Homeland security emergency response wind field plume flow

Lynn Bryant Nielson

University of Nevada, Las Vegas

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HOMELAND SECURITY EMERGENCY RESPONSE

WIND FIELD PLUME FLOW

by

Lynn Bryant Nielson

Bachelor of Science
Utah State University, Logan Utah
1991

A thesis submitted in partial fulfillment
of the requirements for the

Master of Science Degree in Engineering
Mechanical Engineering Department
Howard R. Hughes College of Engineering

Graduate College
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Lynn Bryant Nielson

Entitled

Homeland Security Emergency Response Wind Field Plume Flow

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Master of Science in Engineering

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Examination Committee Chair

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Examination Committee Member

Examination Committee Member

Graduate College Faculty Representative

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ABSTRACT

Homeland Security Emergency Response Wind Field Plume Flow

by

Lynn Bryant Nielson

Dr. Darrell W. Pepper, Ph.D., Examination Committee Chair
Professor of Mechanical Engineering
University of Nevada, Las Vegas

Numerous atmospheric dispersion models for emergency response exist. The Office of the Federal Coordinator for Meteorological Services is leading the development of new atmospheric dispersion models for emergency response.

Collaborative efforts, mutual aid agreements, and partnerships synergize forming meteorological data networks providing atmospheric modeling for enhancing emergency response. Technological advances in computer meteorological forecasts are producing data used for predicting wind field plume flow for potential emergency response.

Fire stations make excellent sites for meteorological towers because they are located in fire response districts distributed throughout a community and the meteorological data gathered may serve multiple purposes.

A tower was sited at a fire station for this study. Meteorological station siting plays an important role in the quality of reported data. Data from this study found wind speed to be greater at 20 meters vs. 10 meters. Wind direction was fundamentally the same at both heights during this study.
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INTRODUCTION

Purpose of the Study

Emergency responders deal with challenging and potentially dangerous hazards every day. Atmospheric hazardous material releases from transportation accidents, released from accidents at residential, commercial, or industrial sites, or releases from structure and wildland fires occur daily. The ever increasing terrorist threat from potential release of biological and chemical weapons of mass destruction and disruption poses additional hazards. Emergency responders are tasked with protecting the public and themselves from the hazards associated with these accidental and intentional releases of hazardous materials.

Once a release occurs and the emergency responders are notified, they need to know answers to many questions, including location, type of release and the direction of the material plume flow, so they can determine the best course of action.

Currently many emergency responders would not be any better off than the general public even with this information, due to the lack of atmospheric dispersion modeling tools, the lack of training on their proper use, and the lack of equipment. Supplying emergency responders with simple tools such as real-time
wind data coupled with rapid puff-plume dispersion models would provide the necessary information and tools for risk assessment, evacuation, shelter in place and possible remediation.

Currently a few sources can produce this information. These range from predetermined hot zone distances found in emergency response manuals to highly complex computer puff-plume dispersion models.

Research Questions

Could it be possible to develop a better atmospheric dispersion model? Researchers at the University of Nevada Las Vegas, Nevada Center for Advanced Computational Methods, believe it is. The basic concept is an easy to use homeland security emergency response wind field plume flow model. This model would incorporate real time meteorological data sampled at locations such as fire stations throughout the community. It would have a rapid start to finish computational time. To improve usability, it would display clearly and concisely terrain data, structure data and have the ability to graphically overlay a dispersion puff or plume.

What atmospheric dispersion models are currently available to emergency responders? This study investigated some atmospheric models currently used for emergency response examining their capabilities. Expecting to find a few models, this study found numerous atmospheric models. Choosing to focus the investigation on only one, the ALOHA model was selected. ALOHA was selected because it is supported by the Environmental Protection Agency and National
Oceanic and Atmospheric Administration and is currently used by emergency responders.

Most models need meteorological information to formulate a solution. Meteorological information is typically gathered through instrumented towers. As part of this study, a tower was erected to gather meteorological data. The tower was 20 meters in height. The height provided the opportunity to instrument the tower at two different elevations. This added information could assist in evaluating boundary layer effects and atmospheric stability for two common mounting heights. Additionally, setting up a tower would provide insight into the process of gaining the necessary permits and approvals.

Significance of the Study

Emergency responders have the potential of accessing (near) real time puff-plume flow predictive information.

Mathematical methods of solving fundamental equations of atmospheric motion include; direct (analytical) solutions to the equations, and numerical techniques based on finite difference or finite elements analysis. Within each of these methods, there are various ways of solving the equations. The amount of computational power and time needed to solve equations using a numerical method approach increases when the solution resolution increases. For this reason, the computational response time for a numerical solution can range between a few seconds to several days.
Models use various combinations of the fundamental equations and the mathematical methods to provide a solution. Emergency responders that use computer dispersion models frequently use methods that render rapid solutions. However, results from simpler models are not as precise as more sophisticated numerical models that take days to achieve closure. Nevertheless, for emergency response purposes, an order of magnitude assessment is good enough for an initial estimate.

Most of the models use or have ability to use real time or near real time meteorological data. Typically, this data is in the form of wind speed, wind direction, and ambient temperature. The number of data points used for the input can vary from a single measurement point to multiple points, depending on the model employed. As the number of points used to achieve a solution increases, the reliability, and accuracy of the result generally increases.

One model studied can directly input meteorological data measured on location. This has advantages as long as the sensors are not near the ground, which could jeopardize the data quality. The quality of input data is important in improving solution accuracy. A permanently installed meteorological tower provides sensors properly mounted at correct heights to sample the wind field. However, the tower may not be near the location of the incident, rendering the data potentially useless for a single input model. Another option would be the permanent installation of a series of meteorological towers throughout a community continuously monitoring the regional wind field. The emergency responder could then select data from the tower nearest to the incident.
Some models have the ability to process meteorological data from multiple data points. The results of these models improve as they process more data defining the regional wind field.

Fire stations, used by emergency responders, are uniformly located throughout a community. Locating towers to measure wind speed, wind direction, and temperature at each fire station would provide ability to sample the regional wind field for the community or region.
CHAPTER 2

LITERATURE REVIEW

According to the website chemicalspill.org, 90% of hazardous materials injuries are due to inhalation of an airborne contaminate. Airborne contaminant dispersion is determined by the chemical properties of the material and its interaction with the atmosphere. This part of the study focuses on atmospheric science, puff-plume modeling, and meteorological data acquisition.

Atmospheric Science

Atmospheric motion affects dispersion. Wind speed, wind direction, turbulence or atmospheric stability, ground roughness, and temperature inversions are just a few of the factors involved. The physics of atmospheric motion are force, friction, stress, centripetal acceleration, and the inertial forces acting on air molecules.

The Navier-Stokes equations Eq. (1-3) and the continuity equation Eq. (4) are the fundamental partial differential equations that describe the flow of fluids and are commonly used to model atmospheric motion. These equations result from a simplification of atmospheric physics by assuming, incompressible, viscous flow,
and constant physical properties. The conservation of mass, momentum, and energy laws are satisfied by the Navier-Stokes equations.

The full form of these equations is given by Randerson [1]. He explains that the total derivative on the extreme left side of each equation represents the time rate of change of the speed of an individual particle of air, including the change in velocity due to advection. The right hand side terms represent pressure gradient force (where $\rho$ is atmospheric density, $P$ is pressure), Coriolis effect $fv$ and $fu$, gravitational force $g$ (away from and toward the earth only) and the forces due to viscosity (where $\nu$ is the kinematic coefficient of viscosity). Where $u$, $v$ and $w$ are the components of the wind in the $x$, $y$, and $z$ directions respectively. Finally, he explains that the continuity equation states that if fluid comes into or out of a region, the mass must be conserved. The governing equations are typically written in the form

$$\frac{Du}{Dt} = \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z}$$

$$= -\frac{1}{\rho} \frac{\partial P}{\partial x} + fv + v \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right)$$ (1)

$$\frac{Dv}{Dt} = \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z}$$

$$= -\frac{1}{\rho} \frac{\partial P}{\partial y} - fu + v \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2} \right)$$ (2)

$$\frac{Dw}{Dt} = \frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z}$$

$$= -\frac{1}{\rho} \frac{\partial P}{\partial z} - g + v \left( \frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2} \right)$$ (3)
Various methods are used to find solutions for these equations or to reduce them to even simpler forms. Numerous atmospheric models have been based on solutions to one or more of these methods. Finite element, finite difference, direct solutions, and meshless methods have all been used.

The finite element method has been used successfully to solve the Navier-Stokes equations. A three dimensional solution was shown by Shi [2] using techniques discussed in The Finite Element Method [3]. A moving mesh, finite element method is presented by Yana et al [4].

The finite difference method has also been used to find solutions for these equations. A modified two dimensional layer model was shown by Pepper [5]. A one dimensional case for modeling the atmospheric boundary layer is discussed in Small Scale Processes in Geophysical Fluid Flows [6].

A two dimensional direct solution to the Navier-Stokes equations was shown by Jean Leray in 1933 and the analog three dimensional solution is a Clay Mathematics Institute millennial problem, www.claymath.org/millennium/Navier-Stokes_Equations.

One of the more recent methods of solving Navier-Stokes equations is the use of meshless methods not requiring a computational grid. An overview of this method combined with parallel processing is given by Turkiyyah et al. [7]. Solution of the two-dimensional incompressible Navier-Stokes equations is presented by Shu et al. [8]. A meshfree method using a non-conforming uniform rectangular grid that satisfies all prescribed boundary conditions is presented by

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0
\]
Tsukanov et al. [9]. A comparison and evaluation of the performance of two meshless methods is provided by Li et al. [10]. While still in its infancy, the meshless method appears promising for applications to dispersion meteorology and emergency response.

Atmospheric Puff Plume Modeling

Many types of dispersion models exist. Some use hand calculations, others use complex algorithms and powerful computers; several apply a guide book approach. Some model a pollutant release at a fixed site. Others are used for emergency planning or response purposes. This thesis studies emergency response models.

One of the main purposes of a computer based emergency response model is to provide the user with the ability to see or visualize the probable movement of an airborne release. Not all airborne releases can actually be seen in a physical sense. However, with computer modeling, a graphic image may be created that shows a predicted path. The actual path taken is determined by wind, temperature, humidity, terrain, and chemical properties of the substance. A release typically spreads in a downwind and crosswind manner except when the wind speed is low. Then it may spread in any direction and some models reflect this by showing a circular dispersion pattern around the release site. When released material is much heavier than air and wind speed is low, dispersion typically flows as a fluid following terrain features. The release rate or release
duration, size, and chemical properties may result in an instantaneous puff or a sustained plume.

Basic Principles

Atmospheric diffusion is a complex process. Material released from a source occupies a certain volume and when mixed with air has a concentration value. As the puff or plume is mixed with air, the entrained air causes the volume to increase while the overall concentration decreases. The concentration is non-uniform across the volume because the mixing normally occurs near the edges lowering the edge concentration.

For emergency responders analyzing a release to determine where a pollutant will go and how rapidly it decreases in concentration establishes the areas or zones of risk for the community. To help define these areas or zones diffusion models have been developed.

For many years, the Gaussian diffusion equation, Eq. (5), has been used to model pollutant releases. The basis of Gaussian diffusion comes from classical diffusion theory solutions, based upon a parabolic diffusion equation with constant diffusivity using the central limit theorem of statistics for time averaged concentrations. The analytical Gaussian equation derived from simplification of the fundamental physics leads to modeling limitations.

Randerson [1] shows the derivation of the Gaussian plume expression from the time integral for a continuous point source of strength \( Q \) [g s\(^{-1}\)], at effective height \( h \) above the ground, located at \((0, y_0, h)\) in a uniform transport wind, \( \bar{u} \), with no material boundaries as yielding a concentration \( C \) of:
The symbols $\sigma_y$ and $\sigma_z$ are lateral and vertical standard deviations of the distribution $C$ in the $y$ and $z$ directions and are given as functions of downwind distance and stability, $\sigma_y(x)$ and $\sigma_z(x)$. The standard deviation of the lateral (crosswind, $y$ direction) concentration at a distance $x$ downwind ($x = 0$ at the source) is $\sigma_y$. The standard deviation of the vertical ($z$ direction) concentration at a distance $x$ downwind is $\sigma_z$. The $\sigma_y$ and $\sigma_z$ values describe how the dispersion cloud increases in size and becomes more dilute as it travels downwind.

Careful selection of the diffusion parameters based on the atmospheric stability, travel distance, surface conditions, wind, temperature, cloud cover has been extensively studied. Typically, the Pasquill-Gifford (P-G) [1] curves which assign an atmospheric stability letter associated with these conditions is used. These curves typify the atmospheric stability for about one hour. The curves are normally shown with stability class experimental data plotted as a solid line at distances below 1 km and dashed lines shown for data points beyond 1 km to reflect data interpolation as there is little basis in the observed data.

The Handbook on Atmospheric Diffusion [11], provides analytical estimating formulas, shown in Table 1, for computing $\sigma_y(x)$ and $\sigma_z(x)$ for distances ranging between $10^2 m < x < 10^4 m$. Briggs developed these formulas by combining the Pasquill curves with Brookhaven National Laboratory curves, Tennessee Valley Authority curves and theoretical concepts. However, the Handbook on
Atmospheric Diffusion recommends that when turbulence measurements are available it is preferable that $\sigma_y$ and $\sigma_z$ be estimated by using the standard deviations of wind direction fluctuations in the horizontal $\sigma_\theta$ and vertical $\sigma_\varphi$ directions.

Table 1. Formulas Recommended by Briggs

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<th>$\sigma_z(x)$, m</th>
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<td>Open-Country Conditions</td>
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<td>$0.22x(1 + 0.0001x)^{-1/2}$</td>
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</tr>
<tr>
<td>B</td>
<td>$0.16x(1 + 0.0001x)^{-1/2}$</td>
<td>$0.12x$</td>
</tr>
<tr>
<td>C</td>
<td>$0.11x(1 + 0.0001x)^{-1/2}$</td>
<td>$0.08x(1 + 0.0002x)^{-1/2}$</td>
</tr>
<tr>
<td>D</td>
<td>$0.08x(1 + 0.0001x)^{-1/2}$</td>
<td>$0.06x(1 + 0.0015x)^{-1}$</td>
</tr>
<tr>
<td>E</td>
<td>$0.06x(1 + 0.0001x)^{-1}$</td>
<td>$0.03x(1 + 0.0003x)^{-1}$</td>
</tr>
<tr>
<td>F</td>
<td>$0.04x(1 + 0.0001x)^{-1}$</td>
<td>$0.016x(1 + 0.0003x)^{-1}$</td>
</tr>
<tr>
<td>Urban Conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-B</td>
<td>$0.32x(1 + 0.0004x)^{-1/6}$</td>
<td>$0.24x(1 + 0.001x)^{-1/6}$</td>
</tr>
<tr>
<td>C</td>
<td>$0.22x(1 + 0.0004x)^{-1/6}$</td>
<td>$0.20x$</td>
</tr>
<tr>
<td>D</td>
<td>$0.16x(1 + 0.0004x)^{-1/6}$</td>
<td>$0.14x(1 + 0.0003x)^{-1}$</td>
</tr>
<tr>
<td>E-F</td>
<td>$0.11x(1 + 0.0004x)^{-1/6}$</td>
<td>$0.08x(1 + 0.00015x)^{-1}$</td>
</tr>
</tbody>
</table>

Klug described the governing physics of atmospheric modeling for emergency response using a Gaussian diffusion mathematical model similar to Eq. 5, in a paper [12] published as part of the proceedings relating to the course on atmospheric dispersion of hazardous / toxic materials from transportation accidents given at the International Center for Transportation Studies (ICTS) in Amalfi, Italy in 1983.

