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16. Abstract

This report identifies and evaluates existing remote automatic monitoring and public information systems for both ice detection on bridges and flood monitoring at low-water crossings. The report encompasses all aspects of these systems, including hardware, software, communications systems, data processing, and meteorological services. This study provides a survey of various state agencies and their experiences with these systems.

In addition, this report discusses three alternatives for statewide implementation of these systems. The alternatives examined are those considered by the Texas Department of Transportation, which include (1) the use of two turnkey systems throughout the state (one for ice detection and one for high-water detection); (2) multiple proprietary systems statewide (vendors could vary from district to district); and (3) a combination of components of various proprietary systems. The most feasible and cost-effective option is to allow each district to purchase a system that meets its needs while still remaining within budget. In order for this to work, systems from different vendors must be able to exchange information. Therefore, it is imperative that the systems purchased provide an open systems environment and use a standard data exchange protocol.

The report concludes with suggestions for developing a set of implementation guidelines for a remote automatic monitoring and public information system for use during hazardous conditions.

17. Key Words

Remote automatic monitoring and public information systems, hazardous road conditions, road weather information systems, RWIS

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PRELIMINARY REPORT ON A REMOTE AUTOMATIC MONITORING AND PUBLIC INFORMATION SYSTEM FOR HAZARDOUS CONDITIONS

by

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Benjamin McKeever
Richard Greer

Research Report 1380-1

Research Project 0-1380
Develop a Remote Automatic Monitoring and Public Information System for Hazardous Conditions

Conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the

U.S. DEPARTMENT OF TRANSPORTATION
Federal Highway Administration

by the

CENTER FOR TRANSPORTATION RESEARCH
Bureau of Engineering Research
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IMPLEMENTATION STATEMENT

This report provides a comprehensive survey of existing bridge ice-detection systems and low-water crossing monitoring systems (LWCMS's), as well as a thorough literature review of these systems and their economics. This study also includes discussion of various implementation alternatives for these systems based on information gathered during on-site interviews with system operators and end users. This report could prove to be a useful tool for any organization or state agency that is considering purchasing or implementing a bridge ice-detection system or LWCMS.

Prepared in cooperation with the Texas Department of Transportation (TxDOT) and the U.S. Department of Transportation, Federal Highway Administration (FHWA).

DISCLAIMERS

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation.

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TABLE OF CONTENTS

SUMMARY

This report identifies and evaluates existing remote automatic monitoring and public information systems for both ice detection on bridges and flood monitoring at low-water crossings. The report encompasses all aspects of these systems, including hardware, software, communications systems, data processing, and meteorological services. This study also provides a survey of various state agencies and their experiences with these systems.

In addition, this study discusses three alternatives for statewide implementation of these systems. The alternatives examined are those considered by TxDOT, which include: (1) the use of two turnkey systems throughout the state (one for ice detection and one for high-water detection); (2) multiple proprietary systems statewide (vendors could vary from district to district); and (3) a combination of components of various proprietary systems. The most feasible and cost-effective option is to allow each district to purchase a system that meets its needs while still remaining within its budget. In order for this to work, systems from different vendors must be able to exchange information. Therefore, it is imperative that the systems purchased provide an open systems environment and use a standard data exchange protocol.

This report concludes with suggestions for developing a set of implementation guidelines for a remote automatic monitoring and public information system for hazardous conditions.

CHAPTER 1. INTRODUCTION

1.1 PROBLEM STATEMENT AND PURPOSE

Highway agencies such as the Texas Department of Transportation (TxDOT) are looking for ways to use labor, equipment, and materials as cost effectively as possible. This is a major issue with regard to the maintenance of rural roads during periods of inclement weather. Increasing litigation has also been a cause of concern to highway agencies, which may be liable for accidents attributable to a deficiency in design or operations (Ref 7). Low-volume roads appear particularly vulnerable to lawsuits, since they are typically constructed to standards lower than those used for high-volume routes. Also, because of the magnitude of the Texas roadway system, funding levels are not always sufficient to ensure adequate maintenance of problem areas during bad weather conditions. This is especially a problem with icing on bridge decks and flooding of low-water crossings.

In order to ensure safer driving conditions on rural highways, state highway agencies are exploring the use of new technologies that will improve the flow of information about road conditions. Several states, along with many countries in Europe, have established networks of data-gathering systems that provide valuable information to decision makers and the traveling public regarding potentially hazardous road conditions (Ref 5). These systems are often referred to as *road weather information systems* (RWIS's).

