NEW MEXICO DEPARTMENT OF TRANSPORTATION

RESEARCH BUREAU

Innovation in Transportation

DUST STORM DETECTION AND NOTIFICATION SYSTEM

Prepared by:
Department of Civil Engineering
New Mexico State University
Box 3001, MSC 3CE
Las Cruces, NM 88003-8001

Prepared for:
New Mexico Department of Transportation
Research Bureau
7500B Pan American Freeway NE
Albuquerque, NM 87109

In Cooperation with:
The US Department of Transportation
Federal Highway Administration

Final Report
NM09TT-01

December 2011

US DOT FHWA SUMMARY PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NM09TT-01		

4. Title and Subtitle Dust Storm Detection and Notification System: Phase 1 (Needs and Equipment Assessment) and Phase 2 (Equipment Procurement)	5. Report Data December 2011 6. Performing Organization Code
7. Authors(s): Ruinian Jiang, Jie Zhang, Greg Walke	8. Performing Organization Report No.
9. Performing Organization Name and Address New Mexico State University Department of Civil Engineering P.O. Box 30001, MSC-3CE Las Cruces, NM 88003	10. Work Unit No. (TRAIS) 11. Contract or Grant No. CO 5252
12. Sponsoring Agency Name and Address NMDOT Research Bureau 7500B Pan American Freeway PO Box 94690 Albuquerque, NM 87199-4690	13. Type of Report and Period Covered Final report (May 2008 – December 2011) 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Periodic dust storms in the southwestern region of New Mexico present significant safety hazards to motorists. The associated direct and indirect costs are significant. This project identified the need to continuously detect dust storms and deployed an automated system that will notify motorists of limited visibility conditions, direct motorists how to respond, notify the appropriate authorities, and that is capable of being incorporated into the appropriate New Mexico Department of Transportation (NMDOT) District's existing incident management plan. In Phase I of the project, a needs assessment and equipment survey was performed. The assessment included evaluation of available equipment, appraisal of typical financial and operational requirements of dust storm detection and notification systems, and assessment of associated equipment-specific costs and system performance expectations. The Roadside Weather Information System (RWIS) was selected as the key equipment for dust storm detection. In Phase II, two RWIS stations were purchased and installed: One at MP11 and the other at MP12 on the I-10 New Mexico section. It is recommended that Phase III carry out a two-year, long-term system monitoring and evaluation test. Phase III will verify the performance of the equipment, especially during the dust storm seasons. Optimal ways to maintain and use the equipment and the impact of the dust storm detection system on traffic safety should also be evaluated.

17. Key Words	18. Distribution Statement
Dust storm, RWIS, detection, notification	Available from NMDOT Research Bureau

19. Security Classi. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	66	

DUST STORM DETECTION AND NOTIFICATION SYSTEM: PHASE I (NEEDS AND EQUIPMENT ASSESSMENT) AND PHASE 2 (EQUIPMENT PROCUREMENT)

Final Report (Technical)

Prepared by

Ruinian Jiang, Jie Zhang
College of Engineering, New Mexico State University

Greg Walke
University Architect, New Mexico State University

Report NM09TT-01

A Report on Research Sponsored
by

New Mexico Department of Transportation
Research Bureau

In Cooperation with
The U.S. Department of Transportation
Federal Highway Administration

December 2011

NMDOT Research Bureau
7500B Pan American Freeway NE
PO Box 94690
Albuquerque, NM 87199-4690
(505)-841-9145

PREFACE

The research reported herein explores the needs assessment and equipment survey for the New Mexico highway dust storm detection and notification system. The assessment includes evaluation of available equipment, appraisal of typical financial and operational requirements of dust storm detection and notification systems, and assessment of associated equipment-specific costs and system performance expectations. The assessment also provides recommendations for best-fit options, as justified, and various best-fit alternatives that are intended to satisfy identified needs in consideration of administrative and financial constraints. This system is capable of being incorporated into the appropriate New Mexico Department of Transportation (NMDOT) district's existing incident management plan.

NOTICE

DISCLAIMER

EXECUTIVE SUMMARY

Periodic dust storms in the southwestern region of New Mexico present significant safety hazards to motorists. The associated direct and indirect costs are significant. New Mexico Department of Transportation (NMDOT) has identified the need to automate an incident management process that is currently being performed manually. The objectives of this project were to find and deploy an automated system that will notify motorists of limited visibility conditions, direct motorists how to respond, notify the appropriate authorities, and that is capable of being incorporated into the appropriate NMDOT District's existing incident management plan. The research was carried out in two phases. In Phase I, a needs assessment and equipment survey was performed. The assessment included evaluation of available equipment, appraisal of typical financial and operational requirements of dust storm detection and notification systems, and an assessment of associated equipment-specific costs and system performance expectations. In Phase II, equipment recommended in Phase I was purchased, installed, and preliminarily evaluated, and training for operation was conducted. The site of this research was Interstate 10, from Milepost 5 to Milepost 15 in NMDOT District 1, Animas Dry Lake area.

After extensive literature search, interviews, and research, the research team recommended Roadside Weather Information System (RWIS) to be used as the equipment for dust storm detection. An open bid process was conducted accordingly. Vaisala was selected as the RWIS supplier, and Smith and Aguirre was selected as the local general contractor to install the equipment. Two RWIS stations were installed: One at MP11 and the other at MP12. The RWIS stations are powered by electricity and communication is by cellular wireless.

It is recommended to carry out a two-year, long-term system monitoring and evaluation test as Phase III of this project. The Phase III project will verify the performance of the equipment, especially during dust storm seasons. Optimal ways to maintain and use the equipment and the impact of the dust storm detection system on traffic safety should also be evaluated.

ACRONYMS

Term	Definition
ADOT	Arizona Department of Transportation
ARDIS	Automated Remote Digital Imaging System
AVHRR	Advanced Very High Resolution Radiometer
AWI	All Weather, Inc.
CCTV	Closed Circuit Television
DCI	Dust Concentration Index
DOT	Department of Transportation
ESS	Environmental Sensor System
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
GOES	Geostationary Operational Environmental Satellites
ITS	Intelligent Transportation System
MODIS	Moderate Resolution Imaging Spectroradiometer
MSI	Meteorological Solutions Inc.
NM	New Mexico
NMDOT	New Mexico Department of Transportation
NMSU	New Mexico State University
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
PWD	Present Weather Detector
QTT	Quixote Transportation Technologies, Inc.
RFP	Request for Proposal
ROW	Right of Way
RPU	Remote Processing Unit
RWIS	Road Weather Information Systems
SeaWiFS	Sea-viewing Wide Field of view Sensor
SHRP	Strategic Highway Research Program
TIR	Thermal Infrared
TMI	TRMM Microwave Imager
TOMS	Total Ozone Monitoring Spectrometer
TRMM	Tropical Rainfall Measuring Mission
USGS	U.S. Geological Survey
VNIR	Visible/Near Infrared
WMO	World Meteorological Organization

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION AND RESEARCH NEEDS

1.1 INTRODUCTION

A dust storm is a common phenomenon in arid and semi-arid regions. It is caused by strong wind that carries fine particles, such as clay, silt, sand, and other materials, often for long distances. A dust storm can spread over hundreds of miles and rise over 10,000 feet with wind speeds of at least 25 mile/hour. Dust storms always start without any warning in the form of a dust wall with dust and debris. A dust storm is blinding and can cause environmental and economic damage. Besides that, a dust storm can cause serious accidents on highways. Therefore, detection of dust storms is an important task for departments of transportation in dry regions. FIGURE 1-1 shows a picture on Interstate Road 10 (I-10) in New Mexico when a dust storm is occurring.

FIGURE 1-1 Dust Storms along I-10, New Mexico

There are different types of dust storms. Some occur with cold fronts or strong gradient winds. This synoptic type of dust storm occurs over very large areas. Asian dust storms are known to blow all the way to the United States. Generally, they can be detected with satellite imagery (due to minimal cloud cover), so early warning is possible.

Another type of dust storm occurs with convective winds. These dust storms (also known as haboobs) occur with thunderstorms. Haboobs form under thunderstorms when strong cold downdrafts (convection) create strong surface winds which stir up dust and form gust fronts. Haboobs occur in the Sahara desert, the Middle East and parts of the Southwestern US in areas of low vegetation and low moisture. The average life of a haboob is 3 hours. A haboob generally travels at about half the speed of the storms wind speed.

Haboobs are of particular interest to traffic management because they can form suddenly, create zero visibility, are difficult to detect with satellite images, and are difficult to predict. According to Max Bleiweiss, New Mexico State University (NMSU) professor and physicist for the Army Research Laboratory, haboobs are difficult to detect by satellites because cloud cover often hides the dust, but it is possible that the front edge of a haboob may be visible in front of the clouds (as shown in FIGURE 1-2). Understanding when dust will be lifted into the air is important for any detection system. Generally, a minimum wind speed of 15 knots or 17.2 mph is required to get dust aloft. Dust particles with a diameter of 20 µm will remain aloft, whereas larger particles will fall fairly quickly. If a road is close to the source of dust, such as at Lordsburg, New Mexico, the larger particles may also be of concern.

FIGURE 1-2 A Haboob Under a Storm Cloud *(1)*

1.2 RESEARCH NEEDS

Reduced visibility on highways due to dust storms has often been the cause of tragic traffic accidents. It is possible for vehicles at highway speed suddenly to enter a low visibility area. This can cause serious accidents or even loss of life. Therefore, to detect a real-time dust storm and give warning to drivers before they enter the dust storm area to reduce the risk of an accident is very important.

In southern New Mexico, unpredictable dust storms are common between April and September. Dust storms cause blinding conditions on highways and result in loss of property, injury, and death. Dust storms exist along Interstate 10 from Milepost 0 to 164; the locations where dust storms cause most serious traffic problems are identified on Interstate 10 from Milepost 5 to Milepost 15 in New Mexico Department of Transportation (NMDOT) District 1, close to Lordsburg. For this reason, this section of the road was selected as the project site for this research (see FIGURE 1-3). According to Mike Hardiman of the National Weather Service in Santa Teresa, New Mexico, there is no meteorological observing system at Lordsburg, so local dust storms could pass unobserved until they cause a problem on the highway.

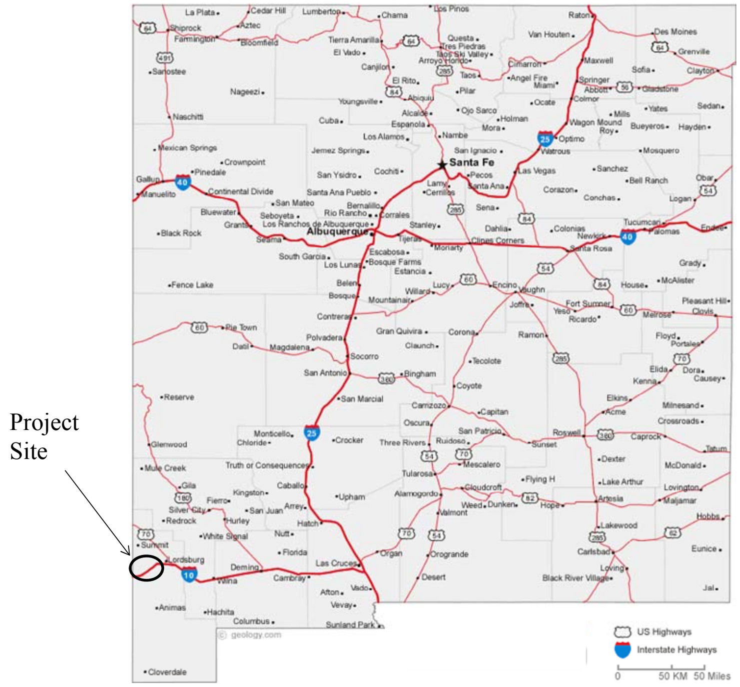


FIGURE 1-3 Project Site

Dust storms come from the La Playa area on both sides of Interstate 10, i.e., the Animas Dry Lake area (see FIGURE 1-4). The large white areas in FIGURE 1-4 are bare earth deposits that are submerged under water during the rainy season (July – September), becoming dry the rest of the year, releasing dirt particles to form dangerous dust storms when the wind blows.

FIGURE 1-4 La Playa Area Near Lordsburg *(2)*

Blinding, blowing dust storms frequently reduce visibility to near zero, creating unexpected and unsafe conditions for motorists. Each year, several serious accidents and many injuries occur on

I-10 in the southwest region as a result of sudden, violent dust storms (see FIGURE 1-5). Because dust storms can occur at any time, their “hit and miss” characteristic makes it difficult to trace all the events. For example, a recent traffic accident caused by a dust storm on I-10 was reported on September 27, 2011. According to the Arizona Department of Public Safety, nine cars and three semis were involved with twelve people injured. The accident occurred at mile post 214 on I-10. Traffic in the eastbound lanes was backed up for miles. Traffic accidents caused by dust storms are generally very severe due to the blinding condition on the road.

NMDOT currently does not maintain an historical record of dust storm events, but records of road closures caused by dust storms are available. Many drivers caught in dust storms have had bad experiences; they express their experiences as feeling like they are “going to die.”

To detect dust storms and warn drivers on highways, NMDOT has decided to install an Intelligent Transportation System (ITS) along I-10, including an automatic dust storm detection and warning system. FIGURE 1-6 gives an illustration of a dust storm detection and warning system.

FIGURE 1-5 Traffic Accident Caused By Dust Storm

In FIGURE 1-6, a section of highway is in a potential dust storm area. When a dust storm happens, the dust storm detection system automatically detects the dust storm. Then the control center sends a message to the warning system on the highway to warn drivers approaching the dust storm (e.g. dynamic message devices). When drivers see the warnings, they can detour to an alternate road and avoid the dust storm area or park at a roadside facility and wait until the dust storm passes. In this way, the dust storm detection and warning system can dramatically reduce the risk of accidents caused by dust storms.

Currently, NMDOT District 1 has highway patrol teams at Deming and Lordsburg areas. People personally patrol the field and inform the public information office which dispatches by phone or radio. Notification of a dust storm is broadcast through NMDOT website, cars 511, and the telephone. Currently, no specified NMDOT personnel strictly do dust storm detection. Because of the severity of traffic accidents caused by dust storms in this area, it has been decided that there is a need to install a more advanced dust detection and notification system to help field people respond more rapidly and take action before a serious incident occurs.

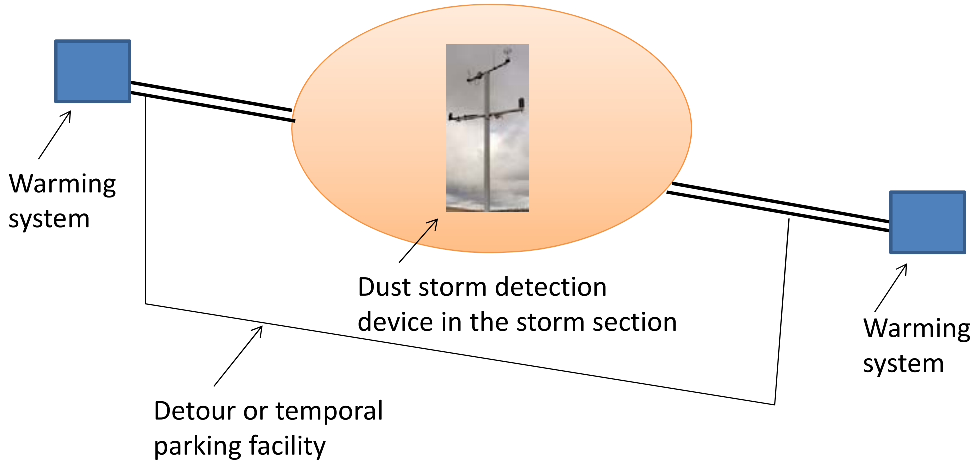


FIGURE 1-6 Schematic of a Dust Storm Detection and Warning System

The research was carried out in two phases. In Phase I, a needs assessment and equipment survey was performed. The assessment included evaluation of available equipment, appraisal of typical financial and operational requirements of dust storm detection and notification systems, and assessment of associated equipment-specific costs and system performance expectations. The assessment also provided recommendations for best-fit options as justified. Various best-fit alternatives intended to satisfy identified needs in consideration of administrative and financial constraints also were provided. In Phase II, equipment recommended in Phase I was purchased, installed, and preliminarily evaluated, and training for operation was conducted.

This report summarizes findings from each phase and provides suggestions for the long-term evaluation and operation of the system. The report is organized as follows. Section 1 introduces the background of this project. Section 2 summarizes the process and findings from Phase I of the project, and Section 3 describes the equipment purchased and installed in Phase II, as well as preliminary evaluation and training. In Section 4, suggestions for long-term evaluation and operation of the system are presented.

2 PHASE I: NEEDS AND EQUIPMENT ASSESSMENT

2.1 SITE ANALYSIS AND MAINTENANCE AND OPERATIONAL ISSUES

Based on information from Natural Resources Conservation Service (NRCS), typical soils in semiarid regions are found along Interstate 10 in New Mexico, from silt to fine sand, which were formed by gradual weathering and leaching of coarse textured sands and gravels washed down from surrounding mountains. They have various colors, such as yellow, brown, gray, and red, retaining characteristics acquired during cycles of heavier rainfall related to continental and alpine glaciers. The soils at the study field are mostly silty clay, silt loam, and loamy sand. They have high wind erosion potential and can be blown aloft in the air when the wind speed reaches 17 mph and above.

As discussed in Section 1, dust storms frequently occur along I-10 New Mexico section and cause serious traffic accidents. NMDOT has both short- and long-term dust storm detection and notification needs. In the short term, NMDOT road patrol teams urgently need technical assistance that is able to detect dust storms continuously in order not to miss any serious events in the field. In the long term, NMDOT needs a comprehensive plan to install sufficient dust storm detection systems along I-10 to cover all the potential dust storm sections and use them effectively based on research on the performance of the equipment and the study of dust storm patterns and ways to integrate the equipment with routine traffic management and safety improvement. Currently there is no ITS team in District 1 but there are people who deal with ITS in the district. The formal ITS team is in Albuquerque. The maintenance patrol in the Lordsburg area and the maintenance office in Deming are the people in charge of dust storm detection in these areas. Dust storm detection currently solely relies on highway patrol teams' personal judgment and experiences.

According to interviews with NMDOT engineers, NMDOT does not want a system that is so complex that it defies the purpose of having a system; it needs to be user-friendly and practical. Alternative systems at different levels are preferable to provide NMDOT with flexibility in decision making. When a proposed system is submitted, it is not only up to one group to decide. A collective decision is made between the research group, NMDOT District 1 in Deming, and NMDOT ITS Bureau in Albuquerque.

Because the dust storm detection systems are small in size, the installation of a dust storm detection system is not expected to have any significant environmental impact. With respect to environmental issues, the main consideration is how the environment (such as temperature, rain, dust, etc.) affects the operation of the equipment.

2.2 EQUIPMENT ASSESSMENT FOR DUST STORM DETECTION

In this report, application surveys and a literature search of the instruments that can be used to detect dust storms on highways were carried out. As a result of application and literature search, it was found that dust storms happen in most countries in the world. To detect dust storms, it is necessary to determine the regions where dust storms can happen. Washington et al. used meteorological data from ground stations, from the space-borne Total Ozone Monitoring Spectrometer (TOMS), and from the National Center for Environmental Prediction-National Center for Atmospheric Research reanalysis project to analyze dust storm source areas *(3)*. This analysis concluded that the key source region of dust storms is the Sahara. Besides the Sahara, other key regions include the Middle East, Taklamakan, southwest Asia, central Australia, the Etosha and Mkgadikgadi basins of southern Africa, the Salar de Uyuni (Bolivia), and the Great Basin (United States).

Different countries and different regions have different approaches and instruments for detecting dust storms in real time. The most widely used instruments and technologies include weather radars, remote sensing technologies, and visibility sensors.

Interviews with other state DOTs, including Texas, Arizona, Idaho, Utah, Colorado, Oregon, Nevada, California, and Wyoming, revealed that visibility sensors are commonly used by these state DOTs in detecting dust storms. Based on comments from these DOTs, the visibility sensor is effective in detecting dust storms. Therefore, as a result of this research, visibility sensors were selected to be recommended to NMDOT. Details of the application surveys and literature search of the instruments are introduced in the following subsections.

It was found that most publications on dust storms focused on theoretical analysis of the source, creation, and characteristics of dust storms. Very limited publications were found pertinent to this practical research. Therefore, intensive communications with other state DOTs were conducted. The results from the literature search provided some guidance for the study.

Four types of dust storm detection systems were found to have a potential impact on this research:

- Weather radar detection system
- Space based sensors/ Remote sensing through satellite
- Optical visibility sensors, and
- Digital camera and machine vision.

2.2.1 Weather Radar

The weather radar was originally used to detect weather, especially precipitation. As the technology developed over time, it was widely used in more areas, including dust storm detecting. Hannesen *et al.* mentioned that the Doppler radar can detect a dust storm when the number, concentration, and size of dust particles are large enough *(4)*. FIGURE 2-1 shows a Doppler radar.

Mechanism of Weather Radar

The radar works by sending radio waves into the atmosphere. When the waves strike an object, they bounce back to the antenna. Objects that reflect the waves can be raindrops, sleet snow, hail, bird migrations, insect swarms, and dust storms. This means the weather radar can detect most weather conditions, as well as dust storms *(5)*.