12
For handling buoyant plumes additional physics are needed. Numerous papers have been written describing buoyant plumes and ways to model fire plumes. A computational model for the rise and dispersion of wind-blown, buoyancy-driven plumes was provided by Zhang and Ghoniem [13]. Quintier and Grove provide correlations for fire plumes [14].

The National Institute of Science and Technology (NIST) have developed a numerical CFD model named Fire Dynamics Simulator (FDS) that provides graphical solutions to Navier-Stokes equations resulting from buoyant plumes. More information about the NIST FDS model is available at fire.nist.gov/fds/.

Another CFD model was described in a paper that shows results of an urban emergency response model being developed by researchers from the National Atmospheric Release Advisory Center at Lawrence Livermore National Laboratory was presented at the American Meteorological Society meeting in 2004 [15].

Emergency Responder Needs

When a hazardous material release occurs, emergency responders need to know where the release occurred, when it occurred, where the pollutant is predicted to go, how rapidly it is dispersing, what type of release was involved, and what the predicted concentration values are. Then they can determine the best course of action to protect the public and themselves. The National Fire Protection Association provides emergency responders guidance for the development of standard operating procedures [16], a recommended practice for responding to hazardous material incidents [17], standards for professional
competence of responders to hazardous material incidents [18], standards for EMS personnel responding to hazardous material incidents [19] and a hazardous materials response handbook.

According to survey data collected by the National Fire Protection Association, municipal fire departments responded to 22,406,000 emergency calls during 2003 [20]. Only 349,500 or 1.56% were hazardous material response calls (e.g., spills, leaks). Information about hazardous material calls was first collected 1986. These calls have increased more than 200% from 171,500 in 1986 [21] to 349,500 in 2003.

Public Law 106-398, Section 1701, Section 33 (b) was enacted to assess the needs and response capabilities of the U.S. Fire Service. This law required the Federal Emergency Management Agency, the U.S. Fire Administration, and the National Fire Protection Association to conduct the assessment. They developed and mailed a survey to 26,345 fire departments. They received 12,240 surveys or 46% back. In their report [22], they found 23% of the fire departments do not respond to hazardous material incidents (mainly small communities), approximately 40% of fire department personnel lack training in hazardous material response, 80% of fire department responders to hazardous material incidents are not trained to the operational level and only 3% to the technician level. This is key as hazardous material technicians are those persons who respond to releases or potential releases of hazardous materials for the purposes of: (1) surveying the incident; (2) classify materials; (3) verify concentrations; (4) collect information; (5) determine extent of damage to containers; (6) predict
behavior of released material; (7) and estimate the size of an endangered area using computer modeling, monitoring equipment or specialists in these areas [18]. They establish recommendations for hot, warm, and cold control zones based on the modeled results. These zones safeguard the public and responders by excluding or restricting access, establish protective equipment levels, a decontamination area, access control points, and a command post. Hazardous material technicians are expected to use computer modeling to estimate the likely size, shape, concentrations, and the potential harm in the hot control zone (endangered area). Based on this information the study found that only a few of the fire departments are capable of performing atmospheric modeling in house or use the resources of others.

Supplement 7 in the National Fire Protection Associations Hazardous Materials Response Handbook [23] describes typical steps involved in the hazard analysis process. The handbook also provides historical data that identifies the top 10 chemicals, as shown in Appendix A, involved in 49.5% of in-facility and in-transit incidents and found those same 10 chemicals accounted for 35.7% of the human injury or death events. According to the supplement, determining the hot zone, where the potential for injury or death to humans is greatest, is the part of the analysis that is the most challenging. A report by the U.S. Fire Administration found this to be one of the greatest challenges faced by the emergency responders who responding to a massive leak of liquefied chlorine gas in Henderson, NV on May 6, 1991 [24].

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Once the material is identified and a hot zone determined, an emergency responder or a hazardous material technician will present the assessment. In presenting the assessments results, the following questions should be answered: (1) what information is needed; (2) when is it needed; (3) how can it best be represented; (4) and how useful is it. A study by the National Institute of Science and Technology examined the answer to these questions and the role technology plays to satisfy these needs [25].

The information needed by emergency responders’ changes depending on their current operation stage. Information is used to determine resource assignments and strategies to be employed. Emergency responders need information such as event location, size, source, source strength, current event status, probable areas affected, the proximity of the public within and near these affected areas, the proximity of important structures, and current meteorological conditions. Answers to these questions are used to determine staging areas, evacuation or shelter-in-place regions, and resource assignments. The incident commander needs to know the location and rate of spread so that crews and the public are kept as safe as possible. The public perspective of emergency responders is that they will keep them safe from the ever increasing threats by terrorists and from accidental hazardous material releases. To accomplish these goals, emergency responders need to have access to as much information as possible. Providing emergency responders with simple tools such as with real-time wind data coupled with rapid puff-plume dispersion models, provides
information needed for risk assessment, evacuation, shelter in place and possible remediation.

Improving the type of hazardous material incident information made available to the fire service enhances safety, effectiveness, and leads to better tactical decisions. One way to accomplish this is to combining incident information with technology to produce clear useable displayable results.

This starting to occur as fire apparatus is being fitted with wireless mobile computers and onboard GPS tracking devices. The fire service needs assessment [22] found with respect to technology that 40% of the fire departments do not have internet access, that 3% have mobile data terminals with 78% indicating no plans to acquire them, and that only 4% have the capability to collect and analyze chemical and biological samples remotely. For the few departments that have mobile data terminals using technology should enhance emergency response.

The result of combining information with improved technology is displayable information that is scalable, reliable, and consistent. Fire service display interfaces vary from pagers, wireless PDA's, cell phones, wireless handheld, and laptop computers to full workstations. The range in display interfaces and multiple transmission means (from low bandwidth wireless to broadband hardwired) result in the need for scalable technologies that provide essential information across a broad array of platforms.

The level of information provided and displayed should match the sophistication of the device being employed. Simple devices should receive only
key pieces of information such as location, size, source, probable areas affected in a textual format. Laptop and handheld wireless computers limited by bandwidth should receive information scaled appropriately to enable a fast response time. Workstations with high bandwidths should receive the most sophisticated level of information. Information prioritization is essential for all display levels.

Varying environmental conditions can affect the functionality of these displays. Low lighting levels, inclement weather, mechanical vibrations affect touch screens. These conditions can affect the information available and the user interface. Consideration should be made to account for decreased functionality. Field deployed technologies should require few user interactions to produce useable, displayable results.

The type of information displayed should be a predictive environmental model that is reliable and near real-time. The output from the predictive model should range from textual information through a footprint picture of environmental conditions overlaid on GIS maps of the region. Graphical representations of data rapidly convey much more information than textual data.

Model Development

Experience with one atmospheric model used by emergency responders lead to the idea that it may be possible to develop a better model. The concept for this model was an emergency response wind field computer model to enhance homeland security. The objectives for this model were a computer code that would run on a standard desktop, laptop, or PDA computing device. This model
would provide relatively accurate and quick evaluation of atmospheric conditions. Wind field data from meteorological towers located at neighborhood fire stations could be used to produce terrain following velocity fields. Incorporating a puff or plume dispersion model requiring little operator entry would enable real-time trajectory release predictions for hazardous materials. The model would then graphically display wind velocity vectors coupled with the modeled puff or plume to enable responders to assess challenging situations.

During the course of performing this research, computer models were investigated and studied. Several good models were found with some including real-time weather data. Instead of developing a model as originally intended, excellent models were found. Teams of programmers and project support staff constantly maintain these models. With some of them, the end user documentation is good. These tools can provide an excellent source of information for emergency responders. These models were found to meet many of the outlined objectives so a computer model was not developed.

Existing Models

As this research progressed, it became apparent that numerous emergency response models exist as listed in Table 2. These models range in complexity from look up tables specifying a predefined hazard zone found in the Emergency Response Guidebook [26] to highly complex computer puff-plume models. The "Directory of Atmospheric Transport and Diffusion Consequence Assessment Models," prepared by the National Oceanic and Atmospheric Administrations' Office of the Federal Coordinator for Meteorological Services and Supporting
Table 2. Emergency Response Models

<table>
<thead>
<tr>
<th>Model</th>
<th>Model Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALOHA</td>
<td>Gaussian</td>
</tr>
<tr>
<td>DEGADIS</td>
<td>Gaussian (Dense Gas)</td>
</tr>
<tr>
<td>Emergency Response Guidebook</td>
<td>Predefined Tables</td>
</tr>
<tr>
<td>HPAC</td>
<td>Second Order Closure Integrated Puff</td>
</tr>
<tr>
<td>HYSPLIT</td>
<td>Eulerian and Lagrangian</td>
</tr>
</tbody>
</table>

Research [27] provides a very good starting point when searching for a computer based model. The directory describes the strengths, weaknesses, ease of use, estimated amount of training required, quality control, modeling capability, buoyant plumes vs. non buoyant plumes, chemical source terms, radiological source terms, weapons source terms, dispersion sub models, transport sub models, and more.

This study investigated the models listed in Table 1, to determine their capability. After careful evaluation, the investigation focused on only one model ALOHA. This model was selected because of its common use for emergency response and its wide spread support by the Environmental Protection Agency and National Oceanic and Atmospheric Administration (NOAA) for use by emergency responders. In the early 1980's, NOAA discovered that fire departments and other response agencies did not have critical information about chemicals. They also recognized the need for emergency responders to have a toxic air dispersion model to predict potential threat areas therefore ALOHA was developed as a response tool.
ALOHA Model

Areal Locations of Hazardous Atmospheres (ALOHA) is a public domain emergency response computer based model. It provides a dispersion estimate of hazardous releases.

The National Oceanic and Atmospheric Administration (NOAA) developed ALOHA in 1982 for emergency responders. ALOHA models a neutrally buoyant or light gas that is assumed to be released from a continuous point source with a Gaussian plume distribution. The physics for this model are described in the Handbook on Atmospheric Diffusion [11], as shown in Eq. 6, as a modified time dependent Gaussian equation. The variables of Eq. 6, are: (1) continuous source strength, Q; (2) effective height, h; (3) downwind wind speed, \( \bar{u} \); (4) downwind direction, \( x \); (5) horizontal or crosswind direction, \( y \); (6) vertical height above the ground, \( z \); (7) lateral diffusion or standard deviation in the \( y \) direction, \( \sigma_y \), a function of distance \( x \); (8) vertical diffusion or standard deviation in the \( z \) direction, \( \sigma_z \), a function of distance \( x \); (9) all yielding the concentration, \( C \). In 1987, the Environmental Protection Agency (EPA) Office of Emergency Preparedness and Prevention joined with NOAA to co-develop ALOHA. In 1991 it was re-written to incorporate a heavier than air model.

\[
C(x, y, z) = \frac{Q}{2\pi \sigma_y \sigma_z \bar{u}} e^{-\frac{y^2}{2\sigma_y^2}} \cdot \left[ e^{\frac{-(z-h)^2}{2\sigma_z^2}} + e^{\frac{-(z+h)^2}{2\sigma_z^2}} \right]
\]  

The physics for the heavier than air model are described in the U.S. Coast Guard Report titled, Development of an Atmospheric Dispersion Model for
Heavier-than-Air gas mixtures [28]. Heavier than air gas information is provided in Appendix B. Incorporating a heavier than air model into ALOHA strengthened the models capabilities. Throughout the years, several academic institutions and emergency response organizations have continued to develop it. The refinement continues to this day. Today ALOHA incorporates source strength along with the modified Gaussian Puff, Gaussian Plume and heavy gas dispersion models and over 700 chemicals in an integrated chemical property library.

The ALOHA software and documentation is available for download from the EPA website www.epa.gov/ceppo/cameo/aloha.htm. Links on the site are provided to training materials for instructors including complete slide show presentations. Numerous websites provide instructional information regarding the use of ALOHA. One example is the website chemicalspill.org, which was originally funded by a grant to the Phoenix Fire Dept as part of the BOLDER Project, which was part of the EPA's Common Sense Initiative. Don't Waste Arizona, Inc., a non-profit environmental organization involved with emergency planning issues, was a participant in the Common Sense Initiative currently maintains the site for use by FEMA and others. The contents of Chemicalspill.org were reviewed and approved by EPA and the Phoenix Fire Department. [S.Brittle DWAZ President (personal communication via email, March 2005)].

ALOHA software operates quickly on small computers. The software operates on both PC and Macintosh computers and is easy to use. Its algorithms represent a compromise between accuracy and speed. It produces results quickly enough to be of immediate use to responders. It checks and cross checks
user data entry providing prompts, warning and caution messages to minimize operator error. The simplified physics used to develop the analytical Gaussian diffusion equation incorporated within ALOHA enable quick calculations but also result in severe modeling limitations.

ALOHA uses as an input, a user entered level of concern (LOC), or one from its chemical library to determine the potential health effects from chemical inhalation at various distances from a source. A LOC is a chemical specific, concentration, and exposure time predicted to result in specific health impacts. Over one-third of the chemicals in the ALOHA chemical library provide an immediately dangerous to life or health (IDLH) LOC. An Emergency Response Planning Guideline (EPRG) LOC value is provided for nearly 35 common chemicals. The IDLH LOC values were defined by the National Institute for Occupational Safety and Health (NIOSH). The ERPG LOC was established by a committee within the American Industrial Hygiene Association providing a three-tier standard with a 1-hour contact duration. Some models use dose which combines both concentration and exposure time. ALOHA uses the LOC to estimate areas of concentration, to indicate the potential scale of a hazard.

ALOHA has many desirable attributes. Emergency responders can deploy it rapidly. A variety of chemical source types is available to select from in the software library. ALOHA models dispersion of both neutrally-buoyant and heavier-than-air gases and predicts indoor and outdoor ground-level chemical concentrations. Display types range from textual outputs to a footprint map. An example of a footprint map is shown in Fig. 1. ALOHA accounts for outward
dispersion along the wind trajectory and the effects of vertical wind shear. The model uses meteorological data to perform calculations and can accept meteorological data transmitted from portable monitoring stations. When accepting data, the model uses a 5 minute $\sigma_{0}$ (sigma-theta) adjusted by wind speed and surface roughness to select the Pasquill-Gilford-Turner stability
class. In the absence of $\sigma_g$ measurements, the model estimates the amount of
turbulence due to solar radiation by using cloud cover, time, date, longitude, and
latitude. ALOHA uses elevation to estimate ambient air pressure.