The purpose of this report is to identify and evaluate existing remote automatic monitoring and public information systems for both ice detection on bridges and flood detection for low-water crossings. The report covers all aspects of these systems, including hardware, software, communication systems, data processing, and meteorological services. The report also includes a survey of other state agencies and their experiences with these systems. Recommendations for developing an implementation procedure for these systems are provided in the Chapter 6.

1.2 BACKGROUND

This section will identify the major components of an RWIS and present some of the potential benefits that state highway agencies can obtain from implementing an RWIS.

1.2.1 Road Weather Information System Components

RWIS's sense and collect on-site weather and road condition information, process and disseminate the information, and create forecasts of road and weather conditions (Ref 5). There are several components of an RWIS. These are:

- sensors
- remote processing units (RPUs)
- central processing units (CPUs)
- telecommunications equipment to transmit data

- computer workstations equipped with software
- forecasts from the National Weather Service (NWS) or other meteorological services

The sensors include ice-detection sensors, which are typically embedded in the pavement, and water-level sensors, which tend to be installed in or around a creek bed. Most RWIS's also include a number of atmospheric sensors that provide additional information about current weather conditions, such as air temperature, relative humidity, wind direction and speed, visibility, and presence of precipitation.

Located at the site, RPUs are responsible for processing raw data from the sensors. These data, whether in digital or analog format, are converted to a usable form and then transmitted either to roadside message signs or to flashing lights or to a CPU. The RPUs are usually either battery or solar powered.

CPUs are located at a central control office. The CPU analyzes, stores, and arranges the data from the RPUs. Data are received from the RPUs, usually via radio or telephone, and converted by the CPU into usable information and graphic displays for decision makers or meteorologists. In some cases, data are formatted for use in forecasting models.

Communications equipment used to transmit RWIS information comes in a variety of forms. Communications can be via direct connection, telephone, cellular link, radio, microwave, satellite, or local area network (LAN). Direct connection requires only cable. For telephone communications, telephone lines and modems are needed. For radio links, transmitters/receivers, antennas, and sometimes repeaters are necessary. Microwave and satellite communications are slightly more expensive and require special types of transmitters/receivers and antennas. LAN connections require an Ethernet card, Token Ring, or some other type of networking device.

Computer workstations equipped with special software can be used to access the RWIS data stored in the CPU, and then to present the data to users in a variety of usable forms. These forms include tabulated text formats, geographical information systems (GIS's), map locators, voice messages, and model outputs. The displays can be tailored to the customer's needs.

The final components of RWIS's are weather and pavement forecasts. Forecasts are often considered a separate entity from the other RWIS components because they require information from other sources. Typical sources of weather forecasts include the public media, the NWS, and Value-Added Meteorological Services (VAMS). Public media and NWS forecasts are often too conservative and not sufficiently detailed for state agencies. On the other hand, by using data from the remote sites combined with NWS data and forecast models, VAMS can provide state agencies with valuable, localized forecasts. VAMS can also provide live radar images.

Figures 1.1 and 1.2 present the major components for a bridge ice detection system and a low-water crossing monitoring system (LWCMS), respectively.

1.2.2 Road Weather Information System Benefits

RWIS will allow TxDOT to better manage its resources during weather emergencies by providing maintenance personnel with real-time information and forecasts of low-water crossing conditions and bridge deck icing throughout their area of responsibility. This will result in lower costs for labor, equipment, and materials. Also, prompt salting, plowing, or clean up of roads will improve the traffic flow and, thus, reduce travel times. Finally, RWIS information can be used during periods of good weather as well, by assisting in the planning of construction activities in which weather and pavement temperature forecasts are crucial.

By providing pretrip and enroute information to drivers on road conditions, an RWIS will reduce the risk of liability and provide safer roads for TxDOT. Safer roads result in fewer accidents and, thus, fewer fatalities. Recent advances in remote sensing and telecommunications, together with a steep decline in price, have made RWIS an entirely feasible and attractive solution to the problem of hazardous weather conditions on rural roads. RWIS, in conjunction with intelligent transportation system (ITS) projects around the country, will make travel safer and save tax dollars.