FIGURE 2-2 explains how the weather radar works to detect precipitation or dust storms. By bouncing a radio wave off of it and detecting the time it takes for the signal to return, the weather radar can detect the presence and location of an object. Using the travel time of the wave and the wave speed, the distance traveled by the wave can be determined *(6)*.

The radar can show the location and intensity of precipitation by converting the radio waves reflected back to the antenna to pictures, and it can also determine the direction of the precipitation and winds by measuring the frequency change in the returning radio waves. The weather radar can detect most precipitation types as far as 90 miles away from the test site, or even 150 miles away for intense rain and snow *(5)*.

FIGURE 2-1 Doppler Radar *(7)*

The weather radar is not specifically used to detect dust storms. Because the radar detection results for precipitation have similar behaviors to that of dust storms, to detect a dust storm technically, there should be some special way to analyze the radar detection data. According to Hannesen et al., dust storm particles are much smaller than precipitation particles *(4)*. As a result of this and due to the reduced backscattering constant of dust particles compared to water, reflectivity values measured by a C-Band Weather Radar will be very low in dust storms *(4)*. These typical characteristics of dust storms can be used to distinguish a dust storm from precipitation. Hannesen et al. give three steps for detecting dust storms:

1. Calculation of mean wind speed
2. 2D-Segmentation of reflectivity data
3. 3D-Segmentation of reflectivity data

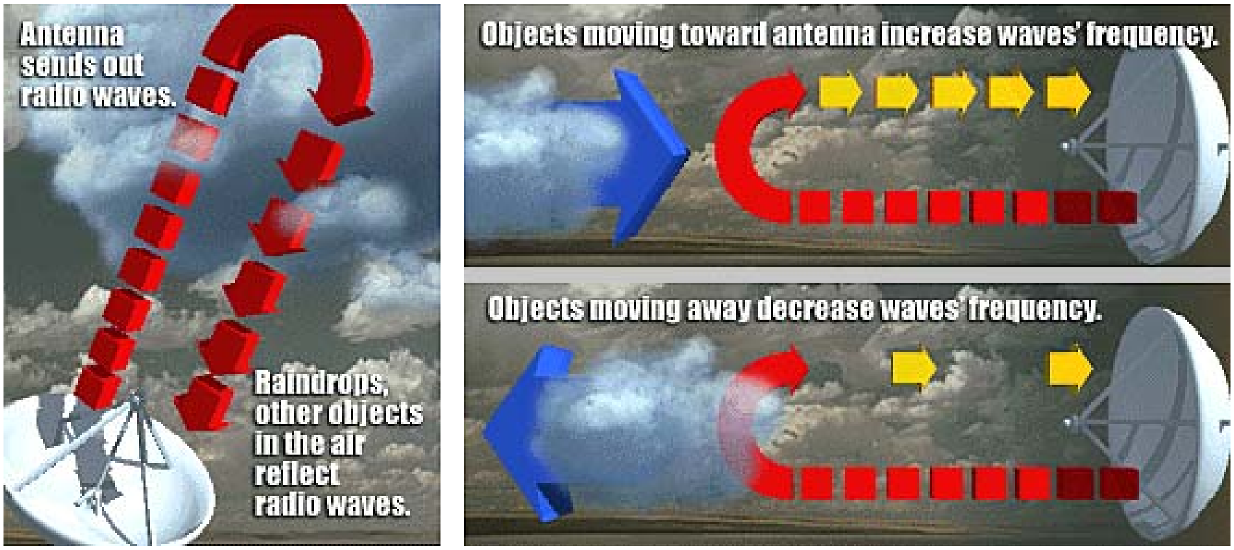


FIGURE 2-2 Detection of Weather with Weather Radar *(6)*

High-speed wind is necessary for dust storm occurrence. According to Hannesen et al. *(4)*, the wind speed must exceed a minimum value (10 m/s) so that it can derive dust storms. On the basis of high wind speed, the reflectivity data of each elevation slice are then smoothened to two-dimensional segments. In these 2D-Segements data, the ones where the percentage of high-reflectivity exceeds 10% are discarded. By analyzing the reflectivity data, the dust storm echoes can be separated from precipitation echoes. Then all the remaining 2D-Segments of all elevations are merged into 3D-Segements. If the merged 3D-Segements meet all four conditions listed in TABLE 2-1, the areas are treated as dust storm occurrences.

TABLE 2-1 Dust storm conditions of 3D-segements.

The vertical extent must be OK, i.e., the top height must be between a user-selectable upper and lower level (default values are 4.0 and 0.5 km, respectively) and the segment must extend down to the lowest elevation slice.
The mean spectrum width (in m/s) must exceed a user-selectable threshold (default value 2.0 m/s).
The reflectivity should decrease with height, so the vertical reflectivity gradient must not be larger than another threshold (default -1.0 dB/km).
To avoid small-scale false alarm phenomena, the 3D-Segment must have a minimum volume (default 500 km^3, i.e. an area of approx. 200-300 km^2).

Weather radar can be used to detect dust storms, as Hannesen et al. mentioned. Weiss and Pazmany *(8)* also mentioned using a W-band (3-mm wavelength) Doppler radar to detect dust storms in Texas. The weather radar can detect the speed and direction that a storm is moving. This can save lives of people in storm areas. Moreover, if the weather condition is likely to produce thunderstorms, the weather radar can forecast thunderstorms by analyzing the images created by the weather radar *(6)*. FIGURE 2-3 shows weather radar images of a hurricane and lake enhanced snow. In addition, as Vincent stated, the weather radar can also be used to detect and track tornadoes *(9)*.

Weather radar detection is area detection. This means, for area detection, one radar can do all the work. The weather radar is now used by many countries in the world, including U.S.A, U.K, Germany, Japan, China, etc.

Disadvantages of Weather Radar

Even though the weather radar is very useful for detecting most weather conditions, including dust storms, it does have some shortcomings. No radar can detect directly above it because the radar antenna is pointing out instead of pointing up. Another disadvantage of weather radar is that the cost of it is very high. The high cost of weather radar makes it impossible to use for some small projects, such as the detection of dust storms in some areas along a highway.

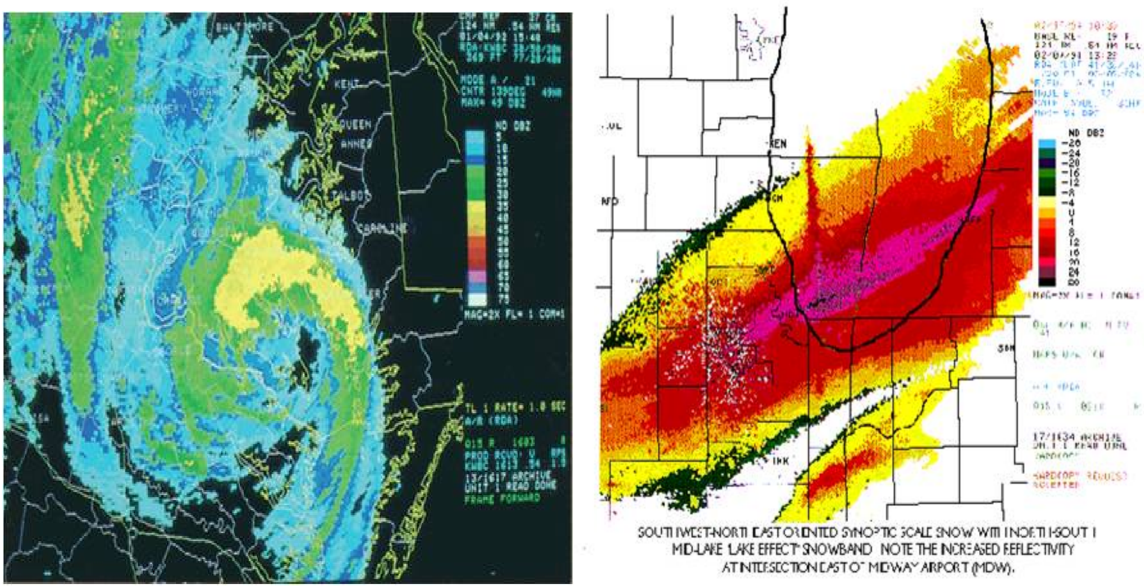


FIGURE 2-3 Doppler Radar Images of A Hurricane (Left) and Lake Enhanced Snow (Right) ***(6)***

2.2.2 Space-Based Sensors/Remote Sensing Through Satellite

Remote sensing through satellite systems can be used to detect the source and the transmission of dust storms occurring over very large areas (synoptic dust storms). Most current research focuses on how to separate dust storms from water/ice clouds. There are many space-based, remote sensors that can be used to detect dust storms. These remote sensors are developed based on satellite technology. Geostationary Operational Environmental Satellites (GOES) have high temporal resolution, so they are considered to be the most suitable systems to track the time evolution of active and short-lived dust storms *(10)*. Landsat TM can be used to map the dust source location accurately if the image is cloud-free because of its good spatial resolution *(10)*. The Sea-viewing Wide Field of view Sensor (SeaWiFS) is very good at detecting dust storms lasting for a long time and having a dark background *(11)*. The Total Ozone Mapping

Spectrometer (TOMS) can be used in the ultraviolet range *(10)*. However, all the above-mentioned space-based sensors have their own limitations for detecting dust storm. Therefore, according to *(10)*, the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) are the best suited for detecting dust storms.

Of particular interest in dust storm detection and monitoring are the Advanced Very High Resolution Radiometer (AVHRR) and MODIS sensors because of their relatively higher temporal resolutions (once per day) compared with Landsat. The nighttime thermal imaging capability of AVHRR and the higher spectral resolution of MODIS also assist with detecting dust emission and mapping the vulnerability of the landscape to wind erosion. MODIS proved to be superior in its spectral and spatial resolution. Utilizing Terra and Aqua MODIS provides an improved temporal resolution over AVHRR as their combined coverage is now twice per day. Although these products are useful for capturing synoptic dust storms, it would not be practical, at present, to use these remote-sensing systems to forecast local dust storms. With further improvement of these systems, it might be feasible in future to rely on such remote sensing systems to detect local dust storm events. At present, certain information such as dust storm origin can be obtained from these systems. For example, FIGURE 2-4 shows the satellite image of the dust storm at White Sands on March 14, 2008.

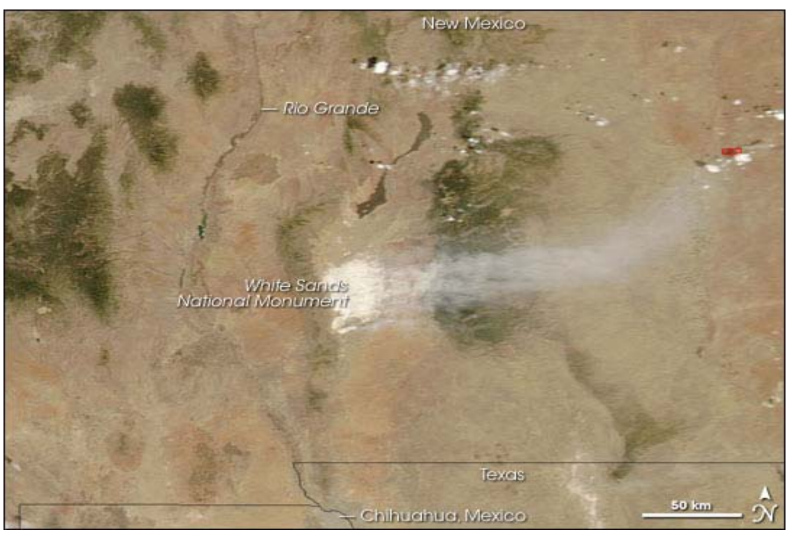


FIGURE 2-4 Dust Storm at White Sands, New Mexico, March 14, 2008

MODIS

Moderate Resolution Imaging Spectrometer (MODIS) is a payload scientific instrument launched into Earth orbit by NASA in 1999 on board the Terra Satellite and in 2002 on board the Aqua satellite *(12)*. Most space-based sensors can be affected by clouds. However, cloud effects can be removed by using the MODIS because it has some useful visible/near infrared (VNIR) and thermal infrared (TIR) bands for cloud screening *(13)*. Additionally, the MODIS is on Terra and Aqua satellites; they can collect data both in daytime and nighttime *(13)*. Thus, they can supply more real-time data to study dust storm motion processes and also supply more information for the government *(13)*. FIGURE 2-5 shows the MODIS dust enhancement (shown on the right) in the dry lake area.

MODIS captures data in 36 spectra bands with a wavelength ranging from 0.4 µm to 14.4 µm *(10)*. It captures data at varying spatial resolutions, such as 2 bands at 250 m, 5 bands at 500 m, and 29 bands at 1 km *(12)*. Together, the two instruments image the entire Earth every 1 to 2 days. They are designed to provide measurements in large-scale global dynamics, including changes in Earth's cloud cover and radiation budget and processes occurring in the oceans, on land, and in the lower atmosphere *(12)*.

Because the MODIS was designed to remotely sense atmospheric temperature, moisture profile, clouds, aerosols, and surface properties *(14)*, to detect a dust storm, proper ways to analyze MODIS data should be determined.

There are many ways to analyze MODIS data to detect dust storms, according to previous research. Han et al. introduced an approach to dust storm detection in the Northwest of China by means of a decision tree classifier based on the Moderate Resolution Imaging Spectrometer (MODIS) visible bands data *(15)*. This technology is based on different reflectance of different materials to detect dust storms and other climate conditions, such as snow cover, water cover, etc. Different materials are classified at different levels in a decision tree by the differences of reflectance. Specifically, the reflectance of snow, cloud cover, and water at 0.47µm is higher than that at 2.1µm, whereas the reflectance of a dust storm at 0.47µm is lower than that at 2.1µm. Based on this property of a dust storm, a dust storm is classified in a different level from other land covers. In addition, a dust storm can be detected by the MODIS because of this property.

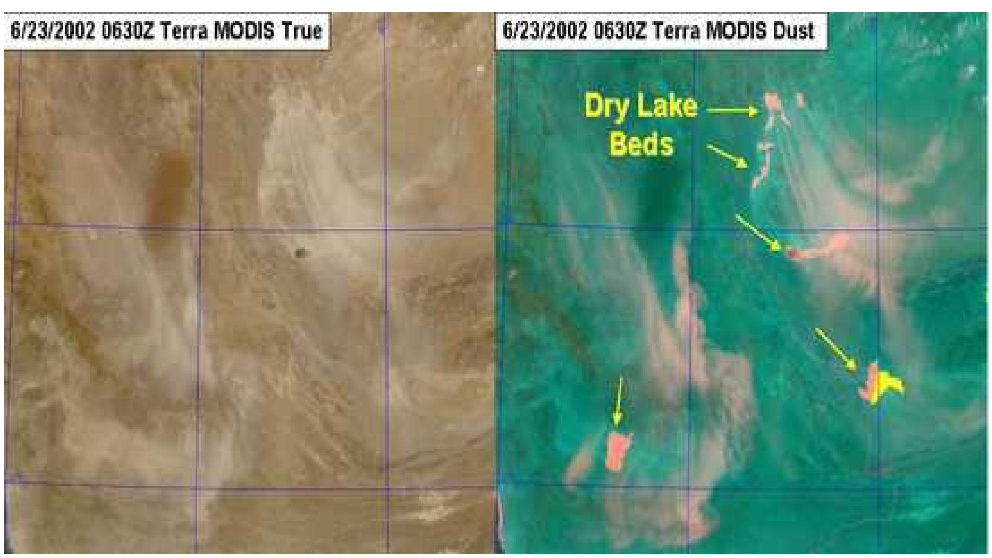


FIGURE 2-5 MODIS Dust Enhancement (Arrows Point to the Dust Source Regions) ***(15)***

Liu et al. *(13)* used a tri-spectral technique with 8.5μm, 11μm, and 12μm wavelengths to detect dust storms for MODIS data. In this research, the authors collected the brightness temperature data from MODIS images. Then, they used the combining brightness temperature differences to detect dust storms. The brightness temperature data are collected from MODIS images. For example, on clear days, the water vapor absorption is stronger in 12μm than that in 11μm. Whereas, on a day during a dust storm, dust particles extinction is stronger in 11μm than that in 12μm. This brightness difference can be used to detect dust storms. Other researchers *(14,16-20)* also used similar techniques based on MODIS data to detect dust storms in China.

2.2.3 Optical Visibility Sensor

Another device that can be used to detect a dust storm is a visibility sensor. Visibility sensors measure atmospheric visibility by determining the amount of light scattered by particles, such as dust, smoke, haze, fog, rain, and snow, in the air that passes through the optical sample volume.

Mechanism of Visibility Sensor

For most kinds of visibility sensors, the parameter of the ultimate extinction coefficient, which gives the amount of attenuation of a light, is measured to check the visibility of the air. The extinction coefficient is related to the scattering coefficient through a complicated extinction integral which includes the scattering coefficient as a parameter. If light travels through an aerosol medium, such as atmospheric air, there will be some amount of attenuation of the light. The light beam on the visibility sensor will experience this attenuation amount *(21)*.

There are a wide range of prior art devices intended to measure the extinction coefficient of an aerosol. The forward scatter is one such kind. It offers several distinct advantages. In forward scatter meters, the receiver accepts light from a source which has been scattered in a near-forward direction. The scattering coefficient in the direction of an angle of approximately 150 degrees between the axis of the beam and the axis of the receiver is nearly independent of the particle-size distribution of the aerosol. For other angles, the ratio of the wavelength of optical energy used to probe the sample, to the size of the particles in the aerosol causes variations in the angular scattering coefficient for a given aerosol. Several regimes of size ratios are addressed in current theoretical literature *(21)*. Most of the visibility sensors that are widely used in the world are using forward scatters in visibility detection, such as visibility sensors from Quixote, Vaisala, Vibtel, Allweather, etc. FIGURE 2-6 shows a forward scatter visibility sensor, Vaisala weather sensor FD12P, which is produced by Vaisala Inc.

The Vaisala weather sensor FD12P includes an optical forward scatter sensor, an analog capacitive surface sensor, a temperature sensor, and a special algorithm. The function of each instrument is described in TABLE 2-2.

FIGURE 2-6 Vaisala Weather Sensor FD12P *(22)*

TABLE 2-2 Instruments on Vaisala weather sensor FD12P and functions *(22)*.

Instruments	Functions
Forward scatter	Senses fog and also distinguishes between precipitation types
Analog capacitive surface sensor	Feels the amount of water falling on it
Sensor a temperature sensor	Measures the temperature
Special algorithm	Calculates accurate present weather and visibility values using data collected from all the sensors

FIGURE 2-7 shows a diagrammatic of a visibility sensor system with a visibility sensor head. This visibility sensor system was mainly designed to detect fog on the highway. The same mechanism can also be used to detect a dust storm. In FIGURE 2-7, the central controller is the control center of the whole intelligent transportation system *(23)*. It controls the behaviors of all the instruments in this system. The micro controller is the control center of the visibility sensor system; it controls the visibility sensor, precipitation sensor, temperature sensor, etc, as shown in FIGURE 2-7. The sensors in the visibility sensor system can be used to measure air temperature, precipitation, humidity, atmospheric pressure, etc. In FIGURE 2-7, the instruments contained in 28 compose the visibility sensor head as a whole *(23)*. The visibility sensor head is the most important part in the visibility sensor system that is used to detect particles in the air.

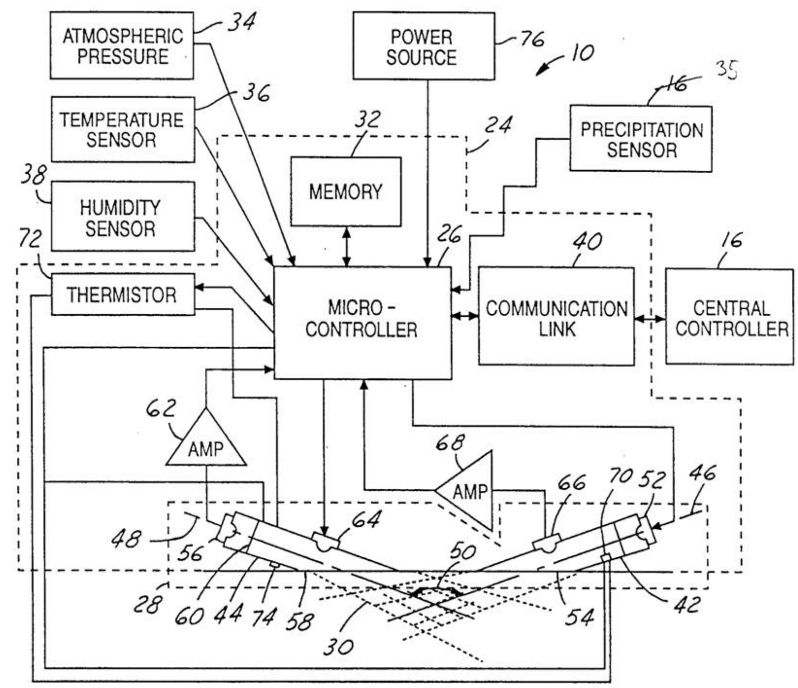


FIGURE 2-7 Diagrammatic of visibility sensor system with a visibility sensor head *(23)*

Application

Visibility sensors are mainly used for weather detecting for airports and roads, air quality studies, and fog warning networks *(24)*. Visibility sensors can detect precipitation types and intensity. By calculating the precipitation accumulation, visibility sensors can distinguish precipitation types. With the same mechanism for detecting precipitation, visibility sensors can also detect other types of particles in the air, such as fog, smoke, and dust storms.