ALOHA predicts the effect of an outdoor gas cloud on indoor concentration
and dose by using building air exchange rate or common type of building.
ALOHA allows the user to enter in different air exchange rate data to make
calculations. When using the common type of building method in ALOHA the
software has settings (different rates of air exchange for various types of
buildings) already built into the program. Enclosed office buildings, sheltered or
unsheltered, have an air exchange rate of 0.50 times per hour. This means that
the air inside the enclosed office building is expected to change out twice per
hour. For a single storied building sheltered by trees or shrubs, the rate of air
exchange is 0.52 times per hour. For an unsheltered single story building, the
rate is 0.62 times per hour. A double storied sheltered building has 0.37 air
exchanges per hour, and 0.44 air exchanges per hour for an unsheltered double
storied building.

ALOHA has several severe limitations. It assumes the topography is flat and
unobstructed. It cannot account for wind speed and direction shifts due to terrain
or upper air steering. The model allows the user to specify a surface roughness,
which it then assumes, is constant. These assumptions introduce errors due to
fluctuations in the amount of mechanical turbulence or drag caused by the
ground roughness, buildings, and vegetation. ALOHA assumes a uniform
horizontal mean wind speed and direction. Conservative estimates of dispersion

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meander under low wind conditions result in a predicted large area of influence due to this assumption. ALOHA does not model particulate transport including particulates from a radiological release. It also assumes that no deposition or scavenging occurs, and it cannot model initial positive buoyancy of a gas. Momentum jets or concentration patchiness are not accounted for. Chemical reactions and mixtures cannot be modeled but the model provides warnings when air and water reactive chemicals are involved. ALOHA cannot model dispersion of chemicals involved in fires. The minimum wind speed is 2.13 mph, warning messages are displayed when the wind speed is 67 mph or more with the maximum possible wind speed of 134 mph [29]. The minimum and maximum release duration modeled ranges between 1 minute and 1 hour. The minimum and maximum distance modeled on a footprint plot ranges between 100 meters and 10 kilometers. An example of the 10 Km limit is shown in Fig. 2. The model will provide text output for distances less than 100 meters but not footprint plots. The maximum distance limit is due to the lack of actual dispersion data across the stability classifications beyond 10 kilometers. These limitations are due to analytical simplifications to the macro-scale Navier-Stokes and continuity equations resulting in a micro-scale Gaussian diffusion equation.
ALOHA, displays consist of a text summary, dispersion footprint, concentration vs. time, dose vs. time and source strength vs. time. A text summary example is shown in Fig. 3.

ALOHA uses atmospheric parameters of stability class, inversion height, wind speed and direction, air temperature, ground roughness, cloud cover and relative humidity in making computations. The source can be a direct point release, a puddle of evaporating liquid, a release from a tank, or a release from a pipe.

Figure 2. ALOHA Footprint Plot – 10 Km Limit

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SITE DATA INFORMATION:
Location: LAS VEGAS, NEVADA
Building Air Exchanges Per Hour: 0.34 (sheltered single storied)
Time: March 22, 2005 0650 hours PST (using computer's clock)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE
Molecular Weight: 70.91 g/mol
ERPG-3: 20 ppm
ERPG-2: 3 ppm
ERPG-1: 1 ppm
IDLH: 10 ppm
Carcinogenic risk - see CAMEO
Normal Boiling Point: -29.3° F
Ambient Boiling Point: -32.2° F
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 2.13 mph from SSE at 28 Ft
Stability Class: B
Relative Humidity: 41%
Cloud Cover: 7 tenths
No Inversion Height
Air Temperature: 54.6° F
Ground Roughness: urban or forest

SOURCE STRENGTH INFORMATION:
Puddle Diameter: 28 feet
Puddle Volume: 55 gallons
Soil Type: Moist
Ground Temperature: 54.6° F
Initial Puddle Temperature: -32.2° F
Release Duration: 5 minutes
Max Average Sustained Release Rate: 257 pounds/min
(total averaged over a minute or more)
Total Amount Released: 717 pounds

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
Red LOC (20 ppm = ERPG-3) Max Threat Zone: 090 yards
Orange LOC (3 ppm = ERPG-2) Max Threat Zone: 1.2 miles
Yellow LOC (1 ppm = ERPG-1) Max Threat Zone: 1.8 miles

Figure 3. ALOHA Text Output

ALOHA has undergone extensive quality assurance benchmarking, model comparison and field data testing. It is in use in the U.S. and throughout the world. Testing and model validation continue in an effort to reduce the probability of model errors. However, efforts to incorporate more physics into the model, especially for variable advection, will require a numerical approach in lieu of using analytical simplification.
Meteorological Data Acquisition

The rule of thumb that bad information input into a model will result in bad information output from a model is true also of atmospheric dispersion models. Meteorological data including wind speed, wind direction, and temperature are needed for accurate modeling.

The data can come from various sources. Potential sources include airport data, national weather service data, local air quality monitoring stations, and site specific installations. The reliability, accuracy, and representativeness of many of these sources are questionable.

Data Sources

Real-time meteorological data can be obtained from meteorological stations and the National Weather Service. Much information is already available on the web – thus permitting wireless access to pertinent meteorological information for the specific location.

Properly located, site specific installations can provide the most representative and usually most reliable data. Several sources of good information for siting meteorological stations exist. One source of guidance for installing meteorological stations comes from the Meteorological Monitoring Guidance document published by the United States Environmental Protection Agency, Office of Air Quality Planning and Standards [30]. Some of the information offered in the report provides guidance and information on the instrumentation used and siting. It recommends types of instrumentation to use, instrumentation tolerance, mounting height, including mounting height for stability.
analysis, distances from obstructions, and length of time for site representativeness.

Data from Meteorological Instruments

The monitoring guidance recommended minimum measurement length of time for site representativeness is one year of site specific data. However, only current conditions are needed for real time emergency response puff/plume modeling.

The monitoring guide recommendations for measurement of wind speed and direction are the use of a three cup anemometer for speed and a conventional vane for direction to measure the vector quantities independently. Wind speed sensors should have a high accuracy at low wind speeds and a low starting threshold of \( \leq 0.5 \text{ m/s} \). Wind direction sensors should be light weight wind vanes with a starting threshold of 0.5 m/s for a 5° change, overshoot of \( \leq 25\% \) and damping ratio between 0.4 and 0.7.

The recommended mounting height for wind speed and direction instruments is a height of at least 10 m above grade for open terrain. Further guidance suggests that instruments should be separated a distance of ten times the height of adjacent obstructions.

The guide does not recommend siting towers on top of buildings due to aerodynamic wake effects. On-site smoke release measurements, wind tunnel studies, and computer modeling can determine wake effect. Building wake depth is conservatively estimated at 2.5 times the building height. For a 20 foot tall building, the anticipated wake would be 50 feet. A 10 meter tower would be
within this wake. A specific study of aerodynamic wake effects for roof mounted meteorological equipment should be performed.

Temperature instrumentation recommendations are for the use of aspirated radiation shielded resistance temperature devices. Temperature sensors are recommended to be a distance of four times the height of nearby obstructions and at least 30 m from large paved areas.

Temperature difference measurements are required at two levels when used to estimate surface layer scaling parameters or when used to estimate the Pasquill-Gifford (P-G) stability category using the solar radiation delta-T method shown in Tables 3 and 4, [30].

The recommended heights for these vertical temperature gradient measurements are 2 m and 10 m. This corresponds to a site with low surface roughness $z_o$ of 0.1 m using the Monin-Obukhov similarity relationship $20 \cdot z_o$ for the lower measurement and $100 \cdot z_o$ for the upper measurement.

Table 3. Daytime, Solar Radiation Method for Estimating P-G Stability

<table>
<thead>
<tr>
<th>Wind Speed (m/s)</th>
<th>Solar Radiation (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>≥ 925</td>
</tr>
<tr>
<td>&lt; 2</td>
<td>A</td>
</tr>
<tr>
<td>2 - 3</td>
<td>A</td>
</tr>
<tr>
<td>3 - 5</td>
<td>B</td>
</tr>
<tr>
<td>5 - 6</td>
<td>C</td>
</tr>
<tr>
<td>≥ 6</td>
<td>C</td>
</tr>
</tbody>
</table>

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Table 4. Nighttime, Delta-T Method for Estimating P-G Stability

<table>
<thead>
<tr>
<th>Wind Speed (m/s)</th>
<th>Vertical Temperature Gradient</th>
<th>&lt; 0</th>
<th>≥ 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2.0</td>
<td>E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0 – 2.5</td>
<td>D</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>≥ 2.5</td>
<td>D</td>
<td></td>
<td>D</td>
</tr>
</tbody>
</table>

The Monin-Obukhov similarity theory has been in existence for over 50 years [31]. The Monin-Obukhov similarity theory is a universal length scale for exchange processes in the surface layer. The Monin-Obukhov similarity relationship provides a mathematical means or description for re-scaling some of the statistical properties of undisturbed turbulent flow within the region that is above the surface roughness elements yet low enough to be within the surface layer. The relationship provides a way to organize and group variables due to consistent and repeatable characteristics within the surface layer. Equation 7, also know as the Monin-Obukhoff (M-O) similarity law for the constant flux or the surface layer is provided in [6] as:

\[
\Phi_F = \frac{kz}{k_s} \frac{\partial F}{\partial z} = \Phi_F \left( \frac{z}{L} \right) = \Phi_F (\zeta)
\]  

(7)

Equations 8, shows the normalized flow profiles for velocity, temperature, humidity and gas concentration respectfully as:
The similarity variable is \( \zeta = z/L \). The Obukhoff length scale or \( L \), shown in Eq. 9, characterizes the effects of stratification.

\[
L = -\frac{\frac{u_*^3}{K} \frac{1}{\text{Pr}} \frac{g}{T_o} \frac{w'T'}{c_p \rho}}{\frac{L}{g}}
\]

The length scale, \( L \), is positive for stable conditions (usually at night), negative for unstable conditions (usually daytime), and approaches infinity for neutral conditions (dawn and dusk transition periods and cloudy, windy conditions) [11].

After the development of the similarity theory, experimental efforts were used to determine universal functions. Based on experimental data, Businger et al. developed universal functions. Due to criticism of the experimental data, the universal functions were re-formatted [31] as shown in Eqs. 10 and 11. The re-formatted velocity and temperature functions are based on \( K = 0.40 \), the von-Kármán-constant, and \( \text{Pr}^{-1} = 1.05 \), the Prandtl-number.

\[
\Phi_M \left( \frac{z}{L} \right) = \begin{cases} 
\left(1 - 19.3 \frac{z}{L}\right)^4 & -2 < \frac{z}{L} < 0 \text{ unstable} \\
\left(1 + 6 \frac{z}{L}\right) & 0 < \frac{z}{L} < 1 \text{ stable}
\end{cases}
\]
As shown in [32] using Eqs. 10 and 11, and the relationship shown in Eq. 12, from [11].

\[
\frac{z}{L} = \frac{R_i}{1-5 \cdot R_i} \quad \text{stable}
\]

Equations 10 and 11 then become Eqs. 13 and 14.

\[
\Phi_H\left(\frac{z}{L}\right) = \begin{cases} 
0.95 \cdot \left(1 - 11.6 \frac{z}{L}\right)^{\frac{1}{2}} & -2 < \frac{z}{L} < 0 \text{ unstable} \\
0.95 + 7.8 \frac{z}{L} & 0 < \frac{z}{L} < 1 \text{ stable}
\end{cases}
\]

\[
\Phi_M\left(\frac{z}{L}\right) = \begin{cases} 
(1 - 19.3 \cdot R_i)^{\frac{1}{4}} & -2 < \frac{z}{L} < 0 \text{ unstable} \\
-\frac{1 + R_i}{(1 + 5 \cdot R_i)} & 0 < \frac{z}{L} < 1 \text{ stable}
\end{cases}
\]

\[
\Phi_H\left(\frac{z}{L}\right) = \begin{cases} 
0.95 \cdot \left(1 - 11.6 \cdot R_i\right)^{\frac{1}{2}} & -2 < \frac{z}{L} < 0 \text{ unstable} \\
-\frac{1}{20} \cdot \left(19 + 61 \cdot R_i\right) & 0 < \frac{z}{L} < 1 \text{ stable}
\end{cases}
\]

From which the Richardson number can then be evaluated using Eq. 15.

\[
R_i = \frac{2 \cdot g \left(\overline{z_2} - \overline{z_1}\right) \left(\overline{T_2} - \overline{T_1}\right)}{\left(\overline{T_2} + \overline{T_1}\right) \left(\overline{u_2} - \overline{u_1}\right)}
\]

Meteorological Tower

Site specific meteorological data or incident specific meteorological data are frequently used as input for modeling. Models like ALOHA are capable of
receiving input directly from portable monitoring stations setup at or near the incident. However, for numerous reasons as mentioned previously this data is often erroneous. Permanently installed meteorological towers provide data that are more reliable. As part of this research, a meteorological tower was erected to acquire site specific meteorological data, compare wind data from two elevations, and learn about siting a tower.

A 20 meter tower manufactured by NRG systems, Inc. provided by the UNLV Nevada Center for Advanced Computational Methods (NCACM) was used. The NRG tower manual [33] provided siting, anchoring, and installation information. The manual also provided information needed to obtain a building permit.

The NCACM had another tower that was not in use at the time the tower for this project was in use. This enabled the tower to be instrumented with two sets of sensors for monitoring two elevations for data comparison.

The location selected to site the tower was the Henderson Nevada Fire Department Training Center, Fire Station 82. This site was selected to demonstrate the benefit of siting meteorological towers at fire station locations.

Summary

Atmospheric spread of a contaminate is determined by the properties of the material and the meteorological conditions at the time of release. Analytical mathematical models exist to represent simplified physical laws that govern contaminate dispersion. Numerous computer programs incorporating various forms of these mathematical models are available for use by emergency
responders. A commonly used atmospheric dispersion computer model is the Areal Locations of Hazardous Atmospheres (ALOHA) model. It quickly produces basic results. However, the simplified physics used to develop the analytical Gaussian diffusion equation incorporated within ALOHA results in severe modeling limitations.

Atmospheric models require meteorological information as an input to perform calculations. Meteorological information is available from numerous sources. Meteorological station siting, plays an important role in the quality of data reported. Federal guidelines provide guidance for site selection, separation distance from obstructions and recommended types of instrumentation to use. Mounting meteorological towers onto building roof is not recommended due to uncertainties of aerodynamic wake effects. A specific study of aerodynamic wake effects for roof mounted meteorological equipment should be performed before permanently siting a tower.

