-line assumption is made on the points assessed previously. The historical data is then plotted along with the relationship assessed in Step 6. From the plot, the user can assess how close his/her estimated relationship is to the historical data. Step 8, the next step, is to compare the estimated relationship, which is called the damage function, to the historical data, and to modify the answers in Step 6 if they are too different. The historical data is not used to calculate damage directly; it helps in the modeling only as a basis for comparison with the estimated relationship. It is assumed that a straight-line interpolation of the points assessed in Step 6 is sufficiently accurate to describe the relationship. The minimum and maximum estimates are also plotted in the graph. If the historical data are mostly lying outside of the left and right bounds, then the user may decide to reconsider the answers to the questions in Step 6. However, the historical data may actually not be very close to the real relationship when there is little relevant data on actual storm surge impacts. There is no difference between how this plot is used and how the damage function is used except that the value to calculate here is *time to recover* (plotted on the vertical axis).

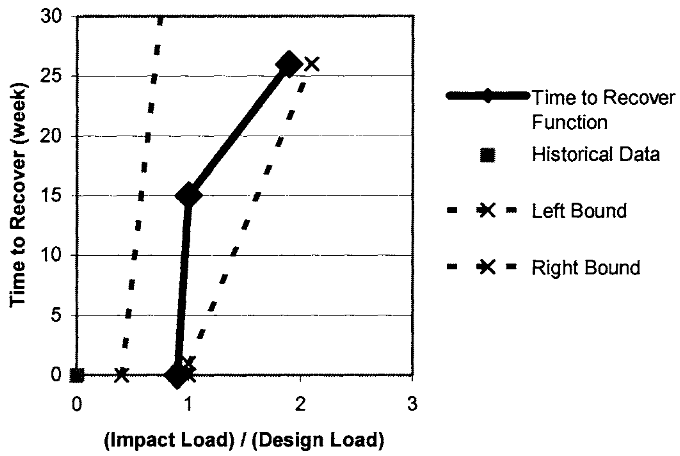


Figure D.17 Plot of *time to recover* versus *storm surge* for historical data and estimated relationship

Shown in Figure D.19, the **Storm Surge** worksheet displays the values that are calculated from the input on the **User Input** worksheet. These values are the costs of reconstruction of the alternatives and various risk metrics. The reconstruction cost is plotted on the vertical axis, while a risk metric is plotted on the horizontal. In this way, the user could see the present investment and the risk of a storm surge accident. There are four risk metrics that describe the consequences of a storm surge impact. They are:

1. Repair Cost / Reconstruction Cost
2. Repair Cost
3. Time to Recover
4. Cost to Industry

In Step 9, the user enters three scenarios of storm surge under which to evaluate the alternatives. For each scenario, the hurricane magnitudes and the return period of the event are pre-set as hurricane categories [I to II], [III], and [IV to V].