To distinguish different kinds of particles in the air, visibility sensors need to be calibrated to a specific critical value for a specific usage, such as a dust storm. Du et al. *(25)* tried to use a visibility sensor to detect dust storms in China with a Dust Concentration Index (DCI) being defined to detect a dust storm. This DCI was developed based on specific particle sizes and the particle numbers of dust storms. As a result of their research, dust storms can be detected with the DCI.

The visibility sensor was originally designed to detect fog and precipitation. To distinguish dust storms, specifically, similar research as for the above mentioned DCI should be analyzed and determined for a specific visibility sensor. Because the dust storm is related to several environmental factors, such as wind, humidity, etc., the final decided index of a dust storm should be a function of the density of dust particles, particle sizes, and environmental factors.

Visibility sensors are widely used in the world, for example in Europe, North America, and Asia. In Spain, United Arab Emirates, and Saudi Arabia, visibility sensors are used in road and rail tunnel applications.

In the United States, visibility sensors are widely used by state DOTs to detect weather, especially precipitation. Some DOTs also use them to detect dust storms along highways.

Disadvantages of Visibility Sensors

Forward-scattering meters are less sensitive to particle size than back-scatter meters or conventional linear path transmissometers *(21)*. In addition, the total scattering coefficient is much greater in a general forward direction than a backward direction, and this manifests itself in an appreciably higher signal to noise ratio at the optical receiver. Another disadvantage of using a visibility sensor is there are no industry standards for visibility *(24)*. Lack of industry standards for visibility may cause misunderstandings of sensor specifications and requirements *(24)*. The accuracy and key parameters of measured data for different sensors also may be different.

2.2.4 Digital Camera and Machine Vision

A digital camera and machine vision is a very promising tool for local dust storm detection. The technology in this field has developed very rapidly in the last decade. The resolution and memory capacity of digital cameras have been improving steadily at a fast pace, while the price has reduced. This makes it more feasible for the application of dust storm detection.

The U.S. Geological Survey (USGS) developed a system using digital cameras that records dust events. Starting in March 2000, the USGS implemented an Automated Remote Digital Imaging System (ARDIS) in the Mohave Desert in California *(26)*. The system consists of four digital cameras, an anemometer (wind speed sensor), a data logger, batteries, solar panel (to recharge the batteries), a 128 MB flash card, and an environmental enclosure. FIGURE 2-8 depicts the ARDIS setup in situ. FIGURE 2-9 shows the inside of the system. Specific information on the equipment being used by the USGS is available. According to USGS, the digital cameras are capable of monitoring dust storms up to 20 km away. Four digital cameras are controlled by a data logger, which receives information from an on-site anemometer (wind velocity sensor). The data logger automatically triggers three of the four cameras to collect digital photographs when wind exceeds a selected threshold. The data logger triggers the fourth camera twice daily to collect photographs for visibility change analysis. A system like this would help build an historical database of information on dust storms in the Southern New Mexico and provide real time dust storm information with some system upgrades. FIGURE 2-10 shows two pictures of a detected dust storm using a camera.

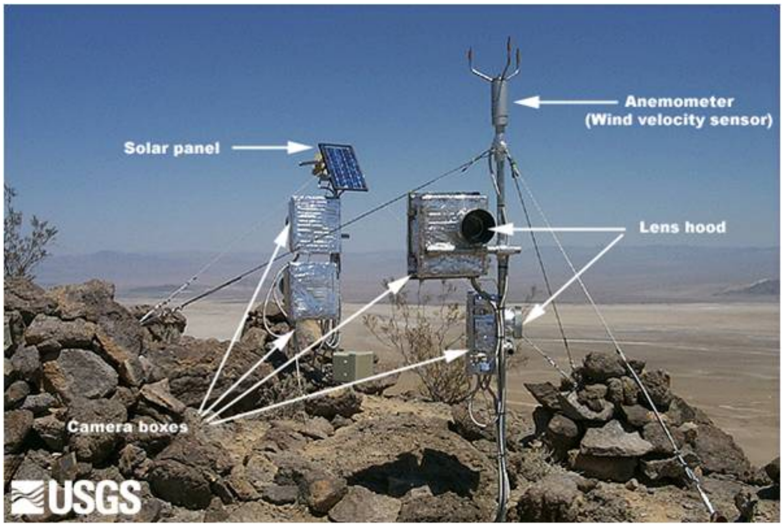


FIGURE 2-8 Automated Remote Digital Imaging System *(26)*

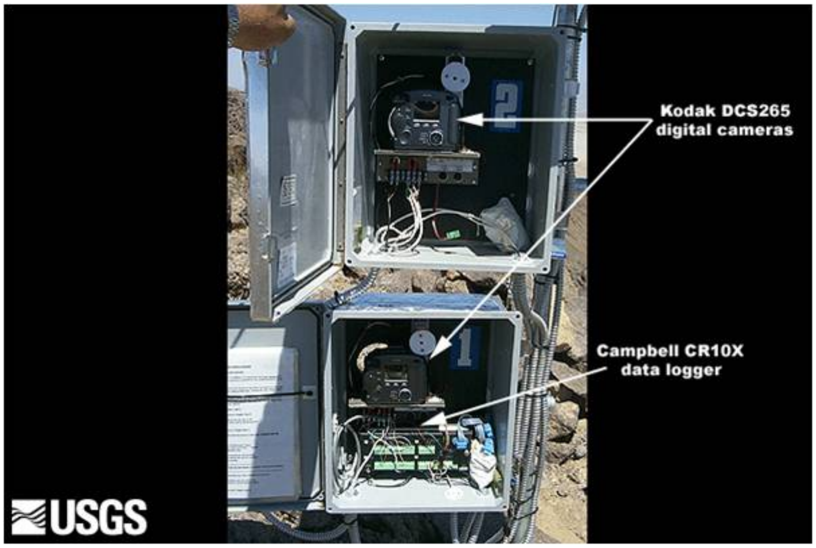


FIGURE 2-9 USGS Automated Remote Digital Imaging System (Inside) *(26)*

FIGURE 2-10 Camera Detection of Dust Storms *(27)*

2.3 TECHNOLOGY CHOSEN FOR DUST STORM DETECTION ALONG I-10

The above literature review and a survey of other state DOTs' practice using dust storm detection and notification systems found that visibility sensors and cameras (snap or video cameras) have been commonly applied for this purpose. Because of the high cost of weather radars and the immature technology of remote sensing technologies for dust storm detection, they were excluded as possible instruments for this project. The visibility sensors and cameras are used together with other weather detection equipment, and the whole system is called Road Weather Information Systems (RWIS). Based on the survey of current practice using dust storm detection, RWIS was selected as the key technology for Interstate 10 dust storm detection.

2.3.1 What is RWIS?

RWIS can be defined as a combination of technologies that uses historic and current climatological data to develop road and weather information (for example, nowcasts and forecasts) to aid in roadway-related decision making. According to Aurora, the pooled-fund program which unites state transportation departments with an interest in RWIS *(28)*, the three main elements of RWIS are:

- Environmental Sensor System (ESS) technology to collect data
- Models and other advanced processing systems to develop forecasts and tailor the information into an easily understood format
- Dissemination platforms on which to display the tailored information

According to the Federal Highway Administration (FHWA), an ESS is a weather station at a fixed roadway location with different types of sensors measuring atmospheric, surface (i.e., pavement and soil), and/or hydrologic (i.e., water level) conditions. These stations are typically deployed as field components of RWIS. Data collected from ESSs are stored onsite in a Remote Processing Unit (RPU). The RPU transmits environmental data to a central location via a communication system. A central RWIS station collects field data from several ESSs, processes data to support various operational applications, and displays or disseminates road weather data in a format that can be easily interpreted by a user.

For dust storm detection, the key issue is how to automatically measure the visibility distance. FHWA Best Practices for Road Weather Management (Version 2.0) explains that visibility distance can be measured directly with sensors or remotely via Closed Circuit Television (CCTV) cameras. Visibility sensors compute visibility distances by detecting the amount of scattered light by particles in the air. Cameras discern visibility distance by aiming at objects at known distances, such as roadside signs with flashing beacons.

2.3.2 The History and Status of RWIS Applications

There are over 2,400 Environmental Sensing Stations (weather stations, components of RWIS) in the United States. Both atmospheric (weather) and surface data are commonly collected. For dust storm purposes, only weather data, including air temperature, amount and type of precipitation, visibility, dew point, relative humidity, and wind speed and direction are needed. Data are collected by sensors placed at the roadside or in the roadway itself.

RWIS technology can be traced to the Strategic Highway Research Program (SHRP) (1988-1993). Two SHRP projects were developed. Project H-207 examined the emerging technology of RWIS, and Project H-208 considered the development of anti-icing technologies. In 1996, several state DOTs decided to develop a highly focused, pooled-fund program named Aurora to promote RWIS technology research and applications. Aurora has now become an international program of collaborative research, development and deployment in the field of road and weather information systems.

FHWA is also actively working to link all states' RWIS systems together into an organic national whole via the Clarus project *(28)*. Clarus is developing an integrated surface transportation weather observing, forecasting, and data management system. The objective of Clarus is to provide information to all transportation managers and users nationwide that can be used to alleviate the effects of adverse weather on surface transportation. Two components comprise Clarus: Initial development of the Clarus system, which is a network for sharing, quality checking, and exchanging surface environmental data and relevant surface transportation conditions; and development of tools (such as decision support systems) that make effective use of the Clarus system.

FHWA *(29)* has developed three categories of RWIS standards – siting standards, calibration standards, and communication standards. Siting standards are used to guide the installation of environmental sensor stations. Siting standards take into account the function of the sensor (forecasting, detecting, or monitoring) and conditions that affect a sensor's performance (including variations in terrain, weather patterns, road classification, and crew experience).

Calibration standards are procedures for testing the accuracy of sensor operations by comparing the performance of the sensor with established criteria and performance measures. There are two categories of communication standards: Communication protocols, used to exchange data between RWIS devices and other ITS devices, and display and message set standards, used to communicate weather and road conditions to end-users.

In this project, nine state DOTs were interviewed, including Texas, Arizona, Utah, Idaho, Colorado, Oregon, Nevada, California, and Wyoming. The basic information on the RWIS applications in these states is summarized in Appendix A, including type of visibility sensors used, companies that provided the RWIS systems, communication methods, system cost, and maintenance methods and costs. The information is valuable for determining system configurations for this project.

2.3.3 Basic Components of RWIS for Dust Storm Detection

The basic components of a RWIS for dust storm detection are listed in TABLE 2-3. It may vary for different companies.

TABLE 2-3 Basic components of RWIS for dust storm detection *(21)*.

a. Camera		**A fixed low light color camera** to provide daytime high quality color images of road and traffic conditions. Images are also provided overnight with the use of IR Illuminators.
b. Anemometer		**Wind Speed & Direction Sensor** to provide readings of wind speed and direction
c. Visibility sensor		**PWD Present Weather & Visibility Sensor** to provide readings of visibility (up to 2000 m or 1.24 miles) and differentiate between rain, drizzle, snow, mixed rain and snow, fog, and smoke/dust. The sensor calculates and provides actual precipitation rates, as well as accumulation of precipitation, and it determines the water equivalent of frozen precipitation (snow).
d. Air temperature & humidity sensor		**Air Temperature & Humidity Sensor** to provide accurate readings of ambient air temperature and humidity
e. Remote processing unit		**Remote Processing Unit** – State of the art electronics for power & communication (includes a cellular modem); Stainless steel weather proof cabinet, additional sensor capability

2.3.4 Design of an Optimal RWIS System

At present, RWISs are sold by most vendors as an integrated package. Vendors sell systems as turnkey products that integrate a suite of sensors, a data acquisition system, and a communication and display system, which restricts the ability of state DOTs to add or change components of the system or to update the system as new hardware or software components are developed. Most state DOTs rely on vendors to run their RWISs and have little flexibility, and the DOT staff has limited knowledge of how to operate and maintain the RWIS system. To provide state DOTs the ability to make a choice of initial sensors and the ability to change sensors or other components over time without completely replacing the system, Aurora has recently developed a programmable, off-the-shelf RWIS. The technical report of Aurora Project 2003-02 published in May 2008 provides a detailed description and all the computer programs needed to run the RWIS system *(30)*. This report provides state DOTs a very valuable reference in developing their RWISs. The main components of the system are summarized below and can be referenced by NMDOT for future improvement of the RWIS system.

When reviewing and selecting sensors and data acquisition systems, the following requirements should be considered *(30)*:

- Sensors should be easily interfaced with a data acquisition system and provide good functional performance and complete documentation to allow interfacing with alternative Remote Processing Units (RPUs).
- RPUs or data acquisition systems should have open programming and provide inputs to the desired sensor types.

To meet the first criteria, a programmable RPU should be chosen (for example, Campbell Scientific CR 5000). Then sensors that are easy to interface with the RPU and offer good performance should be used. For example, the Optical Scientific WIVIS 130 visibility and precipitation sensor has an RS-232C interface and can be specified with either the World Meteorological Organization (WMO) precipitation code for Canada or the National Weather Service (NWS) precipitation code for the U.S.

FIGURE 2-11 gives an overview of the tower and accessories of the model system, and FIGURE 2-12 shows the components of the principal cabinet. The specifications and cost of all the components of the system are provided in the Aurora Project 2003-02 report *(30)*, as well as the original programs used for connecting each component to the RPUs. It provides a valuable reference for the NMDOT dust storm detection project and can be referenced for future system improvements and maintenance purposes.

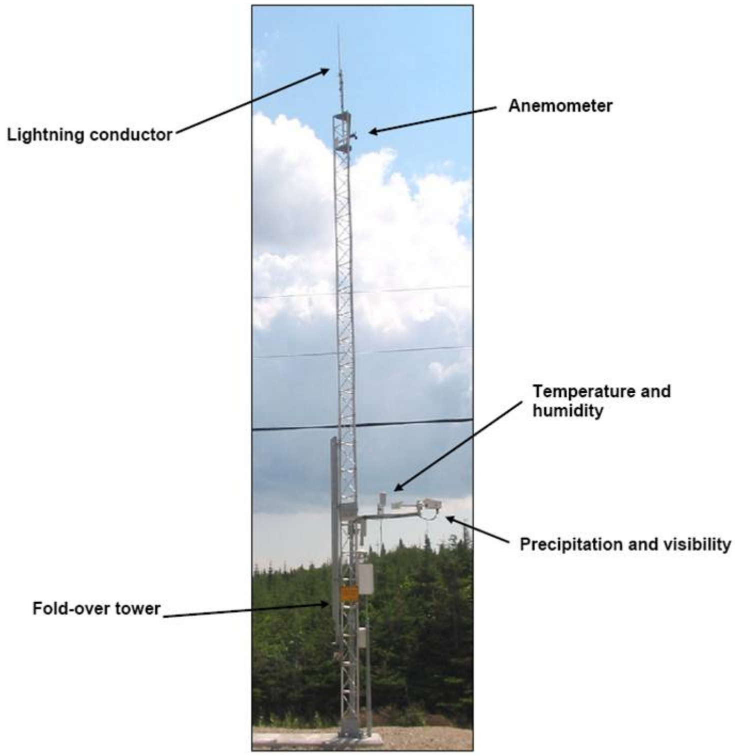


FIGURE 2-11 Overview of the Tower and Accessories of the System *(30)*

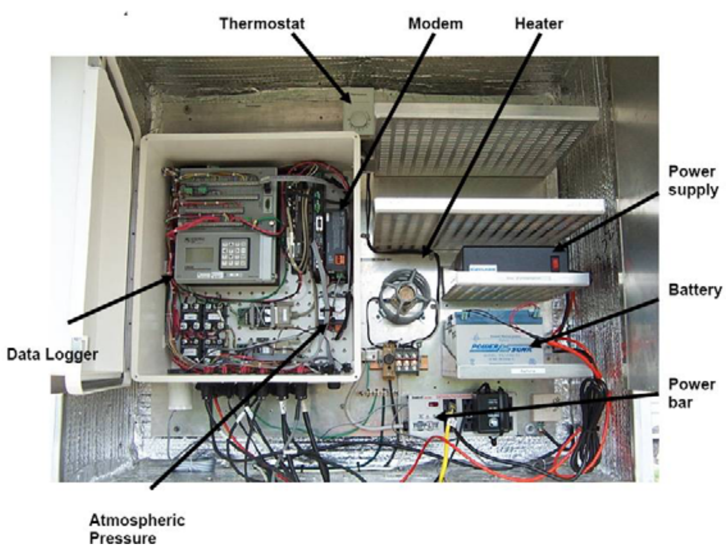


FIGURE 2-12 Components of the Principal Cabinet *(30)*

2.4 UTILITY AND COMMUNICATION OPTIONS

RWIS can either use electric or solar power to support all the instruments. A possible electricity supplier is Columbus Electric, Inc. or a solar power panel. A joint site visit by NMDOT engineers and Columbus Electric, Inc. was made to settle on the alternatives for power supply.

A communication system is needed to transfer data and images from sensors and digital cameras. The possible options are an optical fiber line, a telephone line, or wireless communication.

In order to find a better communication system, infrastructure along Interstate 10 from Mile Marker 5 to Mile Marker 15 was investigated. Three optical fiber lines are available in this area. The first one is owned by Level 3 Communications with the optical fiber laid along the railway, as shown in FIGURE 2-13. The possible splice location is near MM 15 with electricity and air conditioning facilities. FIGURE 2-14 shows the Level 3 optical fiber hub near MM15 on Interstate 10.

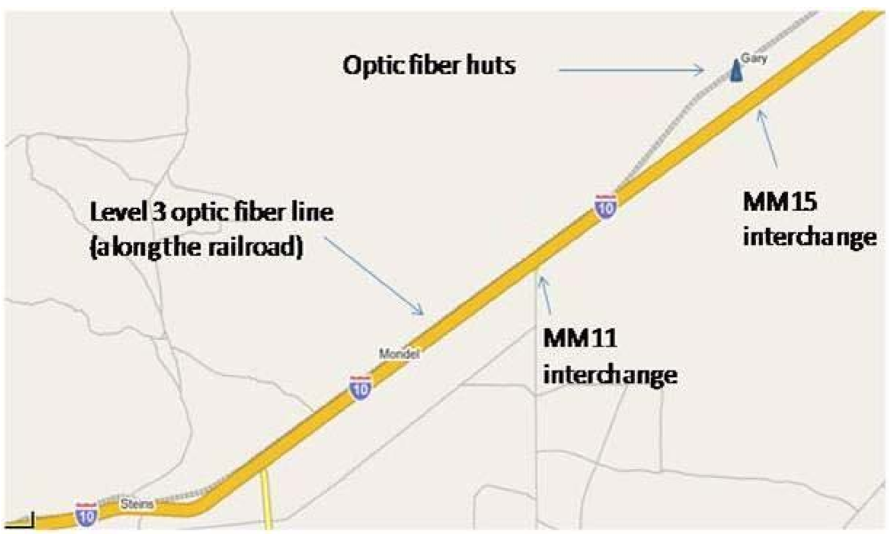


FIGURE 2-13 Level 3 Optical Fiber Line

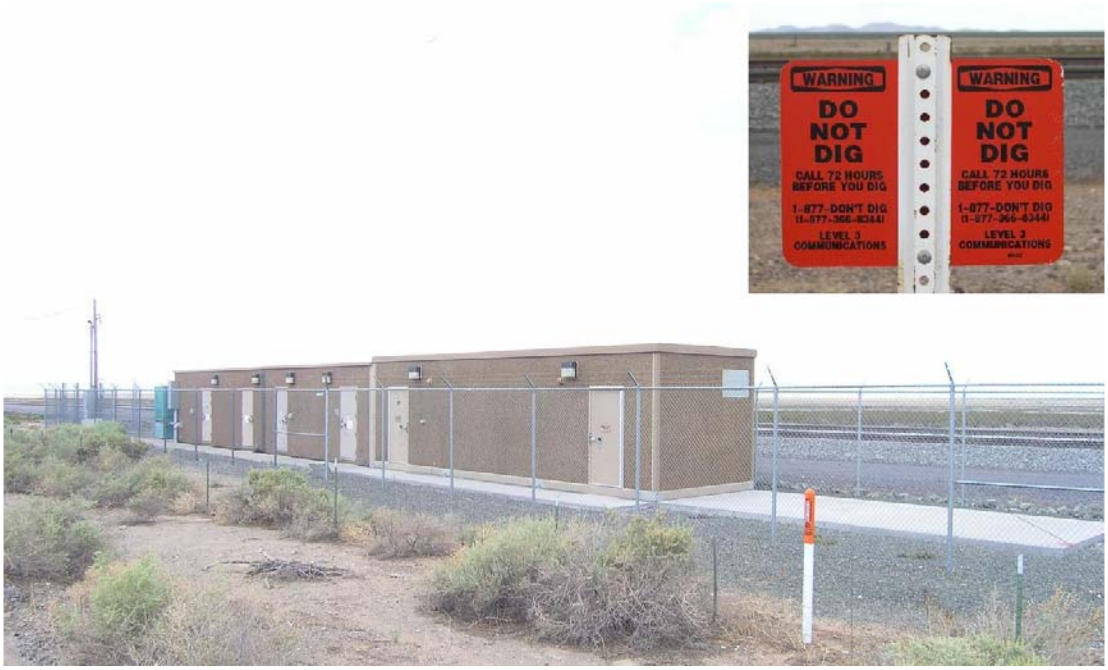


FIGURE 2-14 Level 3 Optical Fiber Hub Near MM15 on Interstate 10

The second optical fiber provider in this area is the Valley Telephone Cooperative, which mainly serves the southern parts of Arizona and New Mexico. The optical fiber network of Valley Telephone Cooperative is shown in FIGURE 2-15. The closest splice point is at Separ, about 10 miles from the dust storm site.