As part of this research, a meteorological tower was erected to demonstrate the benefit of siting a meteorological station at a fire station, to acquire site specific meteorological data, compare wind data from two elevations, and learn about siting a tower.
CHAPTER 3

RESEARCH

Dr. Darrell Pepper, the Director of The University of Nevada Las Vegas, Nevada Center for Advanced Computational Methods (NCACM) provided the concept and idea for an emergency response wind field model. The experience of the faculty, students and staff of the NCACM with dispersion modeling provided a clear vision of the potential benefit an emergency response model could have for the community. Recent research performed by the center focused on predicting winds and air quality for the Las Vegas Valley. This research used a hybrid adaptive of the finite element method [34]. The researchers suggested that other quicker methods for predicting winds and atmospheric dispersion exist that would be better suited for emergency response.

The research path selected led to a literature study, model study, data gathering study, and a meteorological tower study. The literature study, in part was discussed previously, as was a portion of the model study. This chapter discusses the data gathering and tower installation studies.
Data Gathering Study

A key component of real time or near real time atmospheric modeling is meteorological data. Models such as ALOHA and Hazard Prediction and Assessment Capability have built in capability to incorporate current weather. They obtain this data from both portable meteorological stations and airport data respectfully. Others sources of weather data for modeling include Neighborhood Weather Stations, Roman, National Weather Service, and site specific meteorological towers.

Airport Data

Current meteorological airport data is available from the National Weather Service via the internet [35]. However, depending on the airport’s location from the release site significant errors can occur. Researchers in the National Oceanic and Atmospheric Administration, Air Resources Laboratory (NOAA-ARL), Atmospheric Turbulence and Diffusion Division found large discrepancies in wind direction data between meteorological towers sited around downtown Washington D.C. and airport data from Reagan National Airport [36]. The airport is the official source of weather data for downtown Washington D.C. After comparing data for one year, they found consistent wind direction variations of 40 to 90 degrees. They determined that using Reagan National Airport data for plume modeling around downtown Washington D.C. would introduce a high probability of error and would likely cause emergency responders to give inaccurate notification.
DCNet and SensorNet Data

The meteorological data for the Washington D.C. area was gathered through DCNet/UrBANet. An experimental network of meteorological towers placed throughout the D.C. metro area. Some of these 10 meter towers were placed on top of buildings, others were placed in open spaces. The DCNet project was patterned after the Oak Ridge National Laboratory SensorNet project. The SensorNet project instrumented cellphone towers utilizing the communication infrastructure to transmit data. These projects test, evaluate, and acquire meteorological and radiological measurements in an urban environment for use in emergency response modeling [37].

These networks gather meteorological data from met stations placed to sample the regional wind field. This data is then used to model atmospheric dispersion for emergency response when needed. The meteorological data is available on the internet for anyone.

Neighborhood Weather Data

Another source of current meteorological data available to emergency responders is the data gathered through neighborhood weather stations. On August 6, 2002, the National Weather Service (NWS) and the private sector company that operates the neighborhood weather stations, AWS Convergence Technologies, Inc. of Gaithersburg Maryland, announced a public-private partnership designed to strengthen the government's ability to respond. During a hazardous event, real-time weather data from the AWS WeatherNet network is made accessible to emergency responders through the NWS [38]. The AWS
WeatherNet network is primarily located in U.S. metropolitan areas at schools, established in 1993, and currently includes more than 7,000 weather station locations. Several neighborhood weather stations located at schools in southern Nevada participate in the network [39]. In the event of an emergency, real-time access to meteorological data will be granted to Government agencies.

Contacting AWS, Inc. regarding the partnership found that no data is yet accessible through the National Weather Service. However, expensive equipment could be purchased and an agreement entered with them that would yield a meso stream from AWS, Inc. for all their neighborhood weather stations.

The instrument mounting heights, mounting location and clearance from obstructions for most AWS neighborhood weather stations sited at schools are not in conformance with the meteorological monitoring guidance published by the EPA [30]. The recommended mounting height provided as guidance on the AWS website is 10 feet above the roof. This results in the wind sensors installation being too low to the ground and too close to the roof causing the reported wind speeds to be lower than correctly sited instruments. This is documented on the AWS website, www.aws.com/aws_2001/support/faq/TRBLFAQ_A-4.asp, in the question and answer section where the following statement is provided, “The wind speeds on my AWS system are consistently lower than those reported from the airports on TV weather reports. Is something wrong with my system? Not likely. AWS’ systems measure wind speeds very accurately. In typical installations AWS systems are installed in neighborhoods and are influenced by the local terrain. Airport weather stations are typically mounted in the middle of
very large open fields (airfields) with terrain features and tree lines miles away. The airport sensors are also mounted 30' above the ground. In these cases the airport wind speeds are typically higher than those indicated by your AWS system. The AWS system is a true representation of local wind conditions…”

However, according to the Fair Weather report by the National Research Council, the National Weather Service (NWS) and AWS public private partnership is an example of an effective partnership [40]. These types of agreements and partnerships are needed to share resources improving homeland security. Chief meteorologist Mark Eubank of KSL-TV in Salt Lake City Utah spoke about the result of a similar partnership that was established for the 2002 Winter Olympics. In the Fair Weather report, he was quoted saying:

"Working together in the Olympic Partnership has been one of the most rewarding things I have ever done as a meteorologist.... When I first heard the proposal to have academia, government, and the private sector all work together in a common weather forecasting project I was slightly skeptical on how well it would work. As it turned out, that combination yielded greater results than the sum of its parts." [40]

ROMAN Data

Another source of current weather data primarily for western states is the Real-time Observation Monitoring and Analysis Network (ROMAN) internet site [41]. The University of Utah, Department of Meteorology MesoWest project and the National Oceanic and Atmospheric Administration (NOAA) Cooperative Institute for Regional Prediction (CIRP) host the ROMAN internet site. The
MesoWest project is a cooperative project between researchers in the NOAA-CIRP at the University of Utah and forecasters at National Weather Service (NWS) Offices around the west. Numerous governmental agencies, commercial firms, and educational institutions participate in MesoWest [42]. ROMAN consolidates weather observing networks managed by federal, state, local agencies and private firms into one web site. The weather elements emphasized on the site are those most pertinent to fire weather and fire danger.

Use of the ROMAN web site data is provided for governmental agencies to protect lives and property, for the public for general information, and for individuals at educational institutions for instructional and research purposes. The main purpose of the data presented on the ROMAN site is for fire weather professionals and others requiring access to current fire weather conditions around the nation. ROMAN provides weather observations of temperature, relative humidity, wind speed and wind direction, precipitation, and other weather parameters from thousands of locations across the United States. The information provided on the site is very concise.

Available networks in ROMAN are Remote Automatic Weather Stations (RAWS) only, NWS and RAWS, or all Networks. The data is organized by GACC, County Warning Area (CWA), and Fire Weather Zone (FWZ). A user can select the observational networks to display and the amount of data displayed. Once a station is selected from one of the user inter-faces, current weather information is summarized in tabular and graphical forms. Historical data is available for many sites. Data may be output for off-line analysis from the site.

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Tabular summaries for many stations auto-update every 5 minutes; others are updated hourly to provide continuous monitoring. ROMAN may receive data from portable fire Remote Automatic Weather Stations (RAWS) stations as well as permanent RAWS stations to support local fire weather data needs. Station georeferences are updated daily. The site cautions users of the data due to the limitations of the internet since the data may not always be current.

UCAR Data

Another internet site for real-time weather data is the site operated by the National Center for Atmospheric Research (NCAR) and the University Corporation for Atmospheric Research (UCAR) Office of Programs. Their site address for real-time weather data is http://www.rap.ucar.edu/weather/. An example of a large scale surface wind maps is shown in Fig. 4, a screen shot. The screen shot shows wind information graphically using wind barbs. Wind barb symbols give information about wind speed and wind direction in one symbol. The barb points in the direction "from" which the wind is blowing. The barb(s) on the end of the flag pole represents wind speed. Each short barb represents 5 knots, each long barb 10 knots and pennants are 50 knots. The wind speed may be calculated by simply adding the value of each barb together. If no barb is shown for a station circle, the winds are calm. The units for wind speed are expressed in knots, which is 1 nautical mile per hour (1 knot = 1.15 mph = 1.9 Km/Hr). The surface station data is available in raw or converted text format from the individual reporting stations.
National Weather Service Data

Using the latest technology the National Weather Service disseminates climate, water, and weather information in gridded, graphical, and text form.

Access to current weather information is provided through numerous National

The National Weather Service Office of Operational Systems provides the emergency management community with access to almost real time current weather information at no recurring cost through its Emergency Managers Weather Information Network system [44]. The system was developed in partnership with the Federal Emergency Management Agency and other public and private organizations.

Emergency Managers Weather Information Network is intended to be used primarily by emergency managers and public safety officials who need timely weather information to make critical decisions. The service allows users to obtain weather forecasts, warnings, and other information directly from the National Weather Service. It provides round-the-clock data feed of current weather warnings, watches, images, advisories, forecasts, and other products issued by the National Weather Service. Information is provided in an almost real time state as compared to other National Weather Service products.

Emergency Managers Weather Information Network feeds may be obtained through direct satellite broadcast, repeat radio broadcast and feeds directly over the Internet. Some of the Internet methods include Internet push, File Transfer
Protocol (FTP) also known as Internet pull, and Interactive Weather Information Network, or Interactive Weather Information Network.

Predictive Data

Predictive data for the Las Vegas Valley is available through the NOAA Air Resources Laboratory (ARL) Special Operations and Research Division (SORD) located in Las Vegas.

The ARL/SORD website is wwwsordx.nv.doe.gov/arlsord-1.htm; the various missions are displayed. For example, the NOAA ARL SORD office runs the Regional Scale Atmospheric Prediction Model (RAMS) over the Nevada Test Site and the Las Vegas Valley. The Regional Scale Atmospheric Prediction Model (RAMS) produces graphical results for the predictive wind field (speed and direction) over the Las Vegas Valley as shown in Fig. 5. a screen shot. The website is wwwsordx.nv.doe.gov/home_models.htm. The resolution for the model is a 2 km grid box ($\Delta x = 2$ km, $\Delta y = 2$ km).

The NOAA ARL SORD also runs a lightning detection system and the dispersion model HYbrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT). A screen shot of the HYSPLIT model is shown in Fig. 6. Using predictive data from the Regional Scale Atmospheric Prediction Model or similar models can yield powerful results by applying the data to a dispersion model.

Since the Regional Scale Atmospheric Prediction Model predictions are for more than one day, there is some concern as to the accuracy of the data. A comparison between the prediction from a previous day and the data reported on one of the 30 site meteorological towers at the Nevada Test Site showed some
discrepancies in wind speed and direction. These errors were felt to be due to powerful storm front that crossed the region.

Figure 5. Regional Scale Atmospheric Prediction Model - LAS
Figure 6. HYSPLIT Model Screen Shot – Concentration Las Vegas Valley
Another source of predictive data is the forecast model employed by the Las Vegas - National Weather Service (NWS) office. This predictive information source is their graphical prototype forecast product, as shown in Fig. 7.

The NWS model provides predictive wind speed, wind direction, and temperature. The goal for this data is an output resolution using a 5 km grid box. This data can be accessed at www.wrh.noaa.gov/vef/ and selecting the prototype digital forecast. This forecast data may be useful for running predictive models.

Figure 7. NWS Predictive Model Screen Shot – Las Vegas Region

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Application Specific and Site Specific Meteorological Data

Another source for current meteorological data is application specific and site specific data gathered by various organizations or businesses for their own purposes. Some of this information is made available through the internet. For example internet met-data is provided by the Clark County Regional Flood Control District (website www.ccrfcd.org), and the Clark County Department of Air Quality (website www.ccairquality.org). The meteorological stations are owned, operated, and maintained by the respective organization. The cost for operation and maintenance of the stations are borne by each organization.

The Regional Flood Control District collects hydrometeorological data from nearly 140 sites for detecting situations, which could cause flooding. Wind speed and direction data is collected at 24 sites with 12 sites within the Las Vegas area. The District collects data in real-time and the public interface is in near real-time. Current and historical data, the most recent 100 logs, can be examined.

The Department of Air Quality collects data to measure ambient concentrations of pollutants. The monitoring division operates 22 stations within the Las Vegas area. The data is collected in real-time and near real-time. The public interface is near real-time. Current and historical data reported by individual sites can be examined dating as far back as 1996 for some sites.

Other sites around the Las Vegas Valley also have meteorological sensors. One example is the Timet plant near Henderson. Meteorological sensors are installed around the Timet plant for sensing a chlorine release [45]. Timet has one station that provides meteorological information directly to the local fire
department dispatch center. In the event of a release, the chlorine sensors alert
the fire department dispatch center where the dispatchers have the current wind
speed and direction data displayed from the onsite station.

One advantage of site specific and application specific meteorological
monitoring is the ability to have direct access and control of the data stream.
Another is that sites may be selected to provide the greatest representative
sample for the region or area of interest. A disadvantage of the data collected
from other organizations is that the meteorological stations that gather the data
are not sited properly. Many of the wind speed and direction sensors are below
the recommended 10 meter height.

Emerging Data

A future source of meteorological data for southern Nevada may be the
MOSAIC site. The website for MOSAIC is http://www.ciasta.dri.edu/mosaic/.
MOSAIC is underdevelopment by the Desert Research Institute. The goal of
MOSAIC is to provide meteorological data via a webpage interface. This
emerging data source may bring together data for southern Nevada.

Meteorological Tower Installation Study

Dr. Darrell Pepper’s previous experience with an automated emergency
response meteorological system [46] at the U.S. Department of Energy’s
Savannah River Site in Georgia provided a vision for this thesis. At the Savannah
River Site, meteorological data from onsite meteorological towers was gathered
through a VAX microcomputer and used to model the atmospheric dispersion of
releases of hazardous materials from the site. The computer codes used on this VAX microcomputer were retrieved from the tape reel, by Mr. Lee Harris a Lead Programmer and Analyst and Mr. Kim Marshall Director for Utah State University Network and Computing Services, and preserved as part of this study. The emergency response system at the Savannah River Site was later expanded through a meteorological partnership with five counties that surround the site [47] into a mutual aid partnership for emergency response purposes.

Part of this study required working with the Nevada Center for Advanced Computational Methods (NCACM). The NCACM assists the Clark County Nevada Department of Air Quality Management with data gathering and analysis from their meteorological towers. The NCACM also assists the Nevada State Office of Energy (NSOE) with renewable energy wind studies. Through these studies, the NSOE provided two 20 meter meteorological towers to the NCACM. This study installed one of these towers. Site selection, site approvals, site preparation, tower installation, tower removal, site restoration, and data gathering for the tower are discussed below. A photographic depiction of site preparation, tower installation and tower removal is provided in Appendix C.