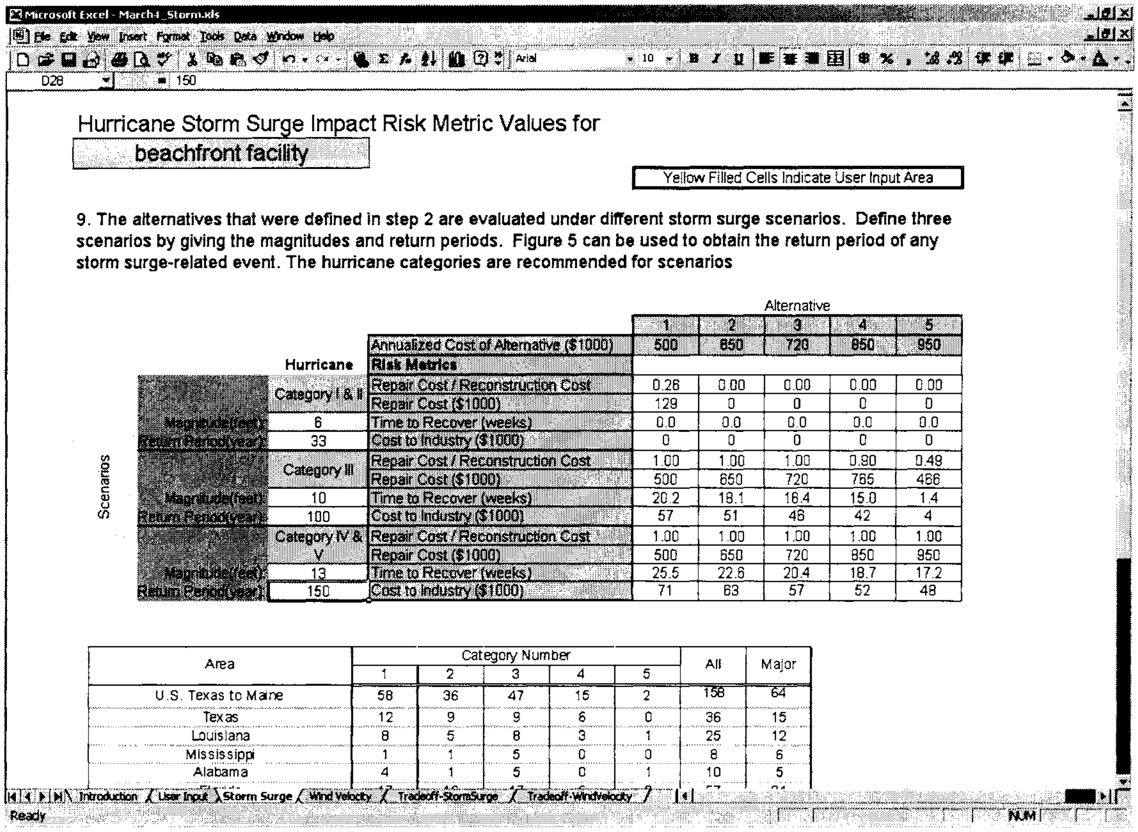


Figure D.19 Top of **Wind Impact** worksheet with scenario entry boxes

Tradeoff Analysis for Storm Surge

The next worksheet, **Tradeoff – Storm Surge,** contains graphs that show the tradeoffs between the alternatives under the storm surge scenarios. Figure D.20 shows the first graph: cost of alternative versus (*repair cost*) / (*reconstruction cost*). A key on the right hand side of the screen describes the components of the legend that accompany each graph. The way to interpret the curves in the graphs is to view the cost of an alternative on the vertical axis as the present investment for that alternative and the value on the horizontal axis as a consequence of a storm surge-related incident provided that the alternative was chosen. The consequence can be any of the risk metrics such as (repair cost) / (reconstruction cost), repair cost, time to recover, or cost to industry. The three curves are associated with the three scenarios entered previously in Step 9. These three scenarios are three probable storm surge incidents that have different probabilities of occurrence, and therefore different return periods. For example, referring to the graph in Figure D.20, the user can tell what the ratio of repair to reconstruction cost is for different levels of investment under the different storm surge scenarios. It should be noted that this view of investment versus consequences is limited by the quality of the alternatives. If all the alternatives entered are not cost-effective, then the curves will give a skewed picture of the tradeoffs. In this case, the curves could only be interpreted strictly as cost of alternative versus the ratio of repair to reconstruction cost. However, if the entered alternatives are some of the best ones, then the user can confidently interpret the curves as showing the tradeoffs between current investment and future consequence. The statements above are true for all the tradeoff curves in the tool.

Again referring to the graph in Figure D.20, the user could see that if an extensive storm surge impact occurred (see the middle curve), investing $850,000 instead of $950,000 would mean having a ratio of repair cost to reconstruction cost of 0.8 instead of 0.07. In other words, a potential damage in the future equal to around 91% of the reconstruction cost is traded off for a cost saving of $100,000 in the present. Also, the user could notice that for the moderate storm surge impact case (curve on the left), investing more than $500,000 does not lessen the repair cost. For example, if the user is only concerned about moderate storm surge impacts because the more severe cases have insignificant probabilities of occurrence in the design life span of the road system and possible flooding is not a concern, then the user will probably choose an alternative that does not exceed $500,000. If the user has reason to believe that an extensive or even extreme storm surge impact would occur during the road system's life span, it may make sense to invest over $500,000. The user should look at the tradeoffs involving these two scenarios. While, there is no reduction in expected repair cost for investing more than $500,000 in the case of a moderate storm, there is significant reduction in repair cost for investing over $850,000 in the case of an extensive storm. The final choice of a design is based on the user's best judgment after looking at the tradeoffs under the different scenarios. This decision is usually not fully determined by the tool. There may be "softer" factors that cannot be measured which affect the decision. For example, a user or stakeholder of the industry might not choose any enhancement that has even a small-expected downtime because of the "dread" of tedious work involved. This dread of work is difficult to measure.