The third optical fiber provider is the Western New Mexico Telephone Company with fiber optical and telephone lines along I-10 on the southern side of the road.

From our site visit, it is known that the distance from the Level 3 splice location to the dust storm site is about 300 to 500 ft. The optical fiber line from the Valley Telephone Cooperative is more than 10 miles from the dust storm site and is not feasible to use at present. The total cost for optical fiber service includes installation, other equipment, and installation fees as well as some recurring charges, which include an annual fee and collocation charges. The optical fiber companies, especially Level 3 Communications and Valley Telephone Cooperative, seem unwilling to provide services for only one or two dust storm detection stations. They are more interested in providing services to the whole Interstate 10 corridor.

From the information collected during the site visit with District 1 engineers, possible dust storm detection stations can be installed in the following locations, i.e., MP 5, MP 11 and MP 14 (as shown in FIGURE 2-16). The description of the field features is summarized in TABLE 2-3.

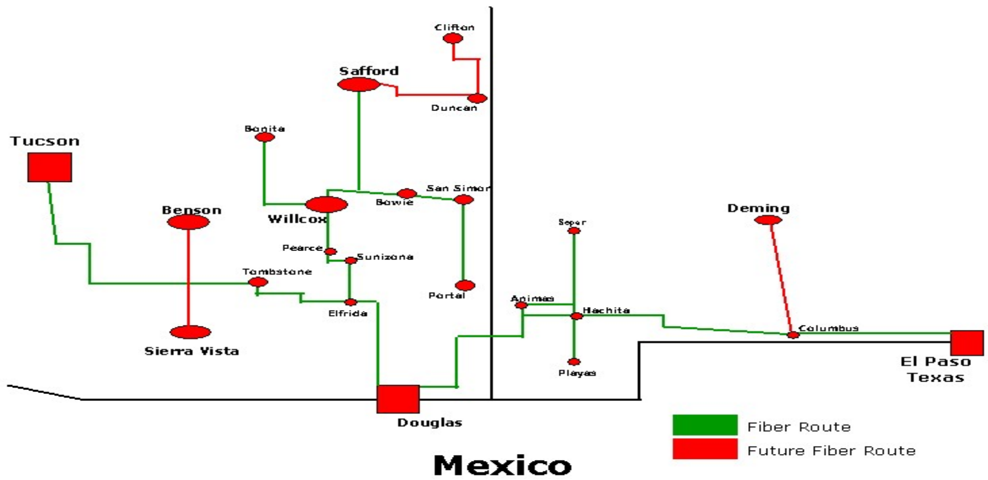
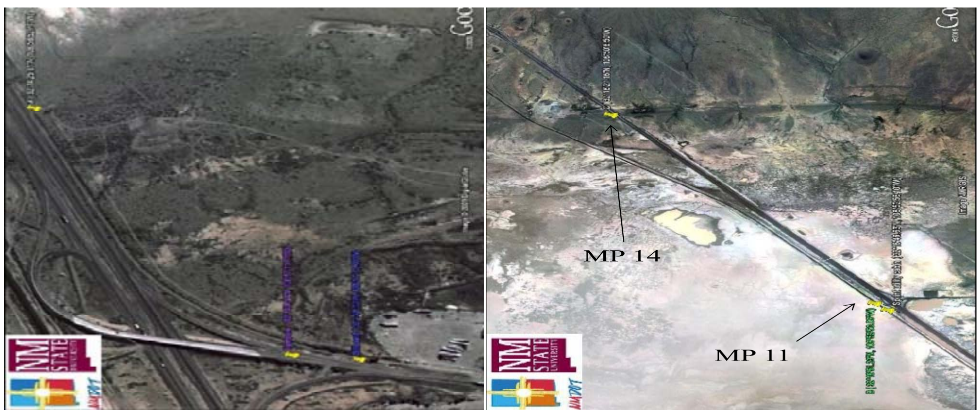


FIGURE 2-15 Fiber Optic Line Layout (Valley Telephone Cooperative)

The power supply estimation was provided by the Columbia Electric Co. It is very optimistic that electricity is available in all three locations. All the vendors suggested using electrical power over solar power because the former is more reliable.

It was also found that the Western New Mexico Telephone Company has fiber optical and telephone lines along I-10 on the southern side of the road. This may solve the communication issue. However, due to the budget restriction, District 1 engineers strongly recommended using a wireless communication system (Wi-Fi) from MM 5 to MM 15. The basic idea is to run a wireless signal from the ITS and dust storm system to the Deming maintenance patrol office.

The southern New Mexico area has more than 300 sunny days annually. As a result, solar energy would be feasible for these sites. In this case, a solar panel and equipment would be placed on a 15-foot pole and locked into place to best preserve the system. Many days during the summer have temperatures higher than 100^{o}F, and temperatures during the winter can be as low as 0^{o}F. The extreme temperature variation should be considered in the choice of dust storm equipment.



(a) MP 5 Potential locations

(b) MP 11&14 Potential locations

FIGURE 2-16 Possible Locations for Dust Storm Detection Stations

TABLE 2-4 Description of possible sites for RWISs.

Mile Post 5	Coordinates	Position Information
Interchange Bridge	N/A	Has a clear height of about 16 feet and 5 inches.
Billboard	32°14'6.50"N 108°57'13.00" W	More than 30 feet high and has a distance to the light pole of about 265 feet.
Light pole	32°14'9.11"N 108°57'13.71" W	It is on the ramp from NM 80 to the I-10 highway. There are three light poles along the ramp. This is the highest one and has the best view.
Position A	32°14'25.81"N 108°56'52.71" W	It is about 0.4 miles from the interchange bridge on the south side of I-10. Both a communication cable and power are available.
Mile Post 11	**Coordinates**	**Position Information**
Interchange Bridge	N/A	Has a clear height of about 16 feet and 6 inches.
Position B	32°16'51.23"N 108°52'50.09" W	It is on the north side embankment of the I-10 exit ramp on a steep slope. Narrow space is available for installing a station. Power is available. Depending on the cost of communication, wireless maybe a better choice.
Sprint utility cabin	32°16'46.63"N 108°52'56.10" W	The utility cabin belongs to SPRINT Company. It is on the north side of I-10 and is approximately 0.13 mile (689 feet) straight-line distance from position B.
Mile Post 14	**Coordinates**	**Position Information**
Position C	32°18'21.16"N 108°50'6.50" W	The position is on the north side of I-10, near MP 14 and is about 3.17 miles away from the interchange bridge at exit 11. Both a communication cable and power are available.

3 PHASE 2: EQUIPMENT PROCUREMENT AND INSTALLATION

This section summarizes the process involved in the equipment procurement, including the commissioning test and site training for how to use the equipment. The process started with a broad market investigation in order to obtain a complete picture. Based on the comprehensive information collected, major suppliers were contacted to find out more detailed information. Finally, an open bidding process was carried out to determine the final supplier of the equipment and an agreement was entered into for its manufacture, delivery and installation. The agreement included provisions for commissioning and training.

3.1 MARKET INVESTIGATION

In order to determine the best source of RWIS equipment, a market investigation was performed. Based on the broad market investigation, five major vendors (the leading RWIS suppliers in the US) were contacted and requested for a solution and quotes for a dust storm detection and notification system. The vendors were:

- Vaisala
- Quixote
- Campbell Scientific, Inc.
- All Weather, Inc.
- Meteorological Solutions, Inc.

Vaisala is a leading international company dealing with environmental and industrial measurement. Headquartered in Finland, the company employs over 1,200 professionals worldwide. The company provides a comprehensive range of applications for highway engineers to deal with adverse weather events. Vaisala has provided services to many highway departments with RWIS.

Quixote Transportation Technologies, Inc. (QTT) is a leading provider of high-tech, innovative solutions for the transportation industry. The company has strong business with local DOTs in the southwestern region of the U.S. and has provided a lot of services with RWIS.
Campbell Scientific, Inc. is a leading company in scientific instruments. It also provides weather stations world-wide for meteorological and climatological monitoring. The main advantage of a Campbell Scientific weather station is its flexibility to easily change sensor configurations, data processing, and data storage and retrieval options. It also requires that the DOT's staff have strong skills in equipment management and programming.

All Weather, Inc. (AWI) is a leading developer of high accuracy, high dependability surface and aviation weather measurement systems. AWI has an installed base of over 1,700 high-end automated weather measurement systems that span the globe. AWI is the preferred development partner of the FAA, providing reliable, high accuracy aviation weather systems. AWI's surface weather measurement systems also meet the stringent requirements of international standards organizations around the world.

Meteorological Solutions, Inc. (MSI) is a company that has a highly regarded reputation for quality and excellence in the field of air quality in the western United States and internationally. MSI is currently operating over 120 air quality, meteorological monitoring and applied meteorological projects in the United States and abroad. MSI has provided many RWIS services to California Department of Transportation.

In responding to the preliminary request for quote and equipment configuration, the five companies all claimed that it is difficult to provide an accurate quote without finalizing the exact location of the RWIS stations. It was impossible for most of them to include the cost for installation; only Quixote provided the installation cost based on their field visit and their experiences with Arizona Department of Transportation.

With the availability of the fiber optical line, it is possible to install streaming video. However, Vaisala stated that it is not a good idea to use streaming video for RWIS; on the other hand, Quixote supported the use of streaming video.

Out of the five vendors,

- AWI did not submit a proposal
- MSI provided an estimated cost for the procurement of monitoring equipment, integration, configuration and bench testing, shipping, systems installation, and field calibrations. MSI proposed the following equipment:

    - 30' Universal Tower w/adjustable mast
    - Campbell Scientific CR1000 Measurement and Control Datalogger
    - Weather resistant enclosure (16 × 18 inch)
    - Vaisala PWD12 Present Weather Detection system
    - Campbell Scientific CC640 Digital Camera w/Enclosure/Mount
    - Campbell Scientific RM Young's 05103 Wind Monitor
    - Texas Electronics, Inc. TE525WS Rain Gauge
    - Solar Power Package with two (2) 65 Watt Panels, Regulator and 12v – 69 Amp hour battery
    - RF 450 900 MHz Spread Spectrum Radio with Antenna
    - Campbell Scientific MD 485 Multidrop Interface

  MSI also required Internet connection provided at the NMDOT facility nearby which would also function as a base station for the radio telemetry connecting the three stations. MSI would provide the following equipment for the polling computer/base station:

    - Campbell Scientific NL100 Network Link
    - RF450 900 MHz Spread Spectrum Radio w/Antenna/Power Supply
    - Loggernet Datalogger Support Software

NMDOT was required to provide excavation and concrete for three tower bases prior to MSI's installation visit.

- Vaisala provided an itemized budget without installation and maintenance costs. Vaisala Present Weather Detector PWD12, which has a visibility measurement range of 10 – 2,000 meters (32 – 6,500 ft), was proposed for this project
- Campbell Scientific provided an itemized budget without an installation maintenance cost. Similar to MSI and Vaisala, Campbell Scientific also proposed Vaisala's Present Weather Detector PWD12, but the price was a little bit higher
- Quixote provided an itemized budget (including installation and maintenance costs) with two options: (1) The first proposal included Quixote's web-based Navigator system in which the data would be pulled back to Quixote's servers in St. Louis and provided through an IP address with a user password that can be accessed anywhere because it is web based. (2) The second proposal included the server being hosted by District 1 office and the data being pulled to the server there. Quixote also provided service on both proposals for the first 6 months (Performance Based) for free

  In both Quixote's proposals, a PTZ Color Camera that is capable of streaming video was proposed in case there is fiber available at the site. This would provide real-time streaming video of weather conditions.

3.2 BIDDING PROCESS

NMSU requires an open, competitive bidding process for the procurement of any capital improvement or major equipment, including RWIS equipment. The university's procurement regulations and procedures are carefully outlined and closely monitored to assure compliance with all applicable state and federal regulations.

A Request for Proposal (RFP) was advertised according to the official procurement procedures of NMSU. The RFP was also sent directly to the five main RWIS suppliers in the market investigation.

The three potential locations (as presented in Section 2) and the decision to use standard grid service electricity as a power supply were provided to the bidders in the RFP. Bidders were requested to visit the potential location sites, to propose an optimal equipment configuration, and to decide the installation options, as well as the communication method.

The proposals were due on January 28, 2010. Due to the merging of Quixote with Vaisala, only one supplier (Vaisala) submitted a responsive proposal. A local construction company experienced in highway construction, Smith and Aguirre, submitted its qualifications as the prime contractor to represent Vaisala and to install the equipment (Under New Mexico law, the prime contractor is required to have certain current licenses.).

After Smith and Aguirre was selected as the general contractor, a field investigation was conducted to finalize the details for installation and utility issues. Representatives from the NMDOT, NMSU, Smith and Aguirre, Vaisala, and Columbus Electric Cooperative visited the three locations jointly. It was decided by the group to install two RWIS stations based on the project budget and the unit price submitted by Smith and Aguirre, one at MP 11 and another at MP 14. The sites were selected in large part because of the nearby availability of power from the Columbus Electric Cooperative grid. Other potential sites were farther away from points of connection to the grid and it was considered too expensive to extend the primary lines to those places. There was some discussion of utilizing photovoltaic solar panels, but eventually NMDOT decided that such panels would be too easily vandalized and would present a continuous maintenance problem for the department.

During the quarterly project meeting in September 2010, it was decided to change the location from MP14 to MP12, considering that MP12 is closer to the source of dust storms and therefore a preferred location. Also, the resources were available from NMDOT to cover the extra cost of extending primary electrical service to MP12. NMSU informed Smith and Aguirre of the location change and Smith and Aguirre submitted a change order accordingly. The change order also included money to cover the additional construction costs involved in building at MP 12 – the existing ground elevation was low and would be under water when it rained, so extra fill was required to bring the pad elevation for the tower to a point well above flood level. It was decided during the quarterly project meeting in January 2011 that the remaining utility money for the research project (NM09TT-01) would be used to cover the extra construction cost, and NMDOT ITS Bureau would provide financial assistance to cover the cost for power delivery from MP14 to MP12 as well as to provide the electrical primary utility cost at MP 11.

3.3 LOCATION AND EQUIPMENT CONFIGURATION

The location and site descriptions are as follows:

MP11: An overhead line approximately 60 ft. from an existing 30 ft. pole, perpendicular to the right-of-way (ROW) fence line but within the right of way of the Burlington Northern Santa Fe Railroad, connects with electrical wiring at another 30 ft. pole on the NMDOT side of the ROW fence. The pad for the tower sits immediately south of the electric pole. The pad sits approximately 18 in. above the existing grade to provide for extra flood protection; its north edge is approximately 7 ft. off the fence line, and the south edge of the pad is approximately 18 ft. from the north edge of the asphalt pavement of westbound I-10. Coordinates for the RWIS tower are: 32º 16’ 46.15”N, 108º 52’ 56.3”W.

MP12: A power line from Columbus Electric’s existing N-S line approximately 1.5 miles east of the site is connected to the site by a line of poles within the highway ROW, close to the south ROW fence line. The pad sits approximately 4.5 ft. above the existing grade. The toe of the slope starts a few feet north of the fence line (ROW). The south edge of the pad is approximately 16 ft. north of the fence line. The north edge of the pad is approximately 50 ft. south of the eastbound lane of I-10. Coordinates for the tower are: 32º 17’ 14.6”N, 108º 52’ 00.6”W.

Each of the sites includes a concrete pad surrounded by a 10’ tall chain link fence topped with razor wire, accessed via a wide gate. Electrical secondary service comes underground from the

primary service pole and meter at the ROW fence to the tower. The 30’ tower is grounded for lightning protection. FIGURE 3-1 shows the RWIS stations installed at MPs11 and 12.
The following major instruments were provided at each site:

- A Remote Processing Unit – State of the art electronics for power & communication (including a cellular modem), stainless steel weather proof cabinet, additional sensor capability, and software
- A HMP155 Air Temperature & Humidity Sensor to provide accurate readings of ambient air temperature and humidity
- A PWD12 Present Weather & Visibility Sensor to provide readings of visibility (up to 2000 m or 1.24 miles) and to differentiate between rain, drizzle, snow, mixed rain and snow, fog, and smoke or dust. The sensor calculates and provides actual precipitation rates, as well as the accumulation of precipitation, and it determines the water equivalent of frozen precipitation (snow)
- A WS425 Ultrasonic Wind Speed & Direction Sensor to provide readings of wind speed and direction
- A fixed low light color camera (ICECAM MOBM12) to provide daytime high quality color images of road and traffic conditions. Images are also provided overnight with the use of IR Illuminators
- Surge Protection, cables and tower protection
- A Verizon Cell Modem Kit.

MP11 MP12

FIGURE 3-1 RWIS Stations Installed at MPs 11 and 12

According to experiences from other state DOTs with RWIS communication and as suggested by the vendor, it was decided to use cellular wireless service for RWIS communication. Because there is no streaming video to be used, cellular wireless communication will be sufficient. According to Vaisala engineers, dust storms have little interference with cellular message transmission. Cellular wireless communication is much more economical compared to other types of communication. For security purposes, we propose to evaluate the cellular wireless communication for at least a year (in the proposed Phase III of this project). If any problem occurs during the bad weather (e.g., data loss, etc.), we could then use other communication methods (wired phone, for example). NMDOT is now planning an ITS facility along I-10 that will provide an alternative communication solution in the near future.

Vaisala will utilize a wireless communication system between the RWIS stations and the Vaisala Data Center. The Data Center will collect data from the sites every 15 minutes, archive the data, and make them available for viewing on their IceNet website. Data will be password protected and available only to individuals with permission to access the website. When the NMDOT has its own service available in the future, the data can then be transferred to a NMDOT server. This can be either a PUSH or PULL process. NMDOT needs to store all the RWIS data even though Vaisala will provide a host server because Vaisala normally keeps the data for a certain period of time and then deletes them. The two RWIS stations are all run by power supplied by the Columbus Electric Cooperative via overhead lines to pole-mounted meters, then via underground lines to the towers.

3.4 COMMISSIONING TESTING AND TRAINING

The commissioning test included testing each component individually and then as a whole system. The contractor provided a list of components and specifications and the test results. In the commissioning test, the contractor (Vaisala) demonstrated the tests to representatives from NMDOT and NMSU. The list of equipment components and the testing results are summarized in Appendix B.

Acceptance (commissioning) for both systems occurred at the same time. Acceptance criteria were established as part of the contractual documents in the agreement with Smith & Aguirre. The acceptance testing demonstrated the published levels of performance and precision for each instrument and associated parameters monitored by the station. In addition, the system demonstrated a full level of publication, notification and display functionality.

Staff from NMDOT headquarter and the District One office were present during the acceptance (commissioning) testing on November 29, 2011, as were staff from NMSU and the general contractor and electrical subcontractor.

Vaisala provided the documentation attached in Appendix C after system checkout and commissioning. Documentation is available for factory testing of entire system including individual sensors/components and on site calibration documentation. Typical test sensors brought on-site are not as accurate as the weather instruments that are installed. All instruments were thoroughly tested individually at the factory in Helsinki and again tested as an assembled complete system at the facility in Boulder, Colorado.

Training was conducted on November 30, 2011 at the NMDOT District One office in Las Cruces, New Mexico with web connections to the RWIS stations. Staff from NMSU and NMDOT was present for the Training, which was run by certified representatives from Vaisala.

Training included the maintenance and operation of the RWIS systems, theory of operation, hands-on troubleshooting, calibration and use of calibration equipment, programming and configuration techniques, communications troubleshooting, performing routine testing of the system and the analysis of logs and failure alarms. Keys to access the RWIS systems were handed over to staff of NMDOT and NMSU after the training class.

As-built drawings of the installation of the RWIS systems were also provided by Smith & Aguirre by the request of NMDOT. The drawings are attached in Appendix D.

4 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE OPERATION

This project confirmed that there is an urgent need to improve the dust storm detection and notification practice along I-10 New Mexico section. Based on a literature review and investigation of other state DOTs' practice, RWIS was selected to assist highway patrol teams in detecting dust storms. Two RWIS stations were installed at MP 11 and 12 accordingly. The RWIS stations will be powered by electricity, and the communication will use cellular wireless.

According to interviews with the NMDOT Research Bureau, ITS Bureau, FHWA New Mexico Section and District 1 engineers, the dust storm detection system will be operated and maintained by District One of NMDOT. The maintenance includes calibration and cleaning of the dust storm equipment and data validation. Three options can be used according to other state DOTs' practice:

(1) Performance-based contract with the vendor. The system is completely owned and operated by the vendor, and DOTs only obtain data from them
(2) DOTs own and run the system completely by themselves, and
(3) Partnership with the vendor. DOTs own the equipment and the vendor shares certain responsibilities in running the system

Because NMDOT uses technical transfer funds to develop the dust storm detection and notification system, NMDOT should understand the technology and own and run the system by training its own staff. Option 1 is not applicable because NMDOT does not get any technology, only services. Many state DOTs that currently use this model would like more involvement in the operation. According to experiences from other state DOTs, maintenance and operation of dust storm detection systems are technically complicated. The disadvantage of option 1 is that DOT has no control at all over the RWIS, and the operation cost is relatively high. According to one DOT maintenance engineer, sometimes there is doubt about the data provided by the vendor, but there is no way to control them. For example, several times the site was dry, but the precipitation data given by the vendor were pretty high. They would like more flexibility and control over the system.