Site Selection

Dr. Pepper suggested siting the tower at a fire station. Siting meteorological stations at fire stations is logical since fire station locations are typically located throughout the community based on response time. Dispatch time, turnout time, and drive time all contribute to determine response time with drive time typically being the determinant. The typical response time goal is 6 minutes. This can be
approximated using an effective radius, which assumes the city has straight roads and flat geography. However, geographical land features affect the placement of fire stations. Available roads, rivers, lakes, ponds, buildings, street interconnectivity, and terrain all affect station placement. Response times have always been either measured by drawing circles on a map or by actually going out and driving streets.

Fire Stations in the Las Vegas valley are situated in a relatively uniform fashion throughout the region as shown in Fig. 8. Siting a tower at each fire station would provide a representative sample of the regional wind field providing meteorological data that could be easily mapped to grids for ready input into numerical model. Additionally the advantage provided through site specific meteorological towers includes controlling the data stream used to generate wind field inputs for an emergency response model. Having a tower with real-time data should also generate a daily interest in the emergency responders and encourage familiarity for daily firefighting, emergency response, and training needs.
Figure 8. Las Vegas Valley Fire Station Location Map
Consequently, a decision was made to site the tower at the City of Henderson fire station 82, which also serves as the fire training center for the City of Henderson.

This fire station was also selected because the site is large enough to allow the tower to be sited following the guidance from the Environmental Protection Agency [30]. The terrain was mostly flat, open, with a few isolated obstacles, and the occasional large obstacle yielding an estimated surface roughness length $Z_0$ of 0.10 m. Other considerations for selecting this fire station was that it was located in an industrial corridor where approvals for a tall tower were more easily obtained and the site offered greater security.

Towers at fire stations could serve other purposes as well. Providing real-time data at the fire station may assist with training decisions and other emergent fire responses. Additionally towers could be provided with air quality instrumentation in regions not already provided with monitoring equipment. Another purpose for meteorological towers is to perform wind energy analyses.

Site Approval

Numerous approvals are required prior to site a tower at a fire station. Approvals are required from the operator, owner, Community Development Department, Utilities Departments, the Building Official, other impacted organizations, and agencies. To enable their approval, plans are required, descriptions of the work involved, and fees to be paid. The prospective site was researched, zoning maps were obtained along with site drawings, aerial...
photographs, and tower drawings. The various organizations listed above were then contacted to obtain the necessary approval.

Meeting with the Community Development Department was required to determine the entitlements allowed by the zoning of the site. The City of Henderson Development Codes with respect to tower siting are very similar to those used in other Southern Nevada jurisdictions. Meeting with Community Development, it was determined that the site was located in an industrial zoned area. The entitlements of this zoning would allow for the installation for a 20 meter tower without being subject to the public approval process. Most fire stations in the City of Henderson are located in residential zoned areas that require public hearings to install a 20 meter tower. Even a standard 10 meter tower would be subject to the public approval process. Staff level administrative approvals may be granted for small towers of slightly more than 3 meters above the roof line for a building. To avoid building affects on the wind profile the instrumentation needs to be located higher than 3 meters above the roof line, subjecting the installation to the public approval process. This process typically involves public hearings, Planning Commission approval and in some instances City Council approval.

The operator for the site selected was the Fire Department. A meeting with the Fire Department Training Division was undertaken to review the area selected for the site and the impacts to fire training operations. An allowable time table for the tower to be sited was established. The impact to their training operations was the closure of a portion of the driver (Fire Engineer) training
course. Following this meeting, a meeting was held with the Fire Chief to discuss the site selected, review the site drawings, zoning information, aerial photographs, tower drawings, the operational impact, and duration. The Chief agreed in principal to the proposal but shortened the duration, lessening the operation impact on the training center. He then required approval to be obtained from the facility and property owner.

The owner of the site was the City of Henderson. The City of Henderson Property Management Department has legal authority to grant approval to use the site. Meeting with the manager of that department the same information was reviewed as with the Fire Chief. The Manager outlined additional conditions and required that they be outlined in a letter request for approval. The Nevada Center for Advanced Computational Methods sponsored this request for approval. The approval was granted subject to the agreed upon duration, subsequent approval of all other appropriate City Departments, exact site location approved by the Fire Department, site restoration and securing of all permits as required.

Approvals from the other City Departments were obtained by applying for and obtaining a building permit. The building permit was reviewed by the Community Development Department, Utilities Department, New Development Department, Fire Department, and Building Department. Submittal packets were prepared showing zoning maps, site drawings, aerial photographs, tower drawings, tower structural information, anchoring information, and copies of the Property Managers and Fire Chiefs approvals. Each of these Departments reviewed the submittal for compliance to their respective requirements. Additional research
was required to determine if the site location affected a line-of-site data transmission network for the Utility Department. Once approved by all the Departments, fees were paid and a Building Department permit was issued.

The Nevada State Office of Energy was informed that the site was approved and the exact coordinates for the site were given so they could inform the military of the new tower location to be added to their data base.

Site Preparation

Once all the approvals were obtained site preparation began. This included gathering materials, and preparing the site.

The tower materials were secured from the NCACM. A gin pole and winch were required to lift the tower. The Nevada State Office of Energy loaned a gin pole and winch to the Ponderosa Dairy in the Aragosa Valley for raising their tower so arrangements were made to borrow it from them.

Because the NCACM had two towers complete with instrumentation, a decision was made to take advantage of the extra set of instrumentation and install sensors at two heights for comparison. The two heights selected were at the 20 meter height and at the standard 10 meter height. Upon reading the tower and data logger manuals, it was learned that the loggers had an extra input that could be used to gather information from a solar or temperature sensor. The NCACM provided temperature sensors for the loggers.

Using the tower installation manual [33] and the approved plans, the site was surveyed to determine the location of the anchors and tower base. Locations for the anchors and base were established and marked.
As with most construction, the planned site varies from reality. This site was no exception. The location where the base was planned was on a steep slope. A platform was required to level the slope for the base. A sand bed was prepared and a wooden platform was built. In attempting to install the standard screw type anchors it was soon discovered that the extremely hard, rocky soil conditions prevented their installation. Consulting with the manufacturer, they suggested the use of arrow head anchors. Since this was a revision to the approved plan, a resubmittal for the anchor type was made and approved. These anchors were to be driven into the ground using a drive rod. However, the soil conditions were so rocky that a jack hammer was required to drive the rod and anchors into the soil.

Tower Installation

Once the site was prepared the tower installation began. Prior to setting up the meteorological tower at Fire Station 82, a temporary 10 meter tower was purchased and set up at another site for practice. With this experience and after reading the tower manuals tower installation began.

The tower was a 20 meter tilt-up tall tower manufactured by NRG systems. It consisted of lightweight steel tubes supported by anchored guy wires at three levels in four directions.

The gin pole used to raise and lower the tower consisted of lightweight steel tubes about 10 meters in height. Tensioned cable was installed to keep the gin pole together. The tower guy wires were premeasured for a specific installation point on the tower. The tower tubes were assembled up to the preset guy point and the guy ring was added followed by more tubes up to the next point and so
on. Once all tubes and guy rings were in place the guy wires were affixed to the anchors. Before the instrumentation could be installed, the tower had to be raised a few feet off the ground. Using the gin pole and winch as a lever and fulcrum the tower was slightly elevated. Supports were added and the gin pole tension was released allowing the instrumentation and wiring to be safely added.

Instrumentation was installed at three mounting heights. At 20 meters an anemometer and wind vane were installed. At 10 meters an anemometer, wind vane and temperature sensor were installed and at 2 meters, a temperature sensor was installed. The data loggers were installed at approximately 1-1/2 meters.

Instrumentation used on the tower consisted of a data loggers, anemometers, wind vanes, and temperature sensors. The tower and instrumentation was protected from lightning strikes through a lightening rod system. The data was logged using a 9 volt battery powered, 3 channel micro power wind energy data logger with removable non-volatile 128 Kbyte data plug. The anemometers were the three-cup design, with a measurement range of 1 m/s to 96 m/s, starting threshold of 0.78 m/s and a low moment of inertia. The wind vanes were 360° mechanical, continuous rotation potentiometric lightweight vanes, with a starting threshold of 1 m/s, dead band 8° Maximum, 4° Typical. The temperature sensors were integrated circuit sensors with internal reference, amplifiers, and linearization enclosed in radiation shield.

Once the instrumentation was added, the tower was raised using the gin pole. As the tower was raised, tension was adjusted on each respective guy wire to
keep the tower straight. When the tower was vertical, the guy wires used to raise
the tower were removed from the gin pole and transferred to the anchor allowing
the gin pole to be lowered. Guy wire tension was adjusted until the tower was
vertical (measured using a level).

With the tower raised, the data loggers were added into the weather proof
enclosures and the sensor wiring was landed. The loggers were activated and
programmed. Data plugs were then added. Since two loggers were used with
each measuring the data independently, the plugs were added to the loggers
quickly so that the data measurement could be within a few seconds of each
other.

The gin pole was removed and the remainder of the site was cleaned. Traffic
cones and caution tape were added to protect the guy wires.

Tower Removal

Meteorological data from the tower was gathered from mid March through mid
June. In May, The Fire Department made contact regarding the removal of the
tower as they needed access to their practice driving area in June. Therefore, in
accordance with the agreement, the tower was removed on time and the site was
restored. The tower was returned to the NCACM and the gin pole and wench
were returned to the Ponderosa Dairy in the Armagosa Valley.

The process to lower the tower was simply the reversal of the process used to
raise the tower.
Site Restoration

Site restoration consisted of repairing the pavement where two anchor points were located, restoring three anchor points in a gravel area and restoring the slope where the tower base had been. Asphalt patches were used for the pavement; simple garden tools were used in the gravel area and base area.

Data Gathering

During the time the tower was installed regular site visits were made to maintain the tower and check on the data loggers. Two sets of data plugs were provided for the data loggers, which allowed one set to be removed so the data could be read while the loggers continued to monitor and log data on the other set. To ensure the loggers were working, the plugs were removed after the first week and sent to the Desert Research Institute to be read. The plugs were labeled prior to being sent to them. They were removed and three separate readings were taken from the plugs. The Desert Research Institute sent the results of these readings back via email. They also returned the plugs via mail so they could be used again. While reading the data plugs the researchers at the Desert Research Institute found that the data loggers were mislabeling based on the plug information. The data was corrected and processed.

Summary

A key component of atmospheric modeling is meteorological data. Possible data sources include portable metrological stations, privately owned and
operated stations and publicly owned and operated stations. Many of these sources share data over the internet while proprietary sources do not share data.

Meteorological networks where data is shared over the internet appear to be very promising sources of data for atmospheric dispersion models. Meso-networks have been formed for the purpose of sharing data and performing modeling using the data. Meteorological partnerships provide a vehicle for collaboration. However, the data quality may be questionable due to improper instrumentation siting.

Predictive meteorological data is currently available and is being used for predicting the wind fields that can be used for emergency response purposes. This method shows great promise. Yet, at times, the weather does not follow predictive trends and the predictive model disconnects with reality, as this study found.

Application of specific meteorological data gathering allows the greatest flexibility, direct access to the data stream and opportunity to capture an accurate representation of the wind field. These stations also have direct cost for equipment installation, operation, and maintenance associated with them. This study did not evaluate these costs.

Siting a tower involved selecting a site, developing a design, gaining approvals, securing materials, preparing the site, installing the instrumentation on the tower and raising the tower. The tower was sited at Henderson Fire Station 82. Fire Stations make excellent sites for meteorological stations as they are situated throughout the community in a fire response district. Spreading stations
throughout the community in response districts and siting towers at the stations yields a good representation of the regional wind field. Meteorological data from these locally sited towers can be easily mapped to grids for input into a numerical model.

Towers at fire stations serve multiple purposes. A request from the fire service while a tower is up at a fire station permitted access to current weather conditions. Providing real-time data from a fire station may assist with training decisions and other emergent fire responses. Additionally towers can be provided with air quality instrumentation in regions not already provided with air quality monitoring equipment.

The tower used in this study was a freestanding 20 meter tower. If the site selected for the tower is not zoned industrial then public approvals may be required to install a 20 meter tower. If a 10 meter tower is installed on top of a building (such as the DCNet project in Washington D.C.), public approval may also be required. Most zoning codes in the Las Vegas valley allow the installation of a tower nearly 3 meters (10 feet) above the roof line of a building with staff approval only. However, to overcome building effects, a tower must be significantly higher requiring public approval. The installers of the SENSORNet project elected to install instrumentation onto cellphone towers thereby precluding the public approval process.
CHAPTER 4

DATA

This study examined atmospheric modeling to enhance Homeland Security. In particular, the role of atmospheric wind field plume flow modeling of hazardous material releases for emergency response purposes. Numerous atmospheric dispersion models were found to exist [27] and some are used for emergency response. Wind field data exists in historical, near-real-time, real-time, and predictive (forecast) forms from numerous sources [35, 38, 41]. Site or region specific wind field data may be obtained through strategically placed meteorological towers. This study sited a meteorological tower at the City of Henderson Fire Station 82. The process of tower siting was discussed previously. Data gathered from this tower is discussed in this section.

Data Gathering

Meteorological data was gathered starting in March and ending in June 2004. The data was gathered and stored on data plugs through a data logger. The data plugs were retrieved from the site and sent to the Desert Research Institute (DRI) in Reno Nevada to be read using a data plug computer interface. Dr. Richard L.
Reinhardt from DRI processed the data plugs. Some of the data received is shown in Appendix D.

Analysis

Three separate sets of data were transmitted and processed by the DRI generating three data files. After receiving all three data sets, they were collected into a continuous chronological ordered data set.

For emergency response purposes, the data used for modeling should be real-time or near real-time. The data gathered for this study was not real-time or near-real-time. It was historical real-time data logged by a data logger. This type of data may be used for a historical analysis, comparative analysis or wind energy analysis. For this study, it was used for all three.

Historical Analysis

In addition to the data gathered from the tower at the fire station, data was gathered from several local meteorological stations through the Real-time Observation Monitoring and Analysis Network (ROMAN). A screen shot of meteorological station locations for Southern Nevada is shown in Fig. 9. Data was accessed from ROMAN stations on the same day at approximately the same time. This data was gathered to compare historical regional wind field real-time data with the historical fire station data. The data used in the comparison is provided in Appendix E.
Comparative Analysis

The tower used in this study was 20 meters high. The monitoring guidelines from the Environmental Protection Agency [30] recommend an instrument height of 10 meters. The tower used in this study was fitted with instrumentation at the 10 meter and 20 meter heights. A comparative analysis was made using a spread sheet.

Figure 9. ROMAN – Las Vegas
Wind Energy Analysis

One possible use for the data gathered is to study wind energy. When historical data is unavailable and time and cost are not preclusive actual site monitoring is typically used.

Wind energy / wind power is a renewable energy source. Wind data gathered for this study was formatted for wind energy analysis by the software that read the data plugs.

After receiving the first data set, it was analyzed and wind energy charts including a wind rose were created. These charts were shown to researchers at the NCACM and they asked to see charts for the entire data set at the conclusion of the study with the addition of a windrose chart.