It is assumed that any damage however minor will be repaired. If the assumption is not true, then repeated occurrences of a certain type of event such as a moderate storm surge impact could cause greater consequences than the model in the tool predicts. The model assumes that the road system is in undamaged condition before an event occurs.

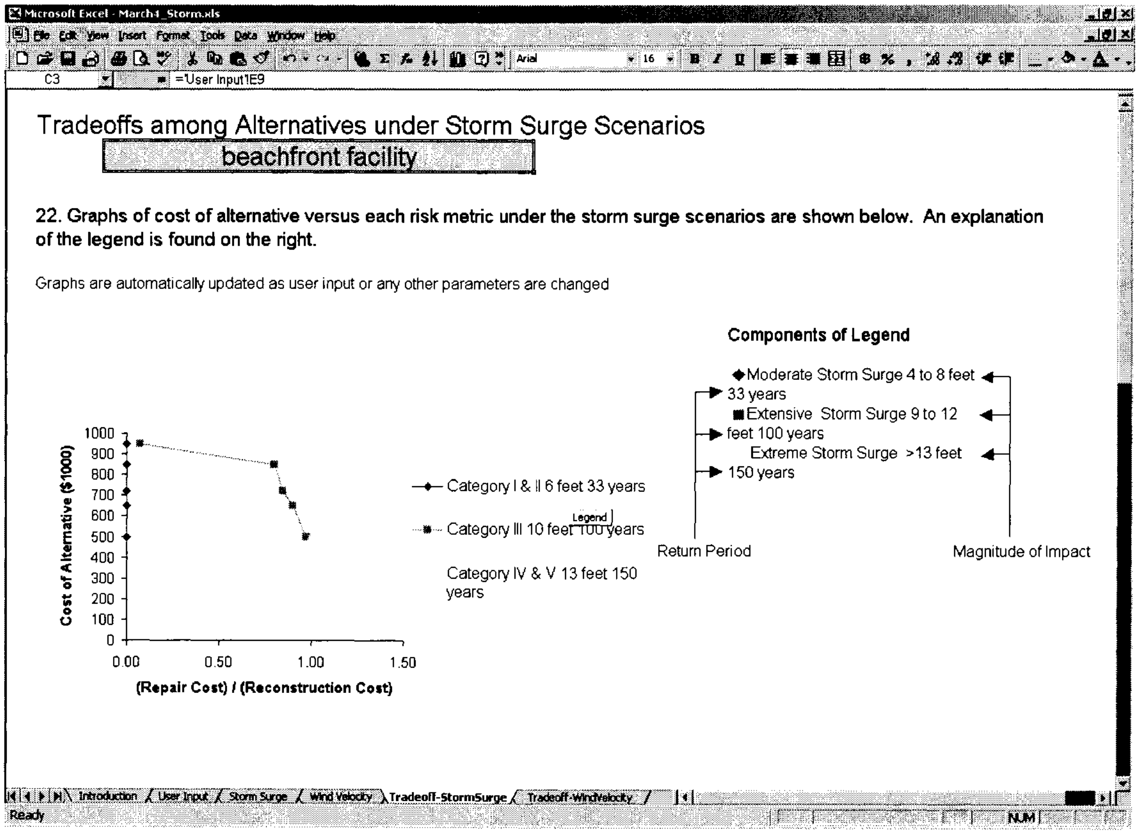


Figure D.20 Tradeoff graph of the cost of the alternative versus the repair cost, reconstruction cost ratio.