With option 2, the DOT has the highest flexibility and control over the system. The premise is that the DOT should have very strong technical support. The only DOT that uses this option is Utah; they have six meteorologists to maintain the system. NMDOT does not have such support at present, so this option is not recommended.

Option 3 is used by most state DOTs and is more suitable to NMDOT. It is optimized to form a partnership between the NMDOT, NMSU, and the vendor to run and maintain the system.

According to other state DOTs' experience, a long-term system evaluation or operational test is needed after the installation of the system in order to validate the equipment and evaluate the effectiveness of the system. For example, Idaho DOT carried out a two-year project to evaluate and test its storm warning systems that were installed to detect and notify drivers of low visibility caused by storms. The purpose of the project was to verify the accuracy of the equipment and determine if visibility sensors and the resultant information supplied to drivers on roadway message signs would impact traffic to safe levels as warranted by weather conditions. The project was extended twice to add another five years in order to cover more storm seasons. At present, the City of Las Cruces is conducting a three-year project (STOP) to evaluate the effect on drivers' behavior by the installation of cameras at intersections in the city for recording violations. NMSU currently has a team working on this project.

Similarly, there is a need to implement Phase III of this project during which the NMSU team can assist NMDOT to evaluate the equipment installed in Phase II over a long-term period (optimally more than two years, i.e., two dust storm seasons). The following basic issues should be addressed in the Phase III project:

- Verify the accuracy of the equipment and the data provided by the vendor
- Verify whether cellular wireless communication functions well during bad weather, especially when dust storms occur. If not, find a solution for it (NMDOT road patrol engineer has such a concern)
- Find a proper method to maintain data and apply them into the daily management (Vaisala only maintains data for a certain period of time on its server). NMDOT should have its own server and database for routine management and analysis purposes
- Find a way to integrate RWIS data into the whole ITS system. For example, find out how to use RWIS data to display dynamic messages and assist traffic closure decisions
- Apply RWIS data to learn the pattern of dust storms and find out the sources and features of dust storms
- Study the impact of RWIS on traffic safety.

The above issues are critical to the proper use of the RWIS systems. Considering the short period of time for equipment evaluation and trial operation in Phase II, District 1 engineers and the NMSU research team strongly recommend a new project (phase III) to perform a two-year, long-term evaluation of the RWIS system due to the following reasons:

(1) RWIS stations along Interstate 10 are for the purpose of detecting dust storms and providing warnings to travelers. The dust storm season is in the late spring and early summer of every year. Since the Phase II project finishes the end of this year, there will be no dust storms for the research team to check the performance of the RWIS stations.

(2) Even during dust storm seasons, it is not guaranteed that the research team will have dust storms at the site every year. During the two-year, long-term evaluation plan, the possibility of catching dust storms will increase.

(3) Patrol engineers need assistance to correctly detect and provide warnings for on-going dust storms using the RWIS data. There is a learning curve for the engineers and technicians to recognize the patterns of dust storms by using data from different sensors. Engineers may not use the RWIS data if they do not feel comfortable doing so.

(4) The proposed communication of RWIS data is cellular wireless communication. Even though the vendor is confident about the applicability of this kind of communication in severe dust storm conditions, it is still necessary to check it for a relatively long period of

time. If a dust storm influences the proposed communication, there should be alternatives. It is impossible to finish such a goal within the timeframe of Phase II.

(5) Many other useful applications can be realized by using the proposed RWIS sensors, such as the maintenance and management of the highway system. Research is needed to find out how to integrate the RWIS system into the ITS and the routine traffic management system.

(6) From experiences of other state DOTs, it is critical to have a follow-up study that can help engineers use the RWIS systems properly. Engineers may not use or even want to use the RWIS systems properly if assistance is not provided.

Therefore, District One engineers and the NMSU research team strongly recommend a Phase III project from 2012 to 2014 to perform a long-term evaluation of the proposed RWIS system.

5 REFERENCES

1. National Oceanic and Atmospheric Administration (NOAA) Homepage
http://www.noaa.gov/
Accessed October 2, 2011.

2. GOOGLE MAP, http://maps.google.com/maps?hl=en&tab=wl
Accessed October 2, 2011.

3. Washington, R., M. Todd, and N.J. Middleton. Dust-storm Source Areas Determined by the Total Ozone Monitoring Spectrometer and Surface Observations. *Annals of the Association of American Geographers.* Vol. 93, 2003, pp. 297-313.

4. Hannesen, R., AMS-G. Neuss and A. Weipert. Detection of Dust Storms with a C-Band Doppler Radar. Presented at 31st International Conference on Radar Meteorology, 2003.

5. Salt Institute Home Page. http://www.saltinstitute.org
Accessed October 03, 2011.

6. Angelfire. http://www.angelfire.com.
Accessed October 05, 2011.

7. National Weather Service Home Page. http://www.weather.gov/
Accessed October 06, 2011.

8. Weiss, C. C. and A. L. Pazmany. Doppler Radar Observations of Dust Devils In Texas. Monthly Weather Review, 2004. National weather service. http://www.srh.noaa.gov.
Accessed October 06, 2011.

9. Vincent, R.K. Possible Application of "Passive Radar" for the Detection and Tracking of Tornadoes. Presentation on the Multinational Conference on "Passive and Covert Radar 2002."

10. El-Askary, H.M., S. Sarkar, M. Kafatos, and T.A. El-Ghazawi. (2003). A Multisensor Approach to Dust Storm Monitoring over the Nile Delta. *IEEE Transactions on Geoscience and Remote Sensing*. Vol. 41, No.10.

11. Chavez, P. S., D. J. Mackinnon, R. L. Reynolds, and M. G. Velasco. Monitoring Dust Storms and Mapping Landscape Vulnerability to Wind Erosion Using Satellite and Ground-Based Digital Images. *Aridlands News Lettle*, 2002, no. 51.

12. Wikipedia Website. History of radio. http://en.wikipedia.org
Accessed October 10, 2011.

13. Liu, S.C., Q.H. Liu, and M.F. Gao. Detection on Asian Dust Storm in China by Combining Daytime and Nighttime Terra and Aqua MODIS Data. *Wuhan Daxue Xuebao (Xinxi Kexue Ban)/Geomatics and Information Science of Wuhan University*, Vol. 31, No. 12, 2006, pp. 1051-1054.

14. Huang, J.P., J.M. Ge, and F.Z. Weng. Detection of Asia Dust Storms Using Multisensor Satellite Measurements. *Remote Sensing of Environment*, Vol. 110, 2007, pp. 186-191.

15. Han, T., Y.H. Li, H. Han, Y.Z. Zhang, and Y.J. Wang. Automatic Detection of Dust Storm in the Northwest of China using Decision Tree Classifier Based on MODIS Visible Bands Data. International Geoscience and Remote Sensing Symposium (IGARSS), Vol. 5, 25th Anniversary IGARSS 2005: IEEE International Geoscience and Remote Sensing Symposium, 2005, pp. 3603-3606.

16. Naval Research Laboratory Home Page. www.nrlmry.navy.mil
Accessed October 11, 2011.

17. Guo, N., Y. Liang, and X.P. Wang. Quantitative Identification of Dust and Sand Storm using MODIS Data. International Geoscience and Remote Sensing Symposium (IGARSS), Vol. 5, 25th Anniversary IGARSS 2005: IEEE International Geoscience and Remote Sensing Symposium, 2005, pp. 3630-3633.

18. Qu, J.J., X.J. Hao, and M. Kafatos, Asian Dust Storm Monitoring Combining Terra and Aqua MODIS SRB Measurements. *IEEE Geoscience and Remote Sensing Letters.* Vol. 3, 2006, pp. 484-486.

19. Zha, Y. and L. Li, Influence of the 17 April 2006 Asian Dust Storm on Moderate Resolution Imaging Spectroradiometer Data for Land Cover Identification. *Journal of Geophysical Research*, Vol. 112, 2007.

20. Hu, X. Q., N. M. Lu, T. Niu, and P. Zhang. Operational Retrieval of Asian Sand and Dust Storm from FY-2C Geostationary Meteorological Satellite and its Application to Real Time Forecast in Asia. *Chem. Phys.*, Vol. 8, 2008, pp.1649-1659.

21. Degunther, R. N. and W. I. Marsh. FreePatentsOnline (1994).
http://www.freepatentsonline.com
Accessed October 11, 2011.

22. Vaisala Website. http://www.vaisala.com
Accessed October 12, 2011.

23. PCT Application, 2000. Visibility sensor system. International Application Published Under the Patent Cooperation Treaty (PCT).
http://www.wipo.int/pctdb/en/wo.jsp?wo=2000041008&IA=US2000000334&DISPLAY=DOCS, Accessed October 12, 2011.

24. Crosby, J.D. Visibility Sensor Accuracy: What's Realistic? 12th Symposium on Meteorological Observations and Instrumentation, 2003.

25. Du, M., S. Yonmura, Z. Shen, Y. Shen, W. Wang, T. Maki, S. Kawashima, and S. Inoue. Measuring Dust Concentration Over Desert and Cropland During Dust Storms using a Visibility Sensor. http://terre.lisa.univ-paris12.fr/DUST2003/poster/du.pdf Accessed October 26, 2011.

26. U.S. Geological Survey Home Page, http://www.usgs.gov/ Accessed October 20, 2011.

27. Texas Tech Atmospheric Science Group Home Page, www.atmo.ttu.edu Accessed October 20, 2011.

28. Kuennen, T. High-Tech Helps Tame Road-Weather Woes, *Better Roads*, September 2006, pp. 32-44.

29. FHWA Home Page. An introduction to standards for road weather information system (RWIS). http://www.standards.its.dot.gov/Documents/rwis-standards.htm Accessed October 26, 2011.

30. Lapointe, C., M. Perchanok, and J. Stickel. Off-the-Shelf Component RWIS, Technical Report for Aurora, Aurora Project 2003-02.

APPENDICES

APPENDIX A

A-1 Investigation on Current State of Practice of RWIS in US

State	Visibility Sensor Type	Company	Communication	Cost	Maintenance	Contact
Texas	Forward Scatter	Quixote Inc.	Fiber Optics	over $4,000,000	approx. $ 6,000 /year	Ted Moore 806-748-4432
Arizona		Quixote Inc.	Telephone line	$2,000 per station per year		Darrell R. Bingham Phone 602-712-439 Fax 602-495-9013 Jon R. Lovell 602-309-5744
Utah	Digital camera and visibility sensor	Campbell Scientific	Wireless	$20,000		Ralph Patterson 801-887-3735 Fax: 801-887-3797
Idaho	Forward Scatter	Vaisala	land lines and wireless	$64,000 average for each site	$600/month per site	Kent Wetzstein 208-334-8472 208-859-3020
Colorado	Forward Scatter	Vaisala		$150,000		Johnny Bland
Oregon	Forward Scatter	Quixote Inc.	landlines and wireless	$ 6,000/ visibility sensor		Doug Spencer 503-856-6528
Nevada						Daniel Harris Office775-888-7685 Fax:775-888-7104 775-888-7867
California	Forward Scatter	Quixote Inc.	Wireless	$60,000/site	Quixote does maintenance for $15,000 for all sites.	Kevin Riley Office: 916-651-9377 Cell:916-708-7234 Fax:916-653-3055 Jose Dealba 559-351-1879
Wyoming	Forward Scatter	Quixote Inc. and Vaisala	multiple ways: microwave Motorola, canopy radio, and dial up	$40,000 per site without infrastructure		Vince Garcia Office: 307-777-4231 888-996-7623 Kevin Cox 307-777-4620

A-2 Summary of RWIS Applications

State: Texas
Contact: Ted Moore
806-748-4432
Visibility Sensor Type: Forward scatter
Company: Quixote Inc. http://www.qttinc.com/index.html
Description: This system is primarily used for winter weather. This system is more complex and expensive than one just for ambient weather conditions; it is designed to keep ice off the bridges where it is installed. It is composed of one RWIS which operates sensors on two bridges which have two sensors each, an active and a passive sensor. A second RWIS site will also be installed to operate sensors on four other bridges which will have two sensors each.

This system has to tap into a portable water supply, an electric power supply, and a fiber-optic communication system. This system is composed of a small ambient weather condition monitoring system, a magnesium chloride pump station, a magnesium chloride spray system mounted on bridge structures, and communication software that monitors and runs the system. This system identifies multiple changes in the weather which include air temperature, wind speed, humidity, falling moisture, bridge deck temperature, visibility, and presence of magnesium chloride. The system is powered with standard 110v AC from the local power company. There is no emergency backup power system if the regular service goes down. The visibility sensor is a forward-scatter technique and gives an indication of how far you can see in miles depending on the weather at any particular time. For instance, on a clear day the system may register a visibility of 7.1 miles, but when wind gusts occur and pick up dust particles, the sensor will register a visibility of maybe 5 miles. The sensors gather information and the software determines whether or not to fire the system based on the parameters set by the operator. The operator can also override the system in order to fire it manually. The system sends out a notification when it fires. The RWIS is located in Lubbock on US 6282 ¼ mile east near loop 289.

Communication: Fiber Optics
Performance: Very good
Maintenance: approximately $ 6,000 /year
Cost: over $ 4,000,000

State: Arizona
Contact: Darrell R. Bingham
Phone: 602-712-6439
Fax: 602-495-9013
Jon R. Lovell
602-309-5744
Website “198.68.8.141” password & Username (mpeters)
Visibility Sensor Type: Forward scatter
Company: Quixote Inc. http://www.qttinc.com/index.html

Description: Arizona has 17 RWIS (Roadside Weather Information Systems); two of these stations are used specifically for dust storm detection. Most of these stations are in the northern sector of the state and are mainly used for cold weather conditions. RWISs are mostly along the I-40 corridor where the cold weather conditions are of great concern. The two stations that are used for dust storms are in the southern part of the state along the Interstate 10 corridor located in Bowie and San Simon.

The weather system interprets the weather data, and with the help of an expert, it can determine whether a dust storm is possible in that area. The system bases that information on humidity, air temperature, air pressure, etc. The visibility sensors detect the lack of visibility whether it is from dust, fog, snow, etc. CCTVs are also used to provide a visual confirmation of the road. Two of the sites on I-10 are powered by utility electricity, the rest are solar. One of the sites has an extra solar panel for satellite communication.

FIGURE A-1 Distribution of RIWS in Arizona

Communication: sent to a server in St. Louis at Quixote's headquarter. Everyone who has the password can access the data worldwide through the Internet.

Performance: Very Well

Cost: Quixote Inc. owns and runs all the stations and provides data to ADOT. ADOT pays for the data, about $2,000 per station per year. ADOT has signed a 5-year contract with Quixote Inc.

State: Utah
Contact: Ralph Patterson
Office: 801 -887-3735
Fax: 801-887-3797
Visibility Sensor Type: Digital camera and visibility sensor
Company: Campbell scientific http://www.campbellsci.com/cc640-digital-camera
Description: Utah has not deployed a full scale visibility system. Instead they use a portable weather station equipped with a complete sensory system that measures all aspects of the weather, such as temperature, humidity, precipitation, wind speed, surface temperature, etc. The portable weather station is equipped with a Campbell digital camera. This camera provides the transportation department with real-time digital images. It is set up to run jpeg video feed with a loop every ten minutes. The camera requires a 12 DC power supply which it derives from its own power supply which consists of three 80-watt solar panels which charges four 12-volt, deep-cycle marine batteries that then power the station.

Campbell scientific RPU or data logger is cheaper for the reason that they build their own. Campbell scientific also has the capability to integrate multiple manufacturers' equipment into the RPU. This RPU has the capability of changing instrumentation as needed and changing the schedule on the system. They send people for training on the system, so they do the maintenance themselves; doing so keeps maintenance costs down. Campbell can also write out the subroutine for the equipment for people to run the program and adjust it as necessary. Vaisala's and Quixote's RPUs are not user-configurable. Therefore, it costs more to have the company come out and do maintenance work on the system.

The transportation department moves this station to an area with low visibility as needed. Utah does have some Vaisala PWD11 but doesn't run these sensors due to high maintenance cost.

Communication: Wireless CVPD technology by BlueTree wireless data
Verizon as carrier
700 MHz radio alternative
Performance: The camera performs great but communication is an issue. The company also provides great customer service
Cost: $2,200 for camera with enclosures
$20,000 for whole weather station system RPU, radiation shield, digital camera, sub road sensor, pyranometer, temperature, and humidity probe

State: Idaho
Contact: Kent Wetzstein
208-334-8472 Desk
208-859-3020 Cell
Visibility Sensor Type: Forward scatter
Company: Vaisala
http://www.vaisala.com/weather/products/weatherinstruments/presentweather/pwd
Description: Idaho has a target of setting up 80 RWIS sites through out the state but, currently, only has 49. Currently, the state of Idaho uses utility energy to power the stations and,

also, solar energy to power the more remote sites. Half of the RWISs have visibility sensors which are the Vaisala present weather detector model 12 “PWD12” and a Mobotix M12D-Night IP Camera. Deployment of the sensors depends upon the Vaisala present weather detector "PWD-12" and the addition of a Mobotix M12D-Night IP Camera.

The combination of the two sensors provides an excellent indication of the visibility on the monitored section of roadway. The PWD-12 provides accurate visibility and present weather measurements of the road environment where low visibility is a serious safety hazard and can reduce traffic flow rates. With a visibility measurement range of 10-2,000 meters, the PWD-12 works very well for road weather applications. The PWD-12 also indicates the cause of reduced visibility to give you a full picture of weather conditions. Calibrated with reference to a highly accurate transmissiometer, Vaisala’s PWD sensors use a proven forward-scatter measurement principle to measure Meteorological Optical Range (MOR).

The sensor is well protected against contamination; the optical components point downwards, and hoods protect the lenses against precipitation, spray, and dust. This design, while providing accurate measurements, also reduces the need for maintenance. In colder climates, a hood heater is recommended. Currently, the system goes through personnel before any action is taken. The station sends out an alert, then personnel are sent out to confirm that the weather conditions do in fact apply.

Communications: Some sites are restricted to land lines.
Some wireless sites use AT&T, Verizon, or whatever is available at the site.
Performance: Very Good; have not had problems with them.
Maintenance: 600/month per site
Currently average about $500,000 per year
Cost: PWD12 sensor $ 10,000
Fixed Camera $4,700
$64,000 average for each of the 49 sites

It would also need a Remote Processing Unit (RPU), but all the specifications (placement, communication needs, etc.) need to be known in order to accurately price it. Kent believes that in order to make a visibility system work well, one should back it up with at least one fixed camera

State: Colorado
Contact: Johnny Bland
Visibility Sensor Type: Forward scatter
Company: Vaisala
http://www.vaisala.com/weather/products/weatherinstruments/presentweather/pwd
Description: The visibility sensors that Colorado uses are mainly used for fog detection. The system in the Denver metro area consists of two Vaisala PWD11 Present Weather Detectors, 2 Skyline dynamic message signs, and 1 static warning sign with flashing beacons. Three encom transmitters and receivers are used to relay the contact closure signal produced by the weather detectors to the two dynamic message signs and the static sign. The attached graphic shows the approximate location of the devices. Not shown on the graphic are the six luminaries (street lighting) that were also installed in the low lying

area around the visibility sensors. They originally installed Addco Brick Modular (variable message) signs that have since been replaced with Skyline signs due to the problems experienced with Addco signs and controllers.

The visibility sensors, transmitters, and receivers are powered from nearby street lighting 120 volts. The visibility sensors are located about 130' apart, one on each side of the highway, and approximately 1.6 miles away from the variable message sign to the south and 2.5 miles from the sign to the north.

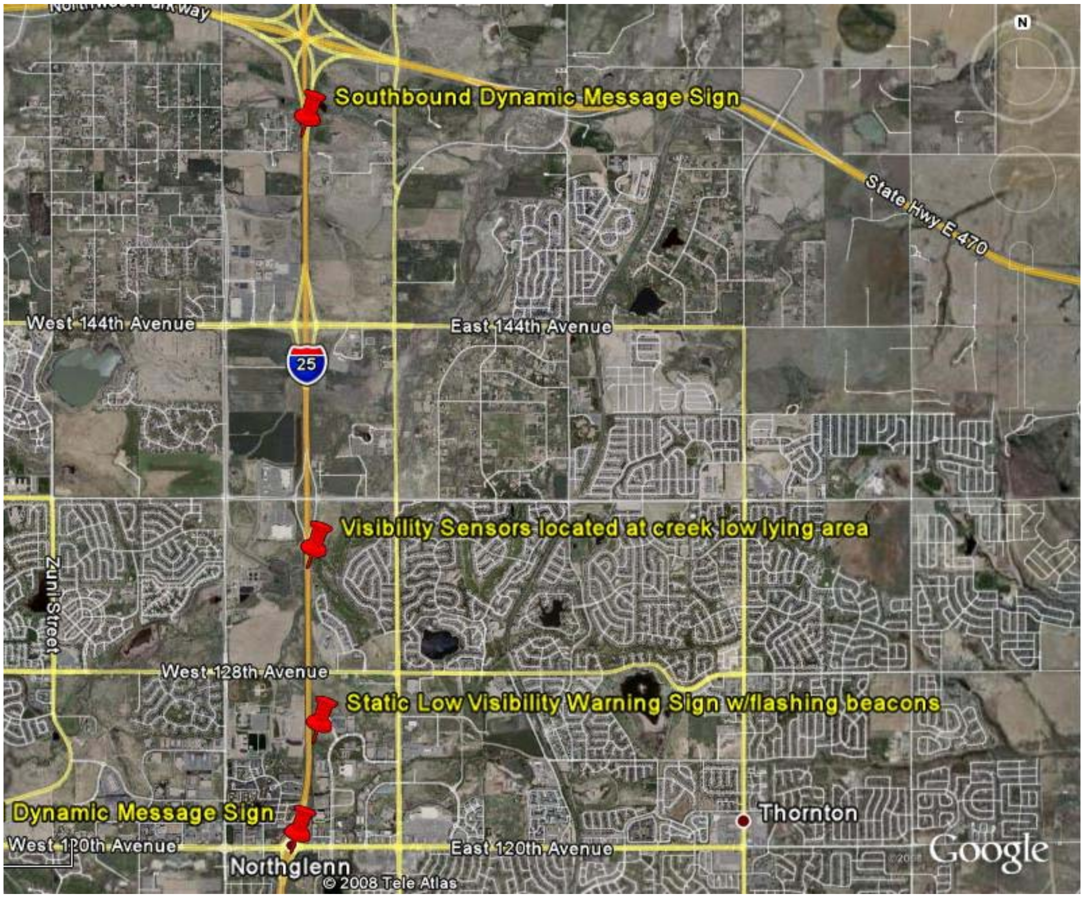


FIGURE A-2 Distribution of RIWS in Colorado.