A windrose chart is a tool used by meteorologists to show the direction, frequency, and intensity of wind. A windrose chart is a polar plot that graphically shows by compass direction the percentage of time that the wind comes from a given direction and the average wind speed in that direction.

Wind energy analysis charts and wind rose diagrams were consequently created for the entire data set. Windrose diagrams for 10 meters and 20 meters are shown in Figs. 10 and 11 respectfully. Wind energy charts are shown in Figs. 12-15.
Figure 10. Windrose Instrumentation at 10 Meters

Figure 11. Windrose Instrumentation at 20 Meters
Figure 12. Wind Speed at 10 Meters

Figure 13. Wind Speed at 20 Meters
Figure 14. Directional Wind Speed Occurrences at 10 Meters

Figure 15. Directional Wind Speed Occurrences at 20 Meters
Findings

While analyzing various reports dealing with atmospheric wind field plume flow modeling of hazardous material releases, a significant report was found. This report titled Federal Research and Development Needs and Priorities for Atmospheric Transport and Diffusion Modeling [48] addresses the issue at a National level. This report clearly describes the complexities and many facets of atmospheric modeling for emergency response. After reading this report and seeing the number of scientists involved in solving this highly complex issue it became apparent that no one person could try to solve these issues alone. Fortunately, the Federal Meteorological Coordinator is taking the lead in bringing National resources together to solve these issues in an organized way. As was found in other studies, multiple public, educational and private entities [40] must come together to solve the issue.

Computer models are a specialized tool that requires significant expertise to use. Significant amounts of training are typically required for the users of these tools as was shown in the evaluations of the various models performed by National Oceanic and Atmospheric Administration [27].

Emergency responders faced with responding 98% [20] of the time to medical, false alarm, fire, mutual aid, and other calls have a low probability of ever needing to use an atmospheric dispersion model. For this reason, many responders do not place a high priority on learning all the nuances of modeling. However, when weapons of mass destruction or disruption are released and
atmospheric modeling is needed, emergency responders will quickly need accurate and reliable information to protect the public.

Going through the process of gaining the approvals necessary to site a meteorological station was invaluable. The approval process to install a tower is time consuming and can be costly. The fire service requested access to the current weather conditions while the tower was up at their fire station. Unfortunately, the data logger did not permit real-time display of the data in the fire station. If towers are installed at Fire Stations, the data needs to be readily accessible to the Fire Department as current meteorological data has multiple beneficial uses for fire personnel in the daily jobs.

**Historical Analysis**

The data gathered from the tower at the fire station and the data gathered for several local meteorological stations showed variations in the regional wind field. Partial listings of the regional (ROMAN) wind field data and fire station data acquired on April 22, 2004 is listed in Appendix E Superimposing the data values given or interpolated for 9:30 p.m. on a map as seen in Fig. 16, graphically shows the variations in the wind field. The boxed number shown on the figure is the wind speed in miles per hour and the arrow shows the direction the wind is coming from. The station id number for each of the ROMAN station is shown and the fire station shown as FS82. The wind field data shown for Fire Station 82 was at the 20 meter height.
Figure 16. Wind field for Las Vegas Valley ROMAN + FS82

Comparative Analysis

The meteorological data for the instrumentation at each mounting height was assembled as listed in Tables 5 and 6. These tables contrasting the amount of time the wind direction was at each of the compass points with the average wind speed at that direction. Comparing the differences between 10 and 20 meters Table 7, was created. Evaluating this table the wind direction was not shown
Table 5. Instrumentation at 10 Meters

<table>
<thead>
<tr>
<th>Direction Degrees</th>
<th>Direction Compass</th>
<th>Percent Time [%]</th>
<th>Mean Wind Speed [mph]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>N</td>
<td>5%</td>
<td>6.0</td>
</tr>
<tr>
<td>23°</td>
<td>NNE</td>
<td>6%</td>
<td>5.9</td>
</tr>
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<td>NE</td>
<td>8%</td>
<td>5.8</td>
</tr>
<tr>
<td>68°</td>
<td>ENE</td>
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<td>SE</td>
<td>3%</td>
<td>4.9</td>
</tr>
<tr>
<td>158°</td>
<td>SSE</td>
<td>4%</td>
<td>4.9</td>
</tr>
<tr>
<td>180°</td>
<td>S</td>
<td>6%</td>
<td>6.9</td>
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<tr>
<td>225°</td>
<td>SW</td>
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<td>NW</td>
<td>4%</td>
<td>6.6</td>
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<tr>
<td>338°</td>
<td>NNW</td>
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<td>6.8</td>
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</table>

Table 6. Instrumentation at 20 Meters

<table>
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<th>Direction Degrees</th>
<th>Direction Compass</th>
<th>Percent Time [%]</th>
<th>Mean Wind Speed [mph]</th>
</tr>
</thead>
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<tr>
<td>0°</td>
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<td>5%</td>
<td>6.7</td>
</tr>
<tr>
<td>23°</td>
<td>NNE</td>
<td>6%</td>
<td>6.4</td>
</tr>
<tr>
<td>45°</td>
<td>NE</td>
<td>8%</td>
<td>6.7</td>
</tr>
<tr>
<td>68°</td>
<td>ENE</td>
<td>4%</td>
<td>4.9</td>
</tr>
<tr>
<td>90°</td>
<td>E</td>
<td>3%</td>
<td>3.7</td>
</tr>
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<td>113°</td>
<td>ESE</td>
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<td>SE</td>
<td>3%</td>
<td>5.9</td>
</tr>
<tr>
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<td>SSE</td>
<td>4%</td>
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</tr>
<tr>
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<td>S</td>
<td>5%</td>
<td>9.0</td>
</tr>
<tr>
<td>203°</td>
<td>SSW</td>
<td>10%</td>
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</tr>
<tr>
<td>225°</td>
<td>SW</td>
<td>22%</td>
<td>10.2</td>
</tr>
<tr>
<td>248°</td>
<td>WSW</td>
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<td>270°</td>
<td>W</td>
<td>4%</td>
<td>4.9</td>
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</tr>
<tr>
<td>315°</td>
<td>NW</td>
<td>4%</td>
<td>8.1</td>
</tr>
<tr>
<td>338°</td>
<td>NNW</td>
<td>5%</td>
<td>7.0</td>
</tr>
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</table>
significantly different between the 10 meter and the 20 meter height with a standard deviation of only 0.01. The recorded wind speed differed by an average value of 1.4 m/s with a standard deviation of +0.96 m/s. As expected, the wind speed was greater at the 20 meter height as it closely followed the one seventh wind speed power law, shown in Eq. 16 with wind speed \( u \) and height \( z \). The wind speed power law and other useful wind equations are provided in the Wind Energy Resource Atlas of the United States [49].

Table 7. Wind Instrumentation Comparison, 10 Meters vs. 20 Meters

<table>
<thead>
<tr>
<th>Direction Degrees</th>
<th>Direction Compass</th>
<th>Difference Percent Time [%]</th>
<th>Difference Wind Speed [mph]</th>
</tr>
</thead>
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<td>0°</td>
<td>N</td>
<td>0.1%</td>
<td>0.7</td>
</tr>
<tr>
<td>23°</td>
<td>NNE</td>
<td>0.5%</td>
<td>0.6</td>
</tr>
<tr>
<td>45°</td>
<td>NE</td>
<td>0.1%</td>
<td>0.9</td>
</tr>
<tr>
<td>68°</td>
<td>ENE</td>
<td>0.6%</td>
<td>1.2</td>
</tr>
<tr>
<td>90°</td>
<td>E</td>
<td>0.2%</td>
<td>1.0</td>
</tr>
<tr>
<td>113°</td>
<td>ESE</td>
<td>0.0%</td>
<td>1.1</td>
</tr>
<tr>
<td>135°</td>
<td>SE</td>
<td>0.2%</td>
<td>1.1</td>
</tr>
<tr>
<td>158°</td>
<td>SSE</td>
<td>0.3%</td>
<td>4.3</td>
</tr>
<tr>
<td>180°</td>
<td>S</td>
<td>0.4%</td>
<td>2.1</td>
</tr>
<tr>
<td>203°</td>
<td>SSW</td>
<td>1.5%</td>
<td>2.5</td>
</tr>
<tr>
<td>225°</td>
<td>SW</td>
<td>2.7%</td>
<td>1.3</td>
</tr>
<tr>
<td>248°</td>
<td>WSW</td>
<td>3.3%</td>
<td>1.0</td>
</tr>
<tr>
<td>270°</td>
<td>W</td>
<td>0.1%</td>
<td>1.1</td>
</tr>
<tr>
<td>293°</td>
<td>WNW</td>
<td>0.2%</td>
<td>1.1</td>
</tr>
<tr>
<td>315°</td>
<td>NW</td>
<td>0.2%</td>
<td>1.5</td>
</tr>
<tr>
<td>338°</td>
<td>NNW</td>
<td>0.5%</td>
<td>0.2</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>0.7%</td>
<td>1.4</td>
</tr>
<tr>
<td>Median</td>
<td></td>
<td>0.3%</td>
<td>1.1</td>
</tr>
<tr>
<td>Maximum</td>
<td></td>
<td>3.3%</td>
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<tr>
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<tr>
<td>Standard Deviation</td>
<td></td>
<td>0.01</td>
<td>0.96</td>
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</table>

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This showed the effect of the boundary layer and surface effects on the lower instruments. Using the wind speed from the lower instruments may cause a Gaussian model to predict a wider dispersion and a slower trajectory.

Wind Energy Analysis

The site conditions were good for monitoring. Trees, buildings or other obstructions did not shelter the sensors. The sensors were new and the bearings were not worn. The data series was continuous with no missing points due to data plug changes. The only fault in the data was the short duration. The duration of the data gathered for this study, about three months, was too short for a good wind energy analysis. Normally, data for a year or more is needed to characterize a site. The data gathered could be improved by extrapolating historical data from other sources. This was not done, as a wind energy analysis was not the primary focus of this study.

Analyzing the wind energy charts, windrose diagram, and tables, several things were learned. The wind energy charts showed the Diurnal cycle of wind very clearly. This information showing the highs and the lows along with the Weibull Distribution may be used to size battery banks. The wind charts showing wind speed at the each of the 16 compass points shows the wind frequency. The frequency distribution shows how much wind energy the site could generate. Strong and reliable winds are necessary for wind-generated electricity. Wind direction is less important that wind speed. However, for this site the predominate

\[ \frac{u_1}{u_2} = \left( \frac{z_1}{z_2} \right) ^\alpha \quad \alpha \equiv \frac{1}{7} \]
winds were shown by the windrose to be from the Southwest, West-Southwest directions which closely approximates the historical, prevailing winds reported by McCarran International Airport of 250° [50]. However, prevailing wind data should not be used for atmospheric emergency response dispersion modeling, as it may not match the wind direction at the time of a release.

Summary

The Office of the Federal Coordinator for Meteorological Services and Supporting Research is taking the lead on solving problems related to atmospheric modeling for emergency response. Time and training are needed for emergency responders to enable them to use an atmospheric model. The approval process to install a tower is time consuming and can be costly.

Meteorological data was gathered for this study from a meteorological tower starting in March and ending in June of 2004. Real-time meteorological data is available online and may be used for atmospheric modeling for emergency response.

Meteorological data was gathered from instrumentation on the tower at an elevation of 10 meters and 20 meters above grade. This data was analyzed and a comparison made. The wind direction was found to be essentially the same at both heights. As expected the wind speed was found to be greater at 20 meters. For this site the average speed varied by 1.4 ±0.96 m/s which very closely follows the 1/7 wind speed power law.
Data gathered through site specific meteorological towers yields itself easily to other purposes including wind energy analysis studies. Performing a wind energy analysis on the data from this study showed the Diurnal cycle of wind, wind speed, frequency, and the prevailing wind direction.
CHAPTER 5

CONCLUSIONS

Emergency responders faced with an accidental release of hazardous materials or a release of hazardous materials from biological and chemical weapons of mass destruction or disruption are tasked with protecting themselves and the public. Fortunately, tools exist to aid them in accomplishing this.

Model Existence

Mathematical models exist that represent simplified physical laws that govern contaminate dispersion. Numerous computer programs incorporating various forms of these mathematical models were found to exist for use by emergency responders. Time and training are needed for emergency responders to effectively use them. Teams of researchers and programmers support many of these programs with training offered for emergency responders. A commonly used atmospheric dispersion computer model designed specifically for emergency response is the Areal Locations of Hazardous Atmospheres (ALOHA) model. ALOHA has a vast chemical library and quickly produces basic results. However, the simplified physics used to develop the analytical Gaussian diffusion equation incorporated within ALOHA results in severe modeling limitations.

80
The Office of the Federal Coordinator for Meteorological Services and Supporting Research is taking the lead on solving problems related to atmospheric modeling for emergency response.

Collaborative efforts, mutual aid agreements, and partnerships have been formed to provide atmospheric modeling for emergency response. These magnify the individual contributions of those involved, increasing the quality of assessment.

Summary of Contributions

Atmospheric dispersion models for emergency response are available from the literature. Atmospheric models require meteorological information as an input to perform calculations. Meteorological information is available from numerous sources. Meteorological station siting plays an important role in the quality of data reported. Federal guidelines provide guidance for site selection, separation distance from obstructions and recommended types of instrumentation to use.

These models need meteorological information to formulate a solution. Meteorological information is normally gathered through instrumented towers. Many of the models use or have the ability to use real time or near real time meteorological data. Typically, this data is in the form of wind speed, wind direction, and temperature. The number of data points used for the input can vary from a single measurement point to multiple points. Depending on the model employed, as the number of points used to achieve a solution increases the reliability and accuracy of the result increases.

81
Wind field data is available from airports through the National Weather
Service, from regional meteorological partnerships such as the Real-time
Observation Monitoring and Analysis Network (ROMAN) and from forecast or
predictive data produced by the National Weather Service or NOAA Air Research
Laboratory. Many of these sources share data over the internet while proprietary
sources do not share data.

Meteorological networks where data is shared over the internet provide very
promising sources of data for atmospheric dispersion models. Meso-networks
have been formed for the purpose of sharing data and performing modeling using
the data. These networks formed through collaborative efforts, mutual aid
agreements, and partnerships synergize the work of the individual contributors
forming meteorological data networks that enhance emergency response
information.

Predictive meteorological data is currently available and is being used for
predicting the wind field for emergency response purpose. This method shows
great promise. However, the uncertainty of weather systems leads to predictive
model disconnects with reality.

Site specific meteorological data gathering allows the greatest flexibility to
directly access the data stream and an opportunity to capture an accurate
representation of the wind field. However, the approval process to install a tower
is time consuming, may require public approvals, and can be costly. If the site
selected for the tower is not zoned industrial then public approvals may be
required to install a 20 meter tower. If a 10 meter tower is installed on top of a

82

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building, public approvals may also be required. However, instrumentation added onto cellphone towers precludes the public approval process.

Siting a tower involves selecting a site, developing a design, gaining approvals, securing materials, preparing the site, installing the instrumentation on the tower and raising the tower.

Fire Stations make excellent sites for regional meteorological stations as they are situated throughout a region in fire response districts. Placing meteorological stations at fire stations should yield a good representation of the regional wind field. Meteorological data from towers at fire stations could be easily mapped to grids for ready input into a numerical model.

Towers at fire stations could serve multiple purposes. Providing real-time data at a the fire house may assist with training decisions and would provide information for emergency response as well as other non-emergent purposes. Sharing the information with the National Weather Service could aid forecasters. Providing towers with air quality instrumentation in regions not already provided with air quality monitoring equipment could satisfy IAQ regulatory requirements. Logging the data gathered would yield itself easily to wind energy analysis studies.

As part of this study, a tower was sited at a Fire Station. The tower was a freestanding 20 meter tower. This tower was instrumented at two elevations to allow data comparison. As expected the wind speed was found to be greater at 20 meters as compared to 10 meters above grade. For this site the average
speed varied by 1.4 +0.96 m/s. The wind direction was found to be essentially the same at both heights.

Future Research

Meteorological partnerships for the Las Vegas Valley should be formed. Numerous entities within the Las Vegas metro area are already involved in homeland security, emergency response, atmospheric monitoring, or atmospheric modeling. Each of these entities could provide specific expertise. Partnerships, interlocal government agreements, and mutual aid meteorological agreements should be developed. These cooperative efforts would enhance homeland security for the metro area. The type of partnership envisioned could have local jurisdictions accomplishing the following: (1) Participating in one or more meso-networks such as the Real-time Observation Monitoring and Analysis Network (ROMAN) operated by the University of Utah MesoWest project; (2) Providing meso-streamed data from the Clark County Regional Flood Control District and the Clark County Department of Air Quality; (3) Installing 10 meter or 20 meter meteorological towers and associated equipment (e.g., computer with internet access) at all local fire stations throughout the metro area; (4) Modeling wind field using meso-network data and providing specific gridded outputs at organizations such as the National Weather Service Las Vegas office; (5) Providing an internet based event specific dispersion model from an organization like the Nevada Center for Advanced Computational Methods; (6) Sharing predictive dispersion scenarios run for the metro area from specialized agencies.
such as the National Oceanic and Atmospheric Administration, Air Resources Laboratory, Special Operations and Research Division located in Las Vegas; (7) Providing emergency responders with a simple, easy to use, internet based graphical user interface to the event.

The costs associated with meteorological partnerships should be studied. The cost of meso-networks, tower installations, computer equipment, communication connections, web servers, model development, internet graphical user interfaces and coordination of all needs to be quantified. Possible funding sources such as Homeland Security grants should also be identified.

Current recommendations for meteorological towers offer very conservative guidance when towers are sited on a building roof. Mounting sensors on a roof is not recommended due to uncertainties of a building's aerodynamic wake effects. A specific study of aerodynamic wake effects for roof mounted meteorological equipment should be performed.

Coordination should be made with The Office of the Federal Coordinator for Meteorological Services and Supporting Research to ensure that model development uses shared resources.
APPENDIX A

HAZARDOUS INCIDENT TOP 10 CHEMICALS

Toluene 3%
Methyl Chloride 3%
Nitric Acid 3%
Methanol / Methyl Alcohol 3%
Sodium Hydroxide 5%
Hydrochloric Acid 6%
Chlorine 7%
Anhydrous Ammonia 8%
Sulfuric Acid 14%
Polychlorinated Biphenyls (PCBs) 48%
Note: Other Chemicals Account for 50.5%

Figure 17. Top 10 Chemicals Involved in Facility and In-transit Incidents

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Figure 18. Top 10 Chemicals Causing Human Injury or Death
Examining a gas's specific gravity is one way to determine if a gas is heavier than air. Specific gravity for a gas is the ratio of the density of a gas to the density of dry air with the specific gravity of air being 1.0. Therefore a gas will rise if the specific gravity is lower than 1 and will sink if the specific gravity is greater than 1. To determine the specific gravity of a gas, you must know its density in kilograms per meter cubed (kg/m³). Then, divide this density by the density of dry air at standard temperature and pressure. This value is approximately 1.29 kg/m³. Another way to determine it is to examine the atomic weights of the gas molecules. The density of a gas is proportional to the sum of the atomic weights in one molecule. A gas having a molecular weight heavier than a molecule of air results in a heavy gas. A molecule of air averages about 29 gm/mole. Most gasses are equal to or heavier than air. A partial list of lighter than air gasses are hydrogen, helium, neon, natural gas (methane, CH₄), hydrogen fluoride (HF), diborane (B₂H₆), acetylene (welding gas, C₂H₂), ethene (C₂H₄), hydrocyanic acid (HCN), nitrogen, and carbon monoxide.
APPENDIX C

TOWER PHOTOS

Figure 19. Tower Site
Figure 20.  Driving an Anchor

Figure 21.  Anchor and Guy Wires

Figure 22.  Base Plate Assembly with Gin Pole and Tower
Figure 23. Winch Used to Raise Tower

Figure 24. Supported Tower Ready to Instrument

Figure 25. Installing Instruments
Figure 26. Tower Top - Instruments at 20 Meters

Figure 27. Raising Tower

Figure 28. Gin Pole Raising Tower

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Figure 29.  Tower Up and Aligned

Figure 30.  Data Logger Enclosures
Figure 31. Data Logger

Figure 32. Tower Instruments at 10 Meters
Figure 33. Tower Raised

Figure 34. Tower In-service at Fire Station 82

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Figure 35. Preparing to Lower Tower

Figure 36. Lowering Tower

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Figure 37. Continuing to Lower Tower

Figure 38. Tower Lowered Resting on Supports for Instrument Removal
## APPENDIX D

### TOWER DATA

Table 8. 10-Meter Data Plug 1404 Header and 10 Samples

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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</tr>
<tr>
<td>Site</td>
<td>0712</td>
</tr>
<tr>
<td>Site Description</td>
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<td>Longitude</td>
<td>115.023</td>
</tr>
<tr>
<td>Units</td>
<td>English</td>
</tr>
<tr>
<td>Logger Model Number</td>
<td>2333</td>
</tr>
<tr>
<td>Logger Serial Number</td>
<td>0712</td>
</tr>
<tr>
<td>Logger Firmware Version</td>
<td>07</td>
</tr>
<tr>
<td>DataPlug Serial Number</td>
<td>01404</td>
</tr>
<tr>
<td>Previously Read</td>
<td>NO</td>
</tr>
<tr>
<td>Start Time</td>
<td>3/13/2004 12:01</td>
</tr>
<tr>
<td>Battery Voltage at Start</td>
<td>9.4</td>
</tr>
<tr>
<td>Gust Speed</td>
<td>026</td>
</tr>
<tr>
<td>Gust Direction</td>
<td>018</td>
</tr>
<tr>
<td>Stop Time</td>
<td>3/18/2004 06:30</td>
</tr>
<tr>
<td>Battery Voltage at Stop</td>
<td>9.2</td>
</tr>
<tr>
<td>[Channel01]</td>
<td></td>
</tr>
<tr>
<td>Sensor Type</td>
<td>01</td>
</tr>
<tr>
<td>Description</td>
<td>&quot;NRG #40 Maximum Anemometer&quot;</td>
</tr>
<tr>
<td>S/N</td>
<td>&quot;None&quot;</td>
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<tr>
<td>Height</td>
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</tr>
<tr>
<td>Scale Factor</td>
<td>1.711</td>
</tr>
<tr>
<td>Offset</td>
<td>78</td>
</tr>
<tr>
<td>Print Precision</td>
<td>###.#</td>
</tr>
</tbody>
</table>
Table 9. 20-Meter Data Plug 1403 Header and 10 Samples

<table>
<thead>
<tr>
<th>Time Stamp</th>
<th>Average Speed</th>
<th>Standard Deviation</th>
<th>Average Direction</th>
<th>Extra Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/13/2004 12:00</td>
<td>0.072</td>
<td>0.0321</td>
<td>0.023</td>
<td>0.0805</td>
</tr>
<tr>
<td>3/13/2004 12:10</td>
<td>0.044</td>
<td>0.0267</td>
<td>0.000</td>
<td>0.0805</td>
</tr>
<tr>
<td>3/13/2004 12:20</td>
<td>0.061</td>
<td>0.0358</td>
<td>0.338</td>
<td>0.0815</td>
</tr>
<tr>
<td>3/13/2004 12:30</td>
<td>0.056</td>
<td>0.0219</td>
<td>0.000</td>
<td>0.0815</td>
</tr>
<tr>
<td>3/13/2004 12:40</td>
<td>0.052</td>
<td>0.0219</td>
<td>0.338</td>
<td>0.0815</td>
</tr>
<tr>
<td>3/13/2004 13:00</td>
<td>0.059</td>
<td>0.0412</td>
<td>0.338</td>
<td>0.0815</td>
</tr>
<tr>
<td>3/13/2004 13:10</td>
<td>0.055</td>
<td>0.0171</td>
<td>0.068</td>
<td>0.0815</td>
</tr>
<tr>
<td>3/13/2004 13:20</td>
<td>0.056</td>
<td>0.0219</td>
<td>0.315</td>
<td>0.0825</td>
</tr>
<tr>
<td>3/13/2004 13:30</td>
<td>0.056</td>
<td>0.0219</td>
<td>0.315</td>
<td>0.0825</td>
</tr>
</tbody>
</table>
Project Code,"New"
Project Description,"New Project"
Location Description,"City, State, Zip"
Site Elevation, 0
Time Zone, 0
Latitude, 0 S
Longitude, 0 W
Units, English
Logger Model Number, 2333
Logger Serial Number, 0709
Logger Firmware Version, 07
DataPlug Serial Number, 01403
Previously Read, NO
Start Time, 3/13/2004 12:01
Battery Voltage at Start, 9.3
Gust Speed, 027
Gust Direction, 015
Gust Time, 3/15/2004 13:51
Stop Time, 3/18/2004 06:30
Battery Voltage at Stop, 9.1
[Channel01]
Sensor Type, 01
Description,"NRG #40 Maximum Anemometer"
S/N,"None"
Height, 0
Scale Factor, 1.711
Offset, .78
Print Precision, ###.#
Units,"mph"
[Channel02]
Sensor Type, 04
Description,"NRG #200P Wind Direction Vane"
S/N,"None"
Height, 0
Scale Factor, 1
Offset, 0
Print Precision, ###
Units,"Degrees"
[Channel03]
Sensor Type, 06
Description,"NRG #110S Temperature Sensor"
S/N,"None"
Height, 0
Scale Factor, 1
Offset, -123.5
Print Precision, ###.#
Units,"Degrees F"
Raw Header:
09 07 09 07 33 23 07 02 7B 05 E4 0A A1 FF FF FF
01 0C OD 03 68 EF FF FF 1F 0B 33 0D 0F 03 68 FF
1E 06 12 03 68 EA FF FF
Time Stamp,Average Speed,Standard Deviation,Average Direction,Extra
Channel
3/13/2004 12:00,007.7,03.32,023,078.5
3/13/2004 12:10,005.0,02.83,000,078.5
3/13/2004 12:20,007.0,02.83,338,079.5
3/13/2004 12:30,006.1,02.57,000,078.5
3/13/2004 12:40,005.7,01.92,023,078.5
3/13/2004 12:50,003.9,01.66,270,079.5
3/13/2004 13:00,006.9,03.80,338,079.5
3/13/2004 13:10,006.6,01.50,045,079.5
3/13/2004 13:20,007.3,01.34,315,080.5
3/13/2004 13:30,006.3,02.09,315,080.5

Table 10. 10-Meter Data Plug 1405 Header and 10 Samples

Read by,DR Version 10,5/4/2004 11:04
Site,0712
Site Description,"Fire Station 82"
Project Code,""
Project Description,"NSOE Anemometer Loan Progrm"
Location Description,"Henderson, NV"
Time Zone,-8
Latitude,36.0598
Longitude,115.023
Units,English
Logger Model Number,2333
Logger Serial Number,0712
Logger Firmware Version,07
DataPlug Serial Number,01405
Previously Read,NO
Start Time,3/18/2004 06:33
Battery Voltage at Start,9.1
Gust Speed,045
Gust Direction,315
Gust Time,4/22/2004 06:47

101
Stop Time, 4/30/2004 05:30
Battery Voltage at Stop, 8.7

[Channel01]
Sensor Type, 01
Description, "NRG #40 Maximum Anemometer"
S/N, "None"
Height, 65.6
Scale Factor, 1.711
Offset, .78
Print Precision, ###.#
Units, "mph"

[Channel02]
Sensor Type, 04
Description, "NRG #200P Wind Direction Vane"
S/N, "None"
Height, 0
Scale Factor, 1
Offset, 0
Print Precision, ###
Units, "Degrees"

[Channel03]
Sensor Type, 06
Description, "NRG #110S Temperature Sensor"
S/N, "None"
Height, 0
Scale Factor, 1
Offset, -123.5
Print Precision, ###.#
Units, "Degrees F"

Raw Header:
12 07 12 07 33 23 07 02 7D 05 D0 60 A1 FF FF FF
21 06 12 03 68 EB FF FF 34 EO 2F 06 16 04 68 FF
1E 05 1E 04 68 DF FF FF

Time Stamp, Average Speed, Standard Deviation, Average Direction, Extra Channel
3/18/2004 06:30, 000.0, 00.00, 000.060.5
3/18/2004 06:40, 000.0, 00.21, 000.061.5
3/18/2004 06:50, 000.0, 00.21, 000.061.5
3/18/2004 07:00, 000.0, 00.00, 000.063.5
3/18/2004 07:10, 000.0, 00.00, 000.065.5
3/18/2004 07:20, 000.0, 00.00, 068.066.5
3/18/2004 07:30, 000.0, 00.00, 068.066.5
3/18/2004 07:40, 000.0, 00.00, 068.066.5
3/18/2004 07:50, 000.0, 00.00, 068.067.5
3/18/2004 08:00, 000.0, 00.00, 068.068.5
Table 11. 20-Meter Data Plug 1404 Header and 10 Samples