Communication: N/A this system is automated
Performance: Very Good
Cost: The Vaisala visibility sensors cost $6,152.00 at the time of purchase. Total cost for the system was around $150,000 including the additional street lighting.

State: Oregon
Contact: Doug Spencer
503-856-6528
Visibility Sensor Type: Forward scatter
Company: Quixote Inc. http://www.qttinc.com/index.html

Description: ODOT has about 80 RWISs. Most of the stations monitor precipitation and not visibility. These sites are powered by several methods, such as utility, solar, and even by generator. The precipitation is used for determining the formation of ice on the road surface. This sensor is cheaper than a visibility sensor because the visibility sensor can also measure the distance of visibility as well as precipitation.

They do have several stations that monitor visibility of a corridor for conditions such as fog and dust storms. The northern part of US97 is an example. Maintenance would use the visibility distance to determine whether to allow oversize vehicles to travel, etc. On I-84, a weather station was added to monitor the visibility due to local dust storms. Their visibility systems are not connected to any systems for an automated response. They are just a monitoring tool for maintenance and operations personnel to use for determining initial roadside conditions. They usually follow up with local crews to verify the conditions or use a roadside camera for verification. They could then post the information to the variable message signs, 511 system, highway advisory radios, etc. for notification.

The difficulty with monitoring visibility is that the distance between the light source and the sensor is only three feet. The sensor looks at the refraction of a light source due to particles traveling between the source and the detector. This is a small sample, and the dust or fog could just be outside the RWIS site. Airport visibility sensors measure over a much greater distance; however, they are much more expensive.

Communications: wireless modems and landlines depending on what's available
Performance: Good
Cost: $ 6,000 /visibility sensor

State: Nevada
Contact: Daniel Harris
775-888-7685 voice
775-888-7104 fax
775-888-7867
Visibility Sensor Type: N/A
Company: N/A
Description: The state of Nevada does not have this kind of system in place. It only has a wind system warning system that will fire and turn on some dynamic message signs.
Performance: N/A
Cost: N/A

State: California
Contact: Kevin Riley
916-651-9377 Office
916-708-7234 Cell
916-653-3055 Fax

Jose Dealba
559-351-1879

Visibility Sensor Type: Forward scatter
Company: Quixote Inc.
Description: Ten of the twelve districts in California use systems made by Surface Systems Inc. The location of the roadside weather information sites is base on the historic data of dust storm reoccurrences. California uses sensors that use the forward scatter method to get visibility data. California's system is user friendly; its weather sites are stand-alone units that just connect to a central computer and a utility power supply. District 6, which is composed of five counties, Fresno, Maderea, Tilery, Kings, and Kern, contain 14 RWIS sites. Each site has a base unit and an RPU into which all the other sensors at that station tie. The roadside weather information sites are also equipped with a surface temperature probe that is placed underneath the road; an air temperature sensor; humidity, due point, barometric, and precipitation intensity sensors, and cameras. Each site only gives point data due to the fact that each one is only capable of gathering data for a few hundred feet. Because some of these units are so far away, the data transfer to and from these units through dial up is expensive. Units in remote areas also use solar energy for power and use a wireless modem to transfer data to the control center. The wireless modem has a flat rate cost regardless of the amount of data transfer which helps keep the cost down. When the system senses a change in visibility, the system sends out a notification to the control center and the dynamic message signs are fired by DOT personnel.
Communications: Wireless
Performance: Maintenance is the biggest issue with the system. California has to have their system calibrated every six months and before the winter season. If the sensors are not calibrated before the winter season, their performance is greatly affected.
Cost: A visibility sensor with and RPU is $20,000 with installation
Each station cost $60,000 in all sites in districts 6.

Quixote does maintenance for $15,000 per year for all sites and replaces damaged equipment due to wear and tear. Back-scatter sensors are also available and are cheaper, but they do not provide quality data.

State: Wyoming
Contact: Vince Garcia
Office: 307-777-4231
888-996-7623

Kevin Cox
307-777-4620
Visibility Sensor Type: Forward scatter
Company: Quixote Inc. and Vaisala
Description: The State of Wyoming has a total of 34 RWIS sites that have been purchased over a long period of time. It uses utility electricity to power up its RWIS sites. Each site is equipped with an RPU to process the data from the sensors. The main use for these RWIS sites is winter weather. The most used sensor for the State of Wyoming is the wind speed and direction sensor. This sensor is crucial for WDOT in the winter because of blowing snow. Only a third of the sites are equipped with a visibility sensor, and they use it for

detecting visibility loss due to blowing snow. The RWIS sites are also equipped with a surface temperature and chemical sensor which is a probe placed underneath the road; an air temperature sensor, a humidity and dew point sensor; barometric, precipitation, and intensity sensors, and a wind speed and direction sensor.

Wyoming manages data from these sites. All the sites tie into one central computer in Wyoming that manages the raw data gathered by the RWIS sites. The data is then accessible through a network. The vendor in this case does not handle any of the data that is collected by the sensors. The vendor, which is Quixote, does do preventative maintenance on the equipment which costs about $1,500 a year per station.

This system is not automated; the information is just used to make decisions. This system also has the capability of setting a threshold that varies by location of the site; when the threshold is met, it gives out a warning.

Communications: Multiple ways of communication, such as microwave, canopy radio, and dial up are used.

Performance: The system has not been evaluated, so no straight response to this question was given. They have not had any serious problems yet but worry that some sensors may not be properly calibrated. Overall they said it performs well.

Cost: About $40,000 per site without infrastructure

APPENDIX B SALES ORDER

xxvso12.p va	7.1.20.6 Sales Order Print with Prices	Date: 04/12/11
Page: 1	Vaisala Inc / LIVE	Time: 09:04:41

Sales Order: 307312	Internal name: RWIS BLOWING DUST SYSx2		Confirmed: Yes
Order Date: 03/02/11	Purchase Order: 5298100425		
Currency: USD	Channel: 1013 ROADS Common	Salesperson1: JWAL	
FOB Point: ORIGIN PP&A	Credit Terms: Payment in advance	Ship Via: BEST WAY	
Disc %: 0.00%	Cost Ctr: 480		
Project: 48011042	Project Manager: MLO		

	Sold-To	Bill-To	Ship-To	End User
Code:	625722	625722	625722	625722
Name:	RT ELECTRIC, INC.	RT ELECTRIC, INC.	RT ELECTRIC, INC.	RT ELECTRIC, INC.
Address:				
Address:	480 N 17TH ST.	480 N 17TH ST.	480 N 17TH ST.	480 N 17TH ST.
Address:				
City:	LAS CURCES	LAS CURCES	LAS CURCES	LAS CURCES
Post:	88005	88005	88005	88005
Country:	United States	United States	United States	United States
VAT:				
FAX:	+1-575-5414261	+1-575-5414261	+1-575-5414261	+1-575-5414261

Please SEND Packing LIST and Tracking # to MLO via EMAIL when SHIPPED
DATA Services to Activate Modems and Transfer Liability to END USDER
Early Shipment Requested 12 Week Promise Date

Ln	Item Number	Description	Due Date	Pro.Date	UM	Ordered	List Price	Disc %	Total Net Price	Comm %
1	RWIS SYSTEMS		04/29/11	07/31/11	EA	1.0 G	67,350.00	0.0	67,350.00	0.00
5	DM322SYS	Road Weather Station ROSA data logger	04/29/11	05/27/11	EA	2.0 g	0.00	0.0	0.00	0.00

MU1NA3N1N2NNN1NN

A.Station ty	ROSAMASTER	ROSA Master Road Weather Station Software Licence	2.0	0.00
B.Software v	DM32NTCIP	Software NTCIP version DM32	2.0	0.00
C. DRI521 In	DRI521	Road Sensor Interface DRI521	2.0	0.00
E. Frame	DMF133	Frame, Incl. Mother Board and Power Supply	2.0	1,030.00
F. Enclosure	212454-8	DIN-Rails+Screws Lenght = 190mm zinc-coat	2.0	0.00
	BOX542	Instrument Cabinet ROSA	2.0	0.00
	DRFLANGE1-2	Flange Set(2ea) Multicate MC25	2.0	0.00
	DRW226783	Type Label DM322SYS	2.0	0.00
H. Lock set	215168	Quarter turn Lock with dust cap	4.0	0.00
J. Mounting	BOX542SET	Mechanical parts for BOX542	2.0	0.00

7.1.20.6 Sales Order Print with Prices
Vaisala Inc / LIVE

Date: 04/12/11
Time: 09:04:41

Sales Order: 307312
Order Date: 03/02/11
Currency: USD
FOB Point: ORIGIN PP&A
Disc %: 0.00%
Project: 48011042

Internal name: RWIS BLOWING DUST SYSx2
Purchase Order: 5298100425
Channel: 1013 ROADS Common
Credit Terms: Payment in advance
Cost Ctr: 480
Project Manager: MLO

Salesperson1: JWAL
Ship Via: BEST WAY

Confirmed: Yes

Ln	Item Number	Description	Due Date	Pro.Date	UM	Ordered	List Price	Disc %	Total Net Price	Comm %
	N. DMC586 Bo	DMC586	Processing Unit DMC586			2.0	0.00			
		DMC586Z1	DMC586 Cable Set Cable Set for DMC586s			2.0	0.00			
10	CELLMODEMVZKIT	CELL MODEM KIT VERIZON	04/29/11	05/27/11	EA	2.0 g	0.00	0.0	0.00	0.00
15	PS5RSD24	Power Supply, DIN rail 110VAC to 24VDC	04/29/11	05/27/11	EA	2.0 g	0.00	0.0	0.00	0.00
20	DRMAINS5	Mains Input Set MCB10A, Surge Protectors	04/29/11	05/27/11	EA	2.0 g	0.00	0.0	0.00	0.00
25	HMP155	Humidity & Temperature Probe	04/29/11	05/27/11	EA	2.0 g	0.00	0.0	0.00	0.00
	D2AB11A0A1A1A0A									
		HMP155B	Structural Elements			2.0	0.00			
	A. PROBE	HMP155D	HMP155D			2.0	0.00			
	B. OUTPUT	HMT300OUT3	Analog Output (CH1+CH2) Output 0...1V			2.0	0.00			
	C. OUTPUT CH	NOANALOGOUTPUT1	No analog output			2.0	0.00			
	D. OUTPUT CH	RHSCALE1	RH (0...100%RH)			2.0	0.00			
	E. UNITS	METRICUNITS	Metric Units			2.0	0.00			
	F. SENSOR	H180R&PT100	H180R and separate PT100 incl. shrinkable tubing			2.0	0.00			
	G. HEATINGS	NOHEATING	No Heating			2.0	0.00			
	H. CHEMICAL	NOPURGE	No chemical purge			2.0	0.00			
	I. FILTER	PTFEFILTER	Sintered PTFE-filter incl. O-ring			2.0	0.00			
	J. CABLE	HMP155CABLE3.5M	Cable 3.5m			2.0	0.00			
	K. T-PROBE	NOTPROBE	No Temperature Probe			2.0	0.00			
	L. CALIBRATI	NORMALCALIBRATION	RH&T-calibration in room temperature			2.0	0.00			
	M. ACCESSORY	15033	Master Label 42x8mm,2x1000 Pcs/Roller			2.0	0.00			
		220076	Type Label HMP155			2.0	0.00			
		M210913EN	Quick Reference Guide HMP155			2.0	0.00			
		NOACCESSORIES	No Accessories			2.0	0.00			
	N. INSTALLAT	NOINSTALLATIONKIT	Installation kit			2.0	0.00			

7.1.20.6 Sales Order Print with Prices
Vaisala Inc / LIVE

Date: 04/12/11
Time: 09:04:41

Sales Order: 307312
Order Date: 03/02/11
Currency: USD
FOB Point: ORIGIN PP&A
Disc %: 0.00%
Project: 48011042

Internal name: RWIS BLOWING DUST SYSx2
Purchase Order: 5298100425
Channel: 1013 ROADS Common
Credit Terms: Payment in advance
Cost Ctr: 480
Project Manager: MLO

Salesperson1: JWAL
Ship Via: BEST WAY

Confirmed: Yes

Ln Item Number	Description	Due Date Pro.Date UM	Ordered	List Price	Disc %	Total Net Price	Comm %
0. PRODUCTTY	HMP155SUBASSEMBLY HMP155 Sub Assembly		2.0	0.00			
26 DTR503A	Radiation Shield for HMP155+Mounting Kit	04/29/11 05/27/11 EA	2.0 g	0.00	0.0	0.00	0.00
30 PTB110	Barometer	04/29/11 05/27/11 EA	2.0 g	0.00	0.0	0.00	0.00
1B1AB							
	PTB110B	Structural Elements	2.0	0.00			
A.Pressure	PTB110PRE1	Pressure Range 500-1100 hPa	2.0	0.00			
B.Output	PTBOUTB	PTB110 Output 0 ... 2.5 Vdc	2.0	0.00			
C.Installati	PTBINSTALL1	DIN rail installation	2.0	0.00			
D.Connector	PTB110CONA	Pressure Connector M5 (10-32)	2.0	0.00			
E.Manual	M210839EN	User s Guide PTB110	2.0	0.00			
35 PWD	Present Weather Visibility sensor	04/29/11 05/27/11 EA	2.0 g	0.00	0.0	0.00	0.00
CNNNN1NANNNNBN							
A.SensorType	PWD12	Present Weather Detector	2.0	0.00			
B.Connection	NOCABLE	No Cable	2.0	0.00			
C.HoodHeater	NOOPTION3	No Option	2.0	0.00			
D.Luminances	NOOPTION2	No Option	2.0	0.00			
E.Future	NOOPTION8	No Option	2.0	0.00			
F.SpecialCon	PWDROSA	PWD conf. for ROSA	2.0	0.00			
G.PowerSuppl	NOOPTION	No Option	2.0	0.00			
H.DataInterf	NOOPTION7	No Option	2.0	0.00			
I.Mast	NOOPTION5	No Option	2.0	0.00			
J.MountingAc	NOACCESSORIES	No Accessories	2.0	0.00			
K.Calibratio	NOOPTION6	No Option	2.0	0.00			
L.Maintenanc	NOCABLE2	No Cable	2.0	0.00			
M.Manuals	M210542EN	User s Guide PWD12	2.0	0.00			
N.Future	NOOPTION9	No Option	2.0	0.00			
36 217150	Mast cable 3.85 m PWD10, 12, 20, 22	04/29/11 05/27/11 EA	2.0 g	0.00	0.0	0.00	0.00
40 ICECAM_MOBM12	Camera, DAY-NIGHT M12-SEC-DNIGHT-D43N43	04/29/11 05/27/11 EA	2.0 g	0.00	0.0	0.00	0.00

7.1.20.6 Sales Order Print with Prices
Vaisala Inc / LIVE

Date: 04/12/11
Time: 09:04:41

Sales Order: 307312
Order Date: 03/02/11
Currency: USD
FOB Point: ORIGIN PP&A
Disc %: 0.00%
Project: 48011042

Internal name: RWIS BLOWING DUST SYSx2
Purchase Order: 5298100425
Channel: 1013 ROADS Common
Credit Terms: Payment in advance
Cost Ctr: 480
Project Manager: MLO

Salesperson1: JWAL
Ship Via: BEST WAY

Confirmed: Yes

Ln	Item Number	Description	Due Date	Pro.Date	UM	Ordered	List Price	Disc %	Total Net Price	Comm %
41	ICEMOBOTIXPLATE	MOBOTIX MOUNTING PLATE	04/29/11	05/27/11	EA	2.0 g	0.00	0.0	0.00	0.00
42	221507	Cable 1m 4FT Network Patch Cable	04/29/11	05/27/11	EA	2.0 g	0.00	0.0	0.00	0.00
43	221361	Ethernet Cable 30 ft Rugged	04/29/11	05/27/11	EA	2.0 g	0.00	0.0	0.00	0.00
45	ICEIRIL08KIT	Kit IR Illuminator	04/29/11	05/27/11	EA	2.0 g	0.00	0.0	0.00	0.00
50	228699	Sensor Mount Kit Lattice Tower	04/29/11	05/27/11	EA	2.0 g	0.00	0.0	0.00	0.00
55	WS425	Ultrasonic Wind Sensor	04/29/11	05/27/11	EA	2.0 g	0.00	0.0	0.00	0.00

B2C2B				
	WS425B	Structural Elements	2.0	0.00
A.Controller	212020	Set of Screws WS425	2.0	0.00
	6000065	Screw, Crosshead 4-40 X 1/4 DIN7985 A2	6.0	0.00
	7067	Washer, Spring Lock B2,5 DIN127 A4	6.0	0.00
	WS425ASH	Array Assembly Stainless, Heated	2.0	0.00
	WS425CS	Controller Stainless Steel	2.0	0.00
B.Protocol	WS425PROTOCOL2	RS-232/RS-485/RS-422 Jumpering option B	2.0	0.00
C.Interface&	ZZ45203	RS232 Cable WS425, Open Leads	2.0	0.00
D.Mountingad	WS425FIX30	Mounting Adapter 30mm WS425 to 1 IN. Pipe	2.0	0.00
E.Manual	M210361EN	User s Guide WS425	2.0	0.00

Ln	Item Number	Description	Due Date	Pro.Date	UM	Ordered	List Price	Disc %	Total Net Price	Comm %
56	WMS30KIT	Mounting Accessories for Combined Wind Sensor	04/29/11	05/27/11	EA	2.0 g	0.00	0.0	0.00	0.00
57	DXS422	Sensor Manager Serial Interface	04/29/11	05/27/11	EA	2.0 g	0.00	0.0	0.00	0.00

7.1.20.6 Sales Order Print with Prices
Vaisala Inc / LIVE

Date: 04/12/11
Time: 09:04:41

Sales Order: 307312
Order Date: 03/02/11
Currency: USD
FOB Point: ORIGIN PP&A
Disc %: 0.00%
Project: 48011042

Internal name: RWIS BLOWING DUST SYSx2
Purchase Order: 5298100425
Channel: 1013 ROADS Common
Credit Terms: Payment in advance
Cost Ctr: 480
Project Manager: MLO

Salesperson1: JWAL
Ship Via: BEST WAY

Confirmed: Yes

Ln	Item Number	Description	Due Date	Pro.Date	UM	Ordered	List Price	Disc %	Total Net Price	Comm %
60	60083030	Roadway 30' Tower Kit (Modem, Radio & Atmosphe	04/29/11	05/27/11	EA	2.0 g	0.00	0.0	0.00	0.00
61	25010001	Padlock, Master With 15/15 Shackle	04/29/11	05/27/11	EA	2.0 g	0.00	0.0	0.00	0.00
62	24051114	Tower Structure Grounding	04/29/11	05/27/11	EA	2.0 g	0.00	0.0	0.00	0.00
65	NAVIGATOR SET UP		04/29/11	07/31/11	EA	1.0 g	0.00	0.0	0.00	0.00
70	SAT	Site Acceptance Test Day	07/31/11	07/31/11	DA	1.0 g	0.00	0.0	0.00	0.00
75	TRAINING		04/29/11	07/31/11	EA	1.0 g	0.00	0.0	0.00	0.00
80	M210242EN	ROSA User s Guide	04/29/11	05/27/11	EA	2.0 g	0.00	0.0	0.00	0.00
85	DIN MOUNT RJ 45	5543630 / 809-431	04/29/11	05/27/11	EA	2.0 g	0.00	0.0	0.00	0.00

Total	67,350.00
Commission	0.00
Total USD	67,350.00
Commission USD	0.00

End of Report

APPENDIX C DUCUMENTS FROM THE COMMISSIONING TEST

VAISALA

Weather Critical Operations | RWIS SAT Report

RWIS Start-Up Component Testing

Site # 1

Blowing Dust MP 11

Site Number	1	Visit Date/Time	11/29/2011 16:00:
Client	RT Electric		
District	N/A		
Site Name	Blowing Dust MP 11		
Highway	I-10		
Milepost	MP-11		
Direction	Westbound		
Latitude	32.16768		
Longitude	-108.52941		
Altitude	1275m		
Customer Rep:	Kevin Tegmeyer		
Vaisala Rep:	Tim Miller		
Contractor Rep:			

SSI / DMC Site

Start-Up Component Testing

Start-Up Component Testing ensures each individual device operates independently and in an integrated fashion; this process is also referred to as *Site Acceptance Testing (SAT)*, and *Commissioning*.