<table>
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<tr>
<th>Column</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Site</td>
<td>0709</td>
</tr>
<tr>
<td>Site Description</td>
<td>&quot;Fire Station 82&quot;</td>
</tr>
<tr>
<td>Project Code</td>
<td>&quot;&quot;</td>
</tr>
<tr>
<td>Project Description</td>
<td>&quot;NSOE Anemometer Loan Program&quot;</td>
</tr>
<tr>
<td>Location Description</td>
<td>&quot;Henderson, NV&quot;</td>
</tr>
<tr>
<td>Site Elevation</td>
<td>1700</td>
</tr>
<tr>
<td>Time Zone</td>
<td>-8</td>
</tr>
<tr>
<td>Latitude</td>
<td>36.0598</td>
</tr>
<tr>
<td>Longitude</td>
<td>115.023</td>
</tr>
<tr>
<td>Units</td>
<td>English</td>
</tr>
<tr>
<td>Logger Model Number</td>
<td>2333</td>
</tr>
<tr>
<td>Logger Serial Number</td>
<td>0709</td>
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<tr>
<td>Logger Firmware Version</td>
<td>07</td>
</tr>
<tr>
<td>DataPlug Serial Number</td>
<td>01383</td>
</tr>
<tr>
<td>Previously Read</td>
<td>NO</td>
</tr>
<tr>
<td>Start Time</td>
<td>3/18/2004 06:33</td>
</tr>
<tr>
<td>Battery Voltage at Start</td>
<td>9.0</td>
</tr>
<tr>
<td>Gust Speed</td>
<td>047</td>
</tr>
<tr>
<td>Gust Direction</td>
<td>323</td>
</tr>
<tr>
<td>Gust Time</td>
<td>4/22/2004 06:19</td>
</tr>
<tr>
<td>Stop Time</td>
<td>4/30/2004 05:30</td>
</tr>
<tr>
<td>Battery Voltage at Stop</td>
<td>8.6</td>
</tr>
</tbody>
</table>

[Channel 01]
- Sensor Type: 01
- Description: "NRG #40 Maximum Anemometer"
- S/N: "None"
- Height: 32.8
- Scale Factor: 1.711
- Offset: 0.78
- Print Precision: ###.#
- Units: "mph"

[Channel 02]
- Sensor Type: 04
- Description: "NRG #200P Wind Direction Vane"
- S/N: "None"
- Height: 0
- Scale Factor: 1
- Offset: 0
- Print Precision: ###
- Units: "Degrees"

[Channel 03]
- Sensor Type: 06

103
Table 12. 10-Meter Data Plug 1404 Header and 10 Samples

<table>
<thead>
<tr>
<th>Date</th>
<th>Average Speed</th>
<th>Standard Deviation</th>
<th>Average Direction</th>
<th>Extra Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/18/2004</td>
<td>0.8</td>
<td>0.27</td>
<td>338</td>
<td>60</td>
</tr>
<tr>
<td>3/18/2004</td>
<td>1.2</td>
<td>0.75</td>
<td>338</td>
<td>60</td>
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<tr>
<td>3/18/2004</td>
<td>1.0</td>
<td>0.64</td>
<td>338</td>
<td>60</td>
</tr>
<tr>
<td>3/18/2004</td>
<td>0.0</td>
<td>0.00</td>
<td>338</td>
<td>63.5</td>
</tr>
<tr>
<td>3/18/2004</td>
<td>0.0</td>
<td>0.00</td>
<td>338</td>
<td>66.5</td>
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<td>3/18/2004</td>
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<td>0.00</td>
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<tr>
<td>3/18/2004</td>
<td>0.0</td>
<td>0.00</td>
<td>338</td>
<td>68.5</td>
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<tr>
<td>3/18/2004</td>
<td>0.0</td>
<td>0.00</td>
<td>338</td>
<td>68.5</td>
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Previously Read, NO
Start Time, 4/30/2004 05:33
Battery Voltage at Start, 8.6
Gust Speed, 052
Gust Direction, 332
Stop Time, 6/11/2004 08:40
Battery Voltage at Stop, 8.5

[Channel01]
Sensor Type, 01
Description, "NRG #40 Maximum Anemometer"
S/N, "None"
Height, 32.8
Scale Factor, 1.711
Offset, .78
Print Precision, ###.#
Units, "mph"

[Channel02]
Sensor Type, 04
Description, "NRG #200P Wind Direction Vane"
S/N, "None"
Height, 0
Scale Factor, 1
Offset, 0
Print Precision, ###
Units, "Degrees"

[Channel03]
Sensor Type, 06
Description, "NRG #110S Temperature Sensor"
S/N, "None"
Height, 0
Scale Factor, 1
Offset, -123.5
Print Precision, ###.#
Units, "Degrees F"

Raw Header:
12 07 12 07 33 23 07 02 7C 05 F4 5E A1 FF FF FF
21 05 1E 04 68 DE FF FF 3C EC 35 15 0B 05 68 FF
28 08 0B 06 68 DA FF FF

Time Stamp, Average Speed, Standard Deviation, Average Direction, Extra Channel
4/30/2004 05:30, 004.8, 01.50, 338, 059.5
4/30/2004 05:40, 009.2, 02.25, 000, 060.5
4/30/2004 05:50, 010.1, 02.09, 000, 060.5
4/30/2004 06:00, 011.2, 01.82, 000, 061.5
4/30/2004 06:10, 011.3, 02.46, 000, 061.5

105
4/30/2004 06:20,011.7,02.03,000,062.5
4/30/2004 06:30,010.9,02.09,000,062.5
4/30/2004 06:40,010.7,01.76,000,063.5
4/30/2004 06:50,010.7,01.55,000,064.5
4/30/2004 07:00,010.4,02.03,023,064.5

Table 13. 20-Meter Data Plug 1403 Header and 10 Samples

Read by, DR Version 10, 6/23/2004 10:14
Site, 0709
Site Description,"Fire Station 82 - upper"
Project Code,"
Project Description,"NSOE Anemometer Loan Program"
Location Description,"Henderson, NV"
Site Elevation, 1700
Time Zone, -8
Latitude, 36.0598
Longitude, 115.023
Units, English
Logger Model Number, 2333
Logger Serial Number, 0709
Logger Firmware Version, 07
DataPlug Serial Number, 01403
Previously Read, NO
Start Time, 4/30/2004 05:33
Battery Voltage at Start, 8.5
Gust Speed, 058
Gust Direction, 323
Stop Time, 6/11/2004 08:30
Battery Voltage at Stop, 8.4
[Channel01]
Sensor Type, 01
Description,"NRG #40 Maximum Anemometer"
S/N,"None"
Height, 65.6
Scale Factor, 1.711
Offset, .78
Print Precision, ###.#
Units,"mph"
[Channel02]
Sensor Type, 04
Description, "NRG #200P Wind Direction Vane"
S/N, "None"
Height, 0
Scale Factor, 1
Offset, 0
Print Precision, ###
Units, "Degrees"
[Channel03]
Sensor Type, 06
Description, "NRG #110S Temperature Sensor"
S/N, "None"
Height, 0
Scale Factor, 1
Offset, -123.5
Print Precision, ###.#
Units, "Degrees F"
Raw Header:
09 07 09 07 33 23 07 02 7B 05 F0 5E A1 FF FF FF
21 05 IE 04 68 DC FF FF 43 E6 35 15 OB 05 68 FF
1E 08 0B 06 68 D9 FF FF
Time Stamp, Average Speed, Standard Deviation, Average Direction, Extra Channel
4/30/2004 05:30, 005.8, 01.44, 338, 059.5
4/30/2004 05:40, 010.0, 02.09, 338, 059.5
4/30/2004 05:50, 011.0, 01.98, 338, 060.5
4/30/2004 06:00, 011.9, 02.03, 338, 060.5
4/30/2004 06:10, 011.7, 02.51, 000, 060.5
4/30/2004 06:20, 012.2, 02.14, 000, 061.5
4/30/2004 06:30, 011.6, 01.82, 000, 061.5
4/30/2004 06:40, 011.7, 01.87, 000, 062.5
4/30/2004 06:50, 011.6, 01.44, 000, 062.5
4/30/2004 07:00, 011.4, 02.14, 000, 063.5
APPENDIX E

STATION DATA

Table 14. Sample ROMAN Met Station Data for C0363

<table>
<thead>
<tr>
<th>Time (PDT)</th>
<th>Temp °F</th>
<th>Dew °F</th>
<th>Relative %</th>
<th>Wind Speed mph</th>
<th>Wind Gust mph</th>
<th>Wind Direction</th>
<th>Quality control</th>
</tr>
</thead>
<tbody>
<tr>
<td>20:50</td>
<td>65</td>
<td>21.8</td>
<td>19</td>
<td>5</td>
<td>10</td>
<td>N</td>
<td>OK</td>
</tr>
<tr>
<td>20:30</td>
<td>66</td>
<td>22.6</td>
<td>19</td>
<td>5</td>
<td>10</td>
<td>N</td>
<td>OK</td>
</tr>
<tr>
<td>20:20</td>
<td>66</td>
<td>22.6</td>
<td>19</td>
<td>4</td>
<td>11</td>
<td>N</td>
<td>OK</td>
</tr>
<tr>
<td>20:00</td>
<td>66</td>
<td>22.6</td>
<td>19</td>
<td>6</td>
<td>14</td>
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<td>OK</td>
</tr>
<tr>
<td>19:50</td>
<td>66</td>
<td>23.8</td>
<td>20</td>
<td>5</td>
<td>13</td>
<td>N</td>
<td>OK</td>
</tr>
<tr>
<td>19:30</td>
<td>67</td>
<td>23.4</td>
<td>19</td>
<td>6</td>
<td>12</td>
<td>N</td>
<td>OK</td>
</tr>
<tr>
<td>19:20</td>
<td>67</td>
<td>23.4</td>
<td>19</td>
<td>4</td>
<td>13</td>
<td>NNE</td>
<td>OK</td>
</tr>
<tr>
<td>19:00</td>
<td>68</td>
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<td>19</td>
<td>7</td>
<td>13</td>
<td>NNE</td>
<td>OK</td>
</tr>
<tr>
<td>18:50</td>
<td>68</td>
<td>24.2</td>
<td>19</td>
<td>6</td>
<td>13</td>
<td>NNE</td>
<td>OK</td>
</tr>
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<td>18:30</td>
<td>69</td>
<td>25</td>
<td>19</td>
<td>9</td>
<td>14</td>
<td>N</td>
<td>OK</td>
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</table>
Table 15. Sample ROMAN Met Station Data for CMP10

ID: CMP10  
NAME: Henderson  
LATITUDE: 36.01  
LONGITUDE: -114.97  
ELEVATION: 2192 ft  
MNET: CEMP


<table>
<thead>
<tr>
<th>Time (PDT)</th>
<th>Temperature °F</th>
<th>Dew Point °F</th>
<th>Relative Humidity %</th>
<th>Wind Speed mph</th>
<th>Wind Gust mph</th>
<th>Wind Direction</th>
<th>Quality Control</th>
<th>Pressure in</th>
<th>Solar Radiation W/m^2</th>
<th>Precipitation Accumulated in</th>
</tr>
</thead>
<tbody>
<tr>
<td>20:10</td>
<td>68.5</td>
<td>25.5</td>
<td>20</td>
<td>6</td>
<td>13</td>
<td>NW</td>
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<tr>
<td>20:00</td>
<td>68.9</td>
<td>25.4</td>
<td>19</td>
<td>7</td>
<td>12</td>
<td>NW</td>
<td>OK</td>
<td>27.59</td>
<td>0</td>
<td>11.05</td>
</tr>
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<td>18</td>
<td>7</td>
<td>14</td>
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<td>11.05</td>
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<td>69.6</td>
<td>24.6</td>
<td>18</td>
<td>7</td>
<td>17</td>
<td>NNW</td>
<td>OK</td>
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<td>0</td>
<td>11.05</td>
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<td>18</td>
<td>8</td>
<td>16</td>
<td>NNW</td>
<td>OK</td>
<td>27.58</td>
<td>3</td>
<td>11.05</td>
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<td>20</td>
<td>6</td>
<td>12</td>
<td>NW</td>
<td>OK</td>
<td>27.58</td>
<td>8</td>
<td>11.05</td>
</tr>
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<td>26.2</td>
<td>19</td>
<td>7</td>
<td>15</td>
<td>NW</td>
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<td>17</td>
<td>11.05</td>
</tr>
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<td>19</td>
<td>7</td>
<td>15</td>
<td>NNW</td>
<td>OK</td>
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LATITUDE: 36.05
LONGITUDE: -115
ELEVATION: 1841 ft
MNET: LAS VEGAS


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LATITUDE: 36.05
LONGITUDE: -115.19
ELEVATION: 2274 ft
MNET: LAS VEGAS


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Table 22. Sample ROMAN Met Station Data for LAS

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<th>Wind Speed mph</th>
<th>Wind Gust mph</th>
<th>Wind Direction</th>
<th>Quality Control</th>
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<td>12:55</td>
<td>68</td>
<td>30</td>
<td>24</td>
<td>20</td>
<td>26</td>
<td>NNW</td>
<td>OK</td>
<td>29.84</td>
<td>29.89</td>
<td></td>
<td>mostly clear</td>
<td>10</td>
</tr>
</tbody>
</table>

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Table 23. Sample Met Station Data at 20m for Fire Station 82

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Average Speed (mph)</th>
<th>Standard Deviation</th>
<th>Direction</th>
<th>Extra Channel Temp (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/22/2004 20:10</td>
<td>11.9</td>
<td>1.98</td>
<td>338</td>
<td>70.5</td>
<td></td>
</tr>
<tr>
<td>4/22/2004 20:00</td>
<td>9.7</td>
<td>1.44</td>
<td>338</td>
<td>70.5</td>
<td></td>
</tr>
<tr>
<td>4/22/2004 19:50</td>
<td>7.7</td>
<td>1.07</td>
<td>0</td>
<td>70.5</td>
<td></td>
</tr>
<tr>
<td>4/22/2004 19:40</td>
<td>9.1</td>
<td>2.14</td>
<td>0</td>
<td>71.5</td>
<td></td>
</tr>
<tr>
<td>4/22/2004 19:30</td>
<td>10.3</td>
<td>1.66</td>
<td>0</td>
<td>71.5</td>
<td></td>
</tr>
<tr>
<td>4/22/2004 19:20</td>
<td>10</td>
<td>1.55</td>
<td>0</td>
<td>71.5</td>
<td></td>
</tr>
<tr>
<td>4/22/2004 19:10</td>
<td>8.9</td>
<td>1.5</td>
<td>0</td>
<td>71.5</td>
<td></td>
</tr>
<tr>
<td>4/22/2004 19:00</td>
<td>9.3</td>
<td>1.87</td>
<td>0</td>
<td>72.5</td>
<td></td>
</tr>
<tr>
<td>4/22/2004 18:50</td>
<td>11.2</td>
<td>1.6</td>
<td>0</td>
<td>72.5</td>
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<td>14.1</td>
<td>2.3</td>
<td>0</td>
<td>72.5</td>
<td></td>
</tr>
</tbody>
</table>

Site 709
Site Description Fire Station 82
Project Description NSOE Anemometer Loan Program
Location Description Henderson, NV
Site Elevation 1700
Latitude 36.0598
Longitude 115.023
BIBLIOGRAPHY


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FA-240, Quincy, MA


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[41] University of Utah, Department of Meteorology MesoWest Project, NOAA Cooperative Institute for Regional Prediction, ROMAN site, http://www.met.utah.edu/roman/


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    Committee Member, Dr. Yitung Chen, Ph.D.
    Graduate Faculty Representative, Dr. Jichun Li, Ph.D.