RWIS External Details

DESCRIPTION	ACCEPTED	COMMENTS / ACTIONS		
Foundation / Pad:	Y			
Grounding:	Y			
RWIS Tower:	Y			
RWIS Enclosure:	Y			
Fence / Enclosure:	Y			
Utility Pole(s):	Y			
Power Energized:	Y	n/a	2 Disconnects inside fence. One breaker and one switch	
Comms Activated:	Y	Cell	Y	166.140.29.39
Cross Arm(s):	Y			
Radiation Shield:	Y			

Vaisala Inc. | Boulder Operations
P.O. Box 3659, Boulder, CO 80307-3659, USA
Phone +1 303 499 1701 | Fax +1 303 499 1767
www.vaisala.com

RWIS RPU Interface Functionality

DM32 RPU	TYPE	S/N	ACCEPTED	COMMENTS / ACTIONS
Enclosure:	Box 542	G025N/A	Y	
Frame:	DMF 133	F445016	Y	
Comms Interface:	DMC 586	F375009	Y	
Comms - External:	BlueTree BT-6621	6621-435560007	Y	
Comms - Sensor:	DXS422	F383016		
Ethernet Hub:	BlueTree BT-6621	N/A	Y	
Interface Card 1:	DRI 521	G011010	Y	
Interface Card 2:	N/A	N/A		
Interface Card 3:	N/A	N/A		
Other:				

RWIS Atmospheric Sensor Analogue Calibrations

ATMOS SENSORS	TYPE	S/N	ACCEPTED	COMMENTS / ACTIONS
Air / Temp / Humid:	HMP 155	G1620005	Y	
Calibration Due Date:	1-Apr			
Pressure:	PTB 110	G1110008		
Precipitation:	PWD 12	G1730006	Y	
Wind:	WAS 425	G1710002	Y	
Snow Sensor:	N/A	N/A		
IR Radiation Sensor:	N/A	N/A		
Other:				

RWIS Pavement Sensors Analogue Calibrations

SURFACE SENSORS	TYPE	S/N / LOC	ACCEPTED	COMMENTS / ACTIONS
Surface 1 Sensor:	N/A	N/A		
Surface 2 Sensor:	N/A	N/A		
Surface 3 Sensor:	N/A	N/A		
Surface 4 Sensor:	N/A	N/A		
Surface 5 Sensor:	N/A	N/A		
Surface 6 Sensor:	N/A	N/A		
Deep Base 1 Sensor:	N/A	N/A		
Deep Base 2 Sensor:	N/A	N/A		

RWIS Cameras

CAMERAS	TYPE	S/N	ACCEPTED	COMMENTS / ACTIONS
Camera #1:	Mobotix M12	10.5.68.132	Y	
Camera #2:	N/A	N/A		
Camera #3:	N/A	N/A		
IR Illuminator #1:	IL08	N/A	Y	
IR Illuminator #2:	N/A	N/A		
IR Illuminator #3:	N/A	N/A		
DC-DC Converter:	N/A	N/A		
Image Capture:			Y	

Environmental Conditions

PARAMETER	LOCAL DATA	RWIS DATA	COMMENTS
Time: 11:30			
Air Temperature:	3.4	3.1	
Relative Humidity:	92	92	
Wind Speed:	7.9	8.3	
Wind Direction:	220	222	
Precipitation Details:	Y	Y	
Surface Temperature:	N/A	N/A	
Surface Condition:	Wet	Wet	
Cloud (Octas):	8	8	
Prevailing Weather:	Rain, windy, cold.		

RWIS Data Verification

X RoSA Status Report (local *.txt file capture).
[ ] RWIS data package (*.csv to RWIDS).
X Camera Image(s) capture (*.jpeg).
X Vaisala WXT510 Weather Transmitter (Serial Number: C1340004_).
[ ] ETI Therma 2 Handheld Digital Thermometer.
X FHWA Clarus Photographs / Images [01]

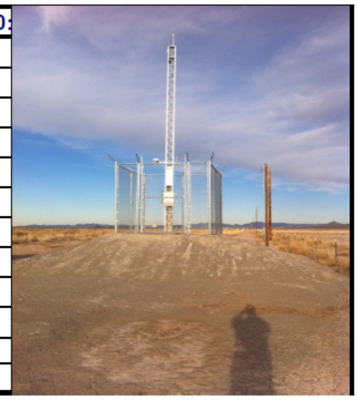
Additional COMMENTS / ACTIONS/ Recommendations:

RWIS Start-Up Component Testing

Site # 2

Blowing Dust MP 12

Site Number	2	Visit Date/Time	11/29/2011 16:00:
Client	RT Electric		
District	N/A		
Site Name	Blowing Dust MP 12		
Highway	I-10		
Milepost	MP 12		
Direction			
Latitude	32.28735		
Longitude	-108.86664		
Altitude	1280m		
Customer Rep:	Kevin Tegmeyer		
Vaisala Rep:	Tim Miller		
Contractor Rep:			



Concrete Site

Start-Up Component Testing

Start-Up Component Testing ensures each individual device operates independently and in an integrated fashion; this process is also referred to as *Site Acceptance Testing (SAT)*, and *Commissioning*.

RWIS External Details

DESCRIPTION	ACCEPTED	COMMENTS / ACTIONS		
Foundation / Pad:	Y			
Grounding:	Y			
RWIS Tower:	Y			
RWIS Enclosure:	Y			
Fence / Enclosure:	Y			
Utility Pole(s):	Y			
Power Energized:	Y	n/a	2 Disconnects inside fence. One breaker and one switch	
Comms Activated:	Y	Cell	Y	166.140.29.39
Cross Arm(s):	Y			
Radiation Shield:	Y			

Vaisala Inc. | Boulder Operations
P.O. Box 3659, Boulder, CO 80307-3659, USA
Phone +1 303 499 1701 | Fax +1 303 499 1767
www.vaisala.com

RWIS RPU Interface Functionality

DM32 RPU	TYPE	S/N	ACCEPTED	COMMENTS / ACTIONS
Enclosure:	Box 541	G025	Y	
Frame:	DMF 133	F504002	Y	
Comms Interface:	DMC 586	F375010	Y	
Comms - External:	BlueTree BT-6621	6621-435560007	Y	
Comms - Sensor:	DXS422	F383002		
Ethernet Hub:	BlueTree BT-6621	6621-435560007	Y	
Interface Card 1:	DRI 521	G011030	Y	
Interface Card 2:	N/A	N/A		
Interface Card 3:	N/A	N/A		
Other:				

RWIS Atmospheric Sensor Analogue Calibrations

ATMOS SENSORS	TYPE	S/N	ACCEPTED	COMMENTS / ACTIONS
Air / Temp / Humid:	HMP 155	G1620006	Y	
Calibration Due Date:	1-Apr			
Pressure:	PTB 110	G1110008		
Precipitation:	PWD 12	G1730006	Y	
Wind:	WAS 425	G1710003	Y	
Snow Sensor:	N/A	N/A		
IR Radiation Sensor:	N/A	N/A		
Other:				

RWIS Pavement Sensors Analogue Calibrations

SURFACE SENSORS	TYPE	S/N / LOC	ACCEPTED	COMMENTS / ACTIONS
Surface 1 Sensor:	N/A	N/A		
Surface 2 Sensor:	N/A	N/A		
Surface 3 Sensor:	N/A	N/A		
Surface 4 Sensor:	N/A	N/A		
Surface 5 Sensor:	N/A	N/A		
Surface 6 Sensor:	N/A	N/A		
Deep Base 1 Sensor:	N/A	N/A		
Deep Base 2 Sensor:	N/A	N/A		

RWIS Cameras

CAMERAS	TYPE	S/N	ACCEPTED	COMMENTS / ACTIONS
Camera #1:	Mobotix M12	10.5.68.122	Y	
Camera #2:	N/A	N/A		
Camera #3:	N/A	N/A		
IR Illuminator #1:	IL08		Y	
IR Illuminator #2:	N/A	N/A		
IR Illuminator #3:	N/A	N/A		
DC-DC Converter:	N/A	N/A		
Image Capture:			Y	

Environmental Conditions

PARAMETER	LOCAL DATA	RWIS DATA	COMMENTS
Time: 11:30			
Air Temperature:	3.4	3.1	
Relative Humidity:	92	92	
Wind Speed:	7.9	8.3	
Wind Direction:	220	222	
Precipitation Details:	Y	Y	
Surface Temperature:	N/A	N/A	
Surface Condition:	Wet	Wet	
Cloud (Octas):	8	8	
Prevailing Weather:	Rain, windy, cold.		

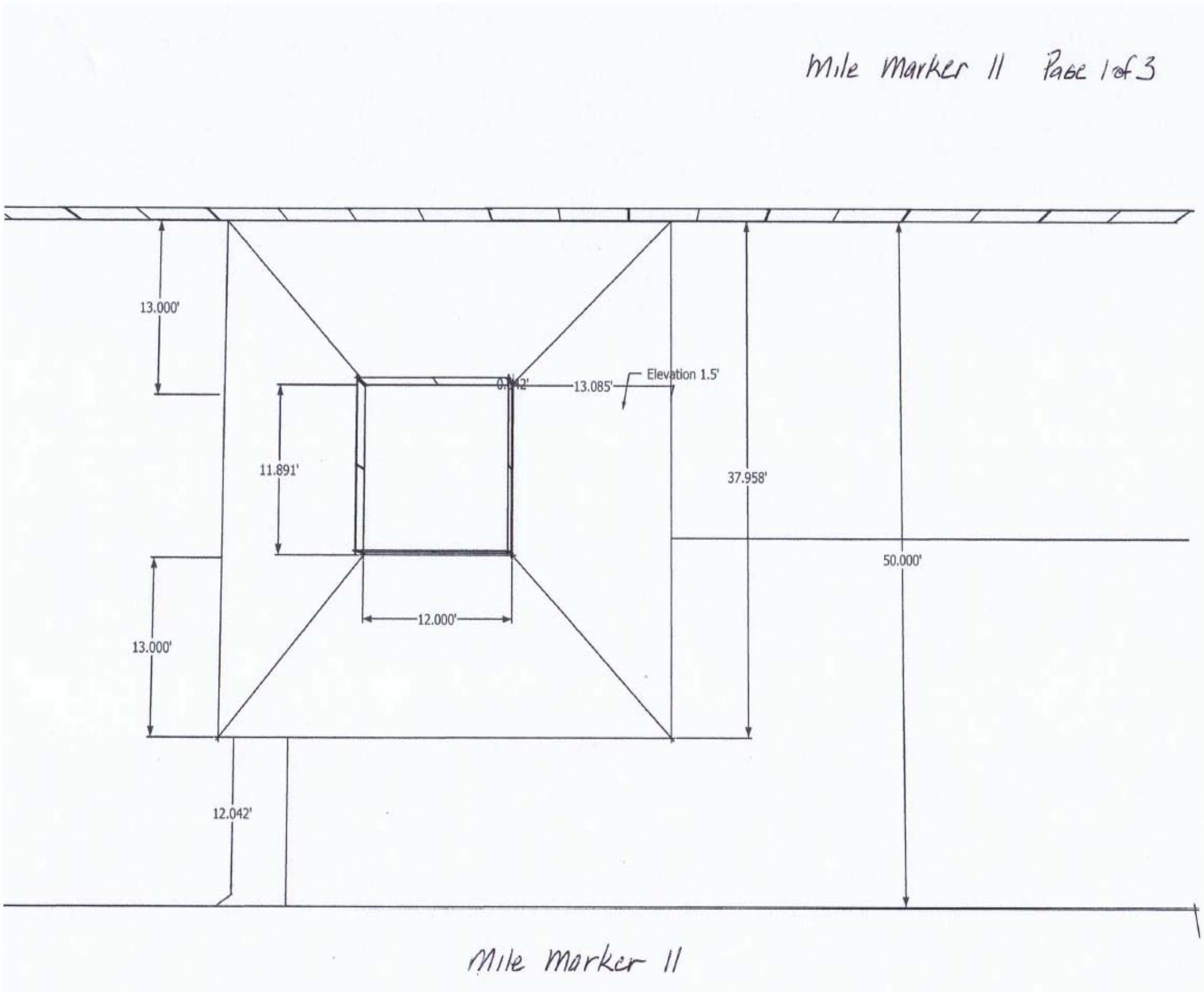
RWIS Data Verification

X RoSA Status Report (local *.txt file capture).
[ ] RWIS data package (*.csv to RWIDS).
X Camera Image(s) capture (*.jpeg).
X Vaisala WXT510 Weather Transmitter (Serial Number: C1340004_).
[ ] ETI Therma 2 Handheld Digital Thermometer.
X FHWA Clarus Photographs / Images [01]

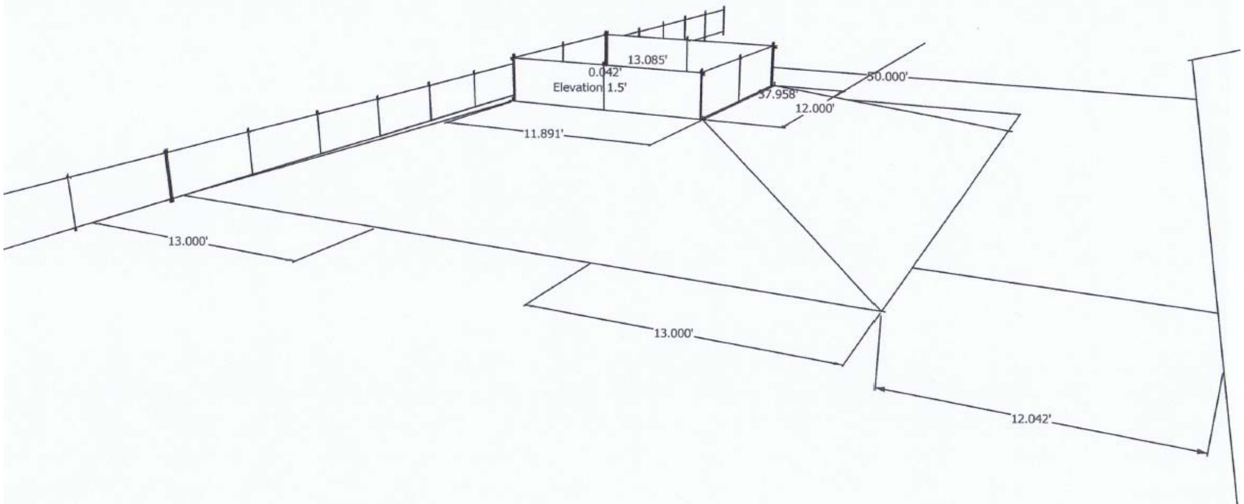
Additional COMMENTS / ACTIONS/ Recommendations:

APPENDIX D AS-BUILT DRAWINGS

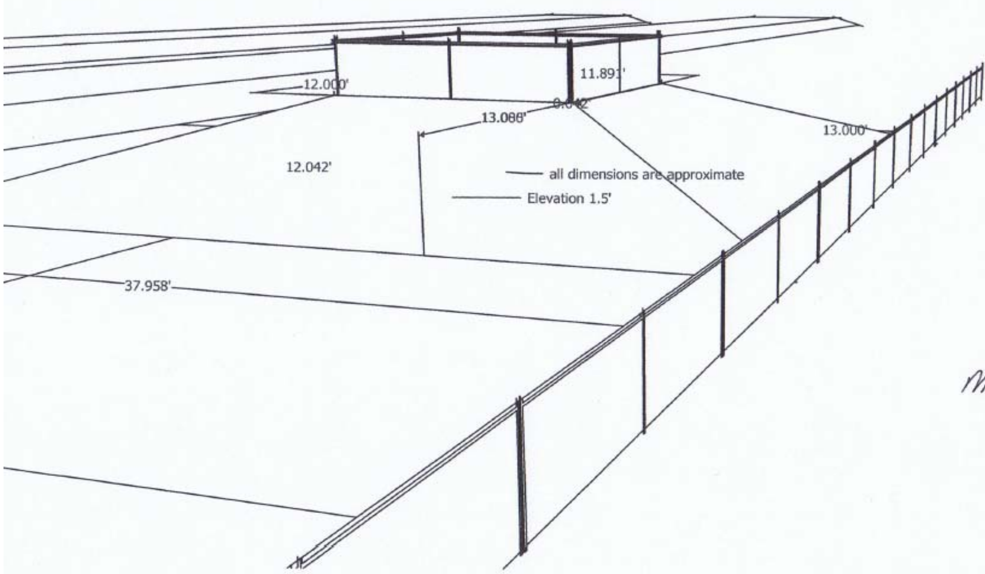
Station at Mile Marker 11:



Mile marker 11 Page 2 of 3

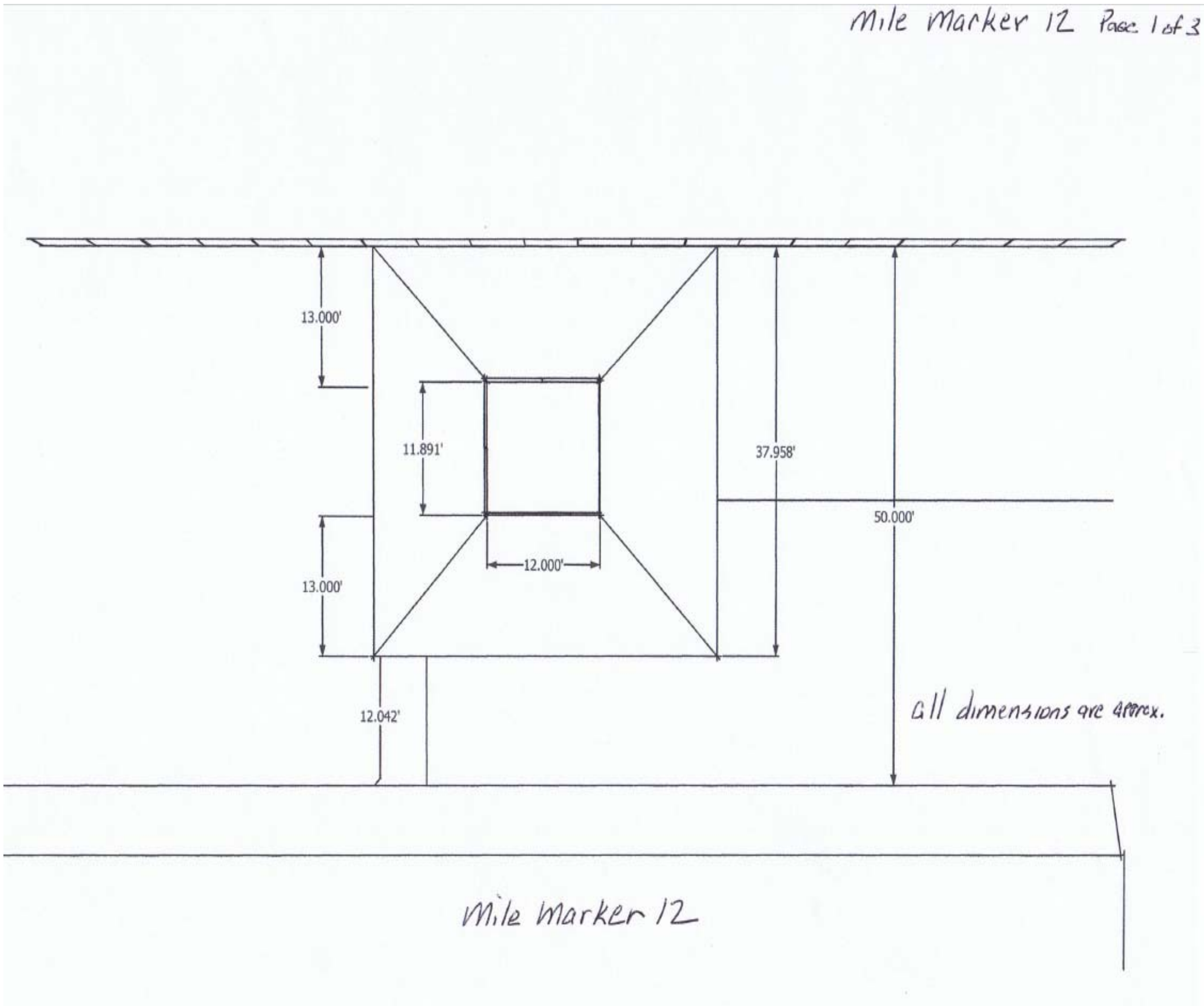


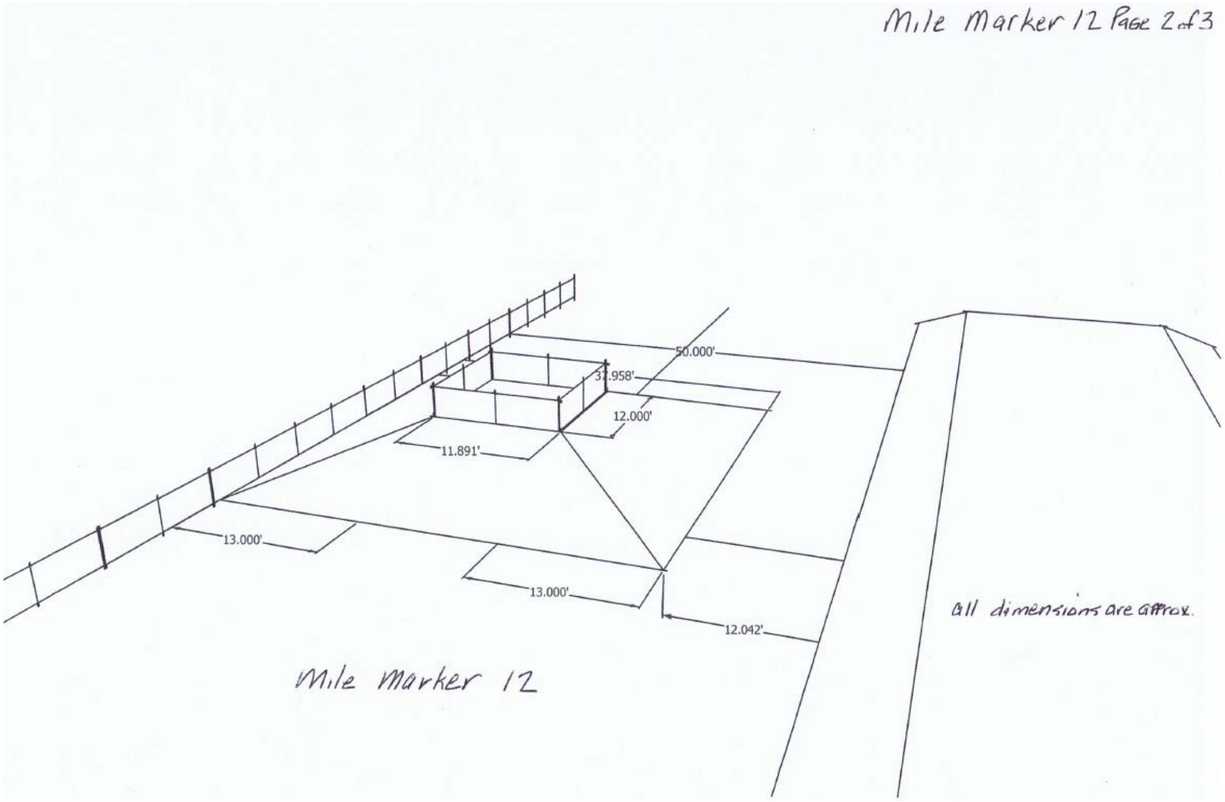
Mile Marker 11 Page 3 of 3

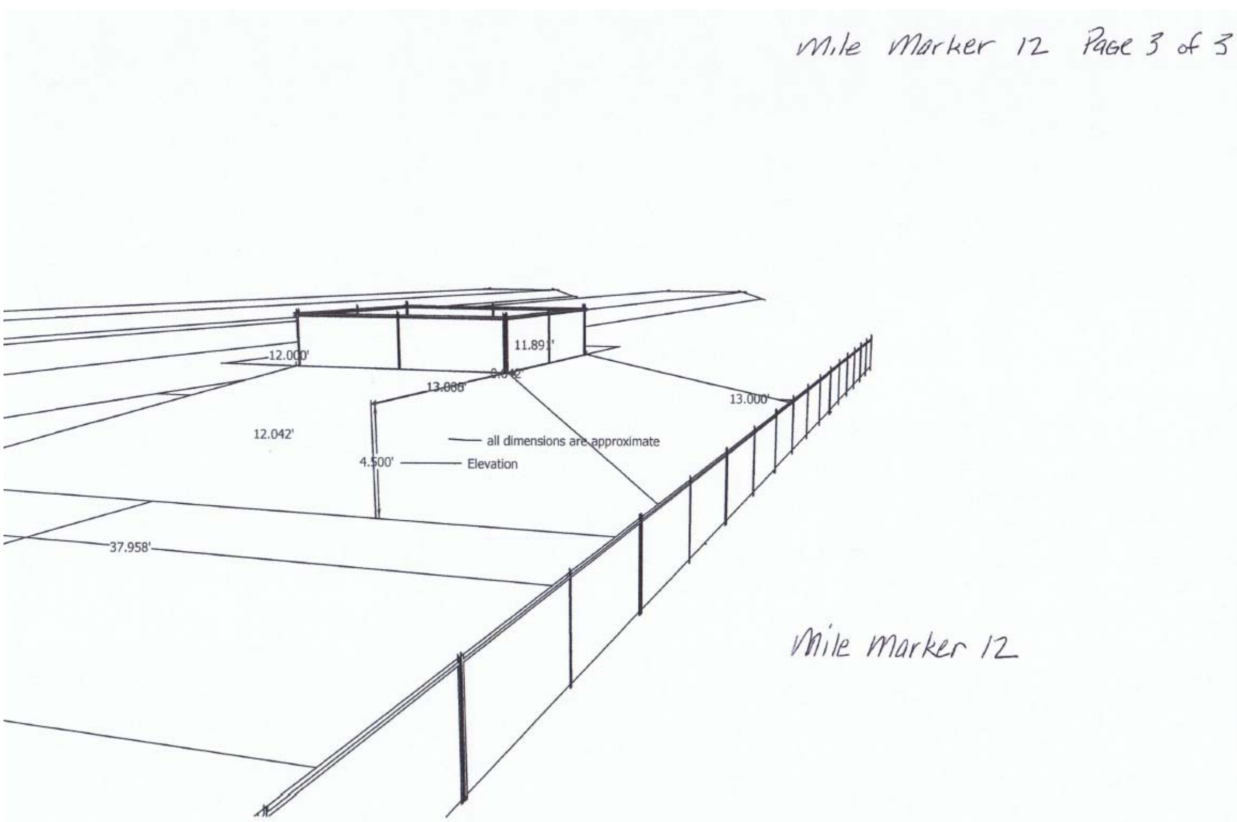


Mile Marker 11

Station at Mile Marker 12:




Mile Marker 12 Page 2 of 3
50.000'
37.958'
12.000'
11.891'
13.000'
13.000'
12.042'
all dimensions are approx.
Mile Marker 12

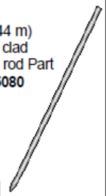

Mile Marker 12 Page 3 of 3
12.000'
11.891'
13.000'
13.000'
12.042'
all dimensions are approximate
4.500'
Elevation
37.958'
Mile Marker 12

Accessories

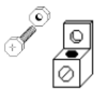
ACCESSORIES

GROUND ACCESSORIES

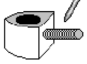
#4
Braided ground wire
Part # **CW-0040**



8-ft (2.44 m)
copper clad
ground rod Part
GR-5080



Grounding Lug
Part # **TL-0470**

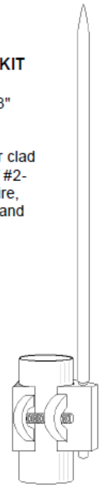


Ground Rod Clamp
Part # **GR-4400**

LIGHTNING ROD KIT

Complete kit with 18" tapered aluminum lightning rod, mast clamp, 8 foot copper clad ground rod, 4 feet of #2-Ø braided ground wire, one Grounding Lug and two Ground Rod Clamps.

Part # **LR-8400**



HOW TO ORDER - Order from your authorized Glen Martin Engineering distributor or call us at the number listed below. Check/money order/MasterCard/ Visa/ C.O.D. accepted. Our foreign sales department specializes in overseas shipments!

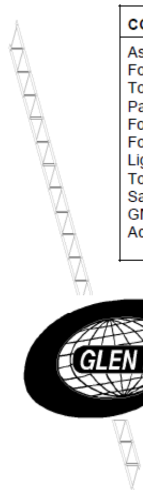
Notice: Dimensions, shipping weights and performance specifications are subject to variation within reasonable tolerances. Since changes and improvements are being made continually, specifications shown are subject to change without notice.

Glen Martin Engineering, Inc.
13620 Old Hwy 40, Boonville,MO 65233
Call our Customer Service Department Mon. - Fri. 9 am - 4:30 pm Central Time

660-882-2734 http://www.glenmartin.com

12

MF-1331 Fold-Over Tower



CONTENTS	PAGE #
Assembly Notes	2
Footing Assembly	3
Tower Assembly	4
Parts Lists	5
Fold-over Kit Assembly	5
Fold-Over Parts Diagram	7
Lightning Rod Kit	8
Tower Operating Instructions	9
Safety Rules	11
GME Warranty	11
Accessories	12

GLEN MARTIN ENGINEERING

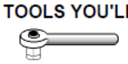
Rev. 4/17/00

1

Congratulations!

We would like to thank you for choosing a Glen Martin Engineering Fold-Over Meteorological Tower. This fold-over tower is manufactured in the USA of quality 6061-T6 anodized aluminum, stainless steel and galvanized steel for durability and long life. Please take the time to inspect the winch cable and winch at least once a month for rust or other problems. Lightly grease the stainless steel winch cable as needed With proper care, your fold-over meteorological tower should give you a lifetime of use.

TOOLS YOU'LL NEED FOR ASSEMBLY AND INSTALLATION



SOCKET SET

ADJUSTABLE END WRENCH

TAPE MEASURE

<u>READ CAREFULLY</u> - THEN PLAN YOUR INSTALLATION PROCEDURE CAREFULLY
Locate your tower site. Maintain a safe distance from all power lines. At least one and one-half to twice the height of the tower and antenna is a safe distance. Remember that any contact with power lines can be fatal to you! All towers should be properly guyed. All tower installations should be grounded per local or national codes. All towers should be installed by trained and experienced personnel and should be inspected by qualified personnel at least twice a year.

Tower Installation:

<u>CONCRETE FOOTING SECTION - FB-13:</u> Dig appropriate size hole. Bolt three legs of footing section together and slip the bottom tower section into the base. Line up fixed base and tower leg holes, then ream 5/16" holes in 18 places (from square holes to round holes) in the tower legs. Bolt fixed base to first section of tower prior to setting fixed base in the hole. The steel portion of the base legs should extend about nine inches from the top of the concrete so that aluminum tower sections never come in contact with the concrete directly. The base assembly and first tower section should be leveled, plumbed, and temporarily guyed or braced while pouring the concrete. Crown the top of the concrete slightly to prevent water acculmulation.

<u>TOWER CONSTRUCTION - M-13:</u> Lay out tower sections so that dark painted ends are at the bottom (pointing downward). Bolt complete sections together using short angle joint clips with a 7/16" nut driver. Make certain bolt heads are seated and torqued to nine foot-pounds. Take care that joining tower surfaces are flush.

<u>FOLD-OVER ASSEMBLY KIT:</u> See assembly instructions beginning on page 5.

<u>TOWER ERECTION:</u> Towers less than 50' may be hinged into vertical position with the help of several good men. Be cautioned to exert equal stress to tower legs to prevent undue stress, twist, or damage to tower. After tower is erected, replumb the tower with main leveling studs. In some cases, it may be preferable to hire a professional tower erector.

2

SAFETY RULES

1. Never mount any tower system close to wires or power lines. Stay at least 1½ times the overall height away from any power lines or wires.

2. Never attempt to touch someone who is in contact with power lines or wires.

3. Never climb the tower. Serious injury could result from a fall. This is even more dangerous when you are on a roof top.

4. If you drop something while working on a roof, NEVER try to catch or stop it. Let it fall and keep your own balance secure.

5. Use the buddy system. Always have someone helping nearby.

6. Always keep children away.

7. NEVER attempt to install or attempt to repair equipment while under the influence of drugs, alcohol or any medication.

Please keep these instructions in a safe place after installation.

GME WARRANTY

Glen Martin Engineering warrants this Fold-over tower for one full year. If this product fails to give the original purchaser complete satisfaction within one year from the original date of purchase, return it to the nearest authorized distributor and Glen Martin Engineering will repair it, free of charge. Glen Martin Engineering will not be liable for loss or damage to property or any incidental or consequential loss or expense from property damage due directly or indirectly from the use of this product.

11

TOWER OPERATING INSTRUCTIONS

To lower hinged section of your folding tower, remove the nuts from the bottom 2 U-Bolt clamps (being careful not to lose the 4 nuts). Next, unlock the leverage arm (if a padlock is being used) and manually pull the bottom of the leverage arm outward from the tower. Crank the winch cable to continue lowering the top sections of the tower.

To return the tower to the normal position, crank the tower vertical with the hand winch, and replace four nuts on the bottom two U-Bolts holding the leverage arm to the bottom section of the tower. If locking the top section is desired, a paclock can be applied through the lock tab at the base of the leverage arm and the face plate on the tower.

Periodic inspection of your tower and fold-over assembly will assure long satisfactory service. A very light coat of oil on the stainless steel winch cable will help.

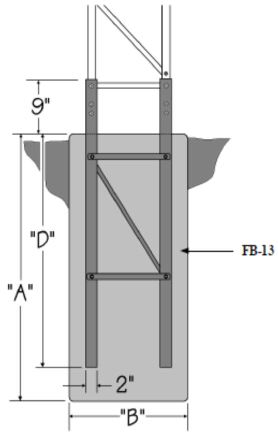
The winch has been fully lubricated at the factory; but for continued smooth performance and increased life, occasional greasing of gears, reel shaft and an occasional drop of oil on drive shaft bearings are recommended. The winch finish can be protected and will provide longer life if it is periodically washed with water and wiped with a light oil or wax.

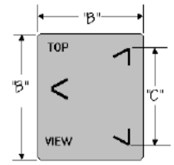
Keep winch in good working order. Damaged or severely-worn parts create unnecessary dangers and could result in personal injury or property damage.

Never install this fold-over tower in a position which, when folded over or erect, could come within one and one half times its height with mast of overhead power lines or other obstacles. The chart on Page 9 gives leverage-arm tolerances when tower is folded over.

10

GLEN MARTIN ENGINEERING



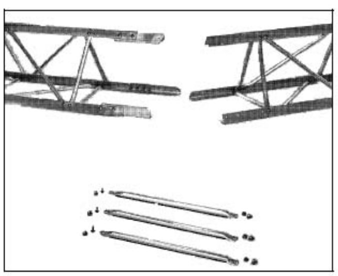


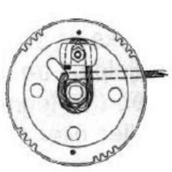
FOOTING TYPE	"A"	"B"	"C"	"D"	CU. YDS. CONCRETE REQ'D.
FB-13	45"	33"	13"	39"	1.05
CHB-13	45"	33"	15.43"	45"	1.05

FB-13 Parts List

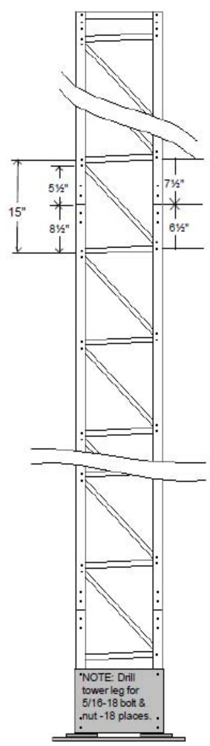
3	Angle legs
6	Horizontal braces
3	Diagonal braces
18	5/16-18 Stainless bolts
18	5/16-18 Stainless nuts
12	1/4-20x3/4 Hex bolts
12	1/4-20 nuts

3





WINCH CABLE
ANCHORING METHOD



4

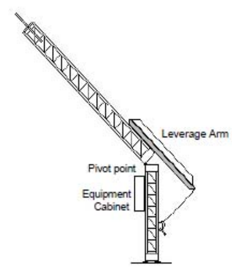
Fold-Over Kit
General Information

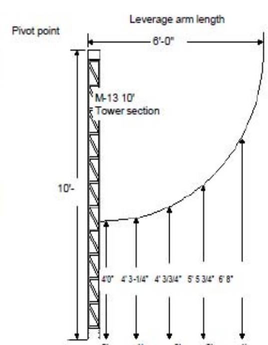
The fold-over assembly permits the installed tower to hinge at the 10' level. This allows the atmospherics mounted on the tower to be serviced by lowering the tower rather than having to reach them from a bucket truck. A hand operated winch lowers the upper section(s) of the tower to ground level for easy access to any components mounted at the top.

The assembly bolts to the tower using existing bolt holes and can be retrofitted to existing installed towers.

Note: The tower folds OVER the equipment cabinet.

Two legs of the tower are hinged and the third leg separates. A 2" pipe is bolted to this third leg serving as a leverage arm. All parts are made of 6061-T6 anodized aluminum, stainless steel or hot-dipped galvanized steel.

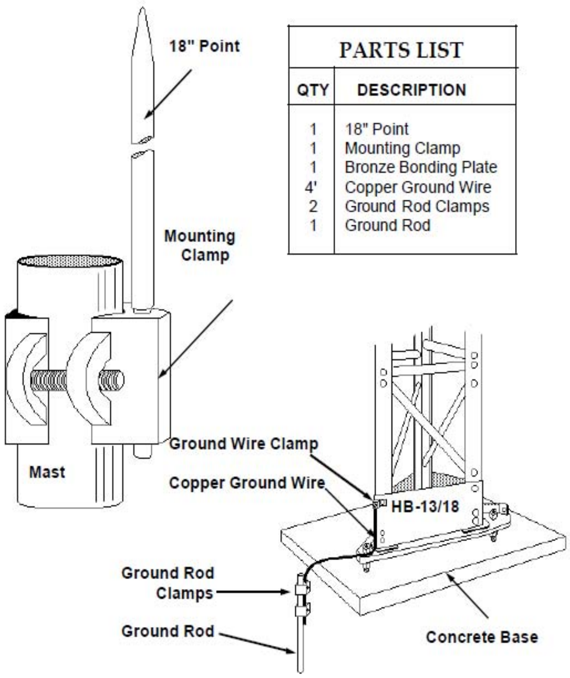




Clearance Required at various distances from the base

9

OPTIONAL LIGHTNING ROD KIT INSTALLATION



PARTS LIST	
QTY	DESCRIPTION
1	18" Point
1	Mounting Clamp
1	Bronze Bonding Plate
4'	Copper Ground Wire
2	Ground Rod Clamps
1	Ground Rod

Fold-Over Assembly Kit Installation Instructions

1. Before assembling please take an inventory of parts received.

2. Bolt the winch to the winch plate using two 3/8" bolts and two 5/16" bolts. Locate the lower edge of the plate 3 feet from the start of the tower. Remove the six 1/4" carriage bolts from under the winch plate. Bolt the plate to the tower leg using six 1/4" hex head bolts. Drill two 1/4" holes in the tower leg and fasten the plate with two additional 1/4" hex head bolts.

3. Locate the U-bolt bracket at the 6'10" level. Remove four 1/4" carriage bolts under the clamp. Position the bracket and fasten with four 1/4" hex head bolts. Drill two additional 1/4" holes in the tower leg and fasten the bracket with two 1/4" hex head bolts.

4. The hinge assembly is bolted between the first two tower sections. If there are inside tower clips at the top of the first section, remove them at this time. Locate the hinge assembly on the tower sections and clamp in place so the mounting holes align. Drill through the mounting holes with a 5/16" bit so as to ream out the square holes in the tower leg. Secure the hinge assembly to the two lower sections with twenty-four 5/16" hex head bolts.

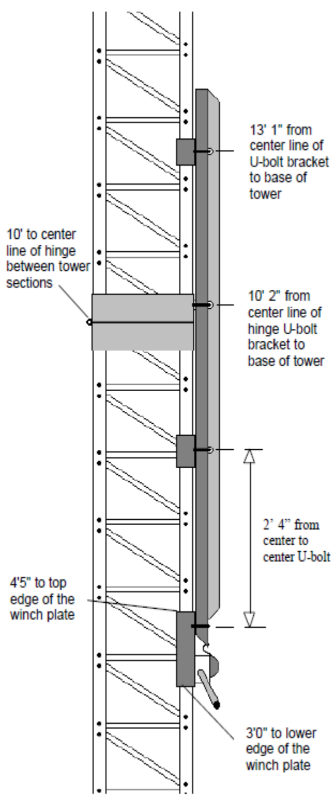
5. Repeat step 2 for the U-bolt bracket at the 13' 1" level.

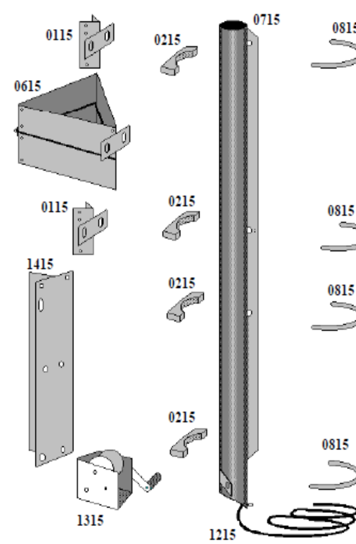
6. Using a U-bolt and saddle placed between the mast pipe and the top mount, attach the mast to the tower. Check the location of the bottom of the mast to make sure the lock tab aligns with the lock hole in the winch plate. Tighten the U-bolt nuts.

7. Install the three other U-bolts in a similar manner.

8. Run the wire rope through the 1/4" hole in the end of the mast and attach the loose end to the winch with the clamps provided (see page 4 for winch cable attachment).

Note: Use existing punched holes in all assemblies and drill through with 5/16 bit to change the 1/4" square hole in tower leg to a 5/16 hole for the bolt.





KM-1000 Fold - Over Part List

Line	Item	Qty	Description	Line	Item	Qty	Description
1	0115	2	Top Tower Mount	5	0715	1	Mast Pipe
2	0215	4	Saddle	6	0815	4	U-Bolt and two locknuts , SS
3	0615	1	Hinge Assembly	7	1215	1	SS Winch Cable & stop
4	1515	1	Hardware Kit 14 -1/4-20 bolts & nuts 2 -3/8 bolt, for winch 2 -5/16 bolts for winch 24 -5/16 bolts & nuts , hinge	8	1315	1	Winch and handle
				9	1415	1	Winch Plate Assembly