1.3 ORGANIZATION OF REPORT

The next two chapters of this report present the results of a product survey. Chapter 2 includes summaries of the available turnkey systems for both high-water detection and ice detection. Chapter 3 breaks these systems down component by component, providing summaries of the products and options available for each component. Chapter 4 includes a survey of other state agencies and their experiences with RWIS. Chapter 5 discusses the economic analyses that have been performed on the benefits of RWIS. Finally, Chapter 6 presents three implementation alternatives and recommends steps required in developing a set of implementation guidelines for these systems.

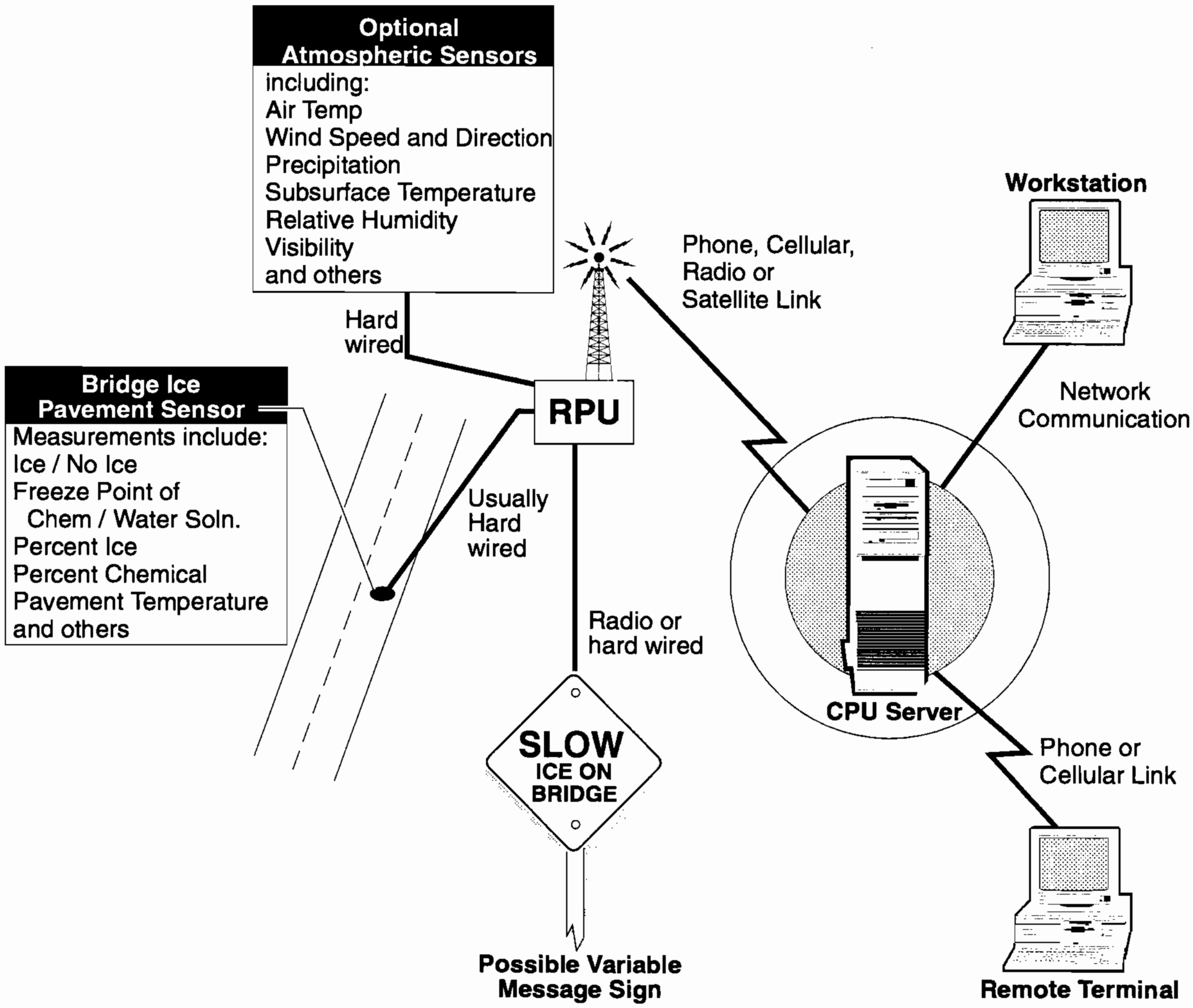

Figure 1.1 Major components of a bridge ice detection system

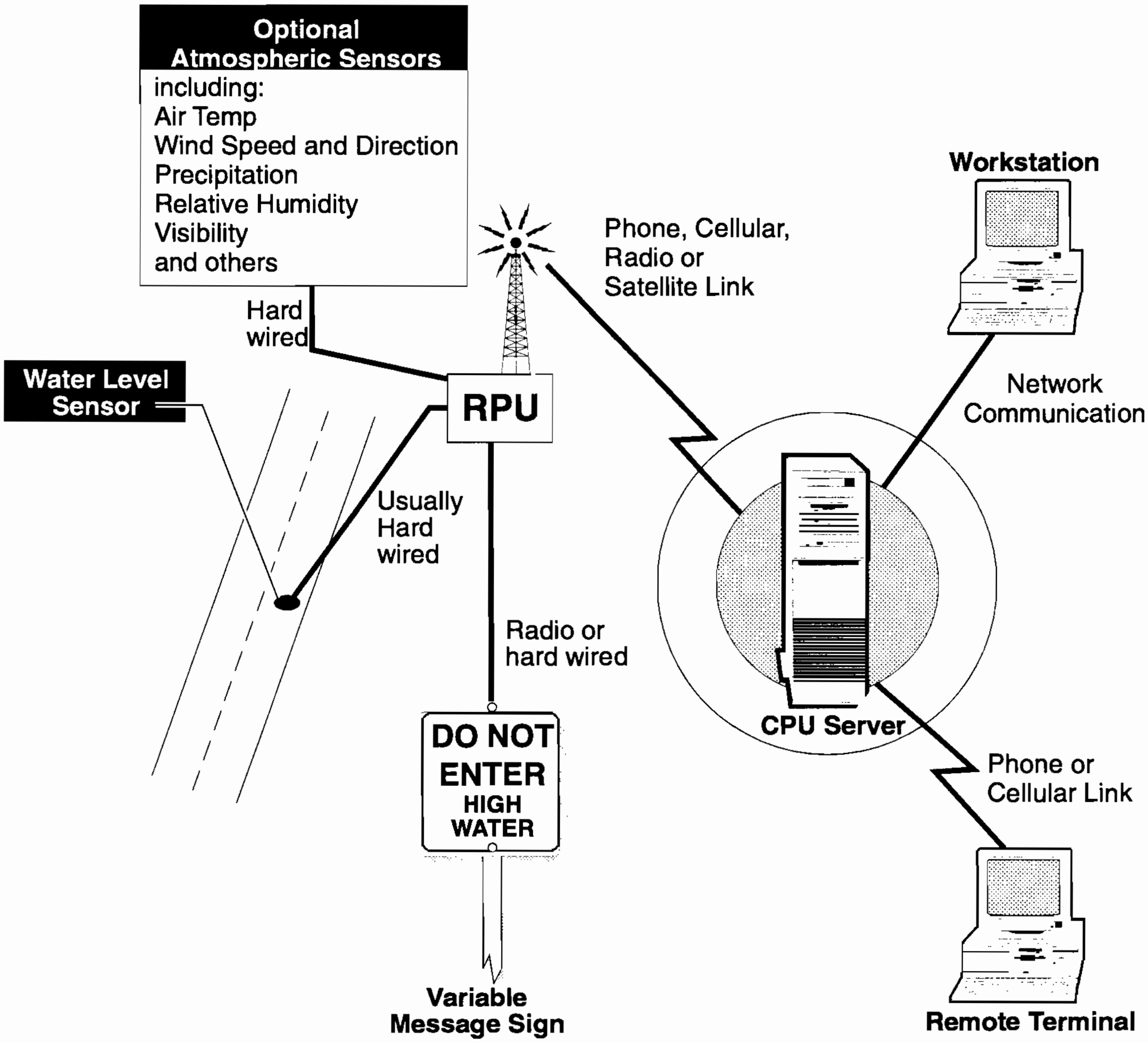

Figure 1.2 Major components of an LWCMS

CHAPTER 2. TURNKEY SYSTEMS

This section documents the vendors nationwide that provide (or indicated they could provide) turnkey road weather information systems (RWIS's). Turnkey means that the vendor supplies all of the equipment and services necessary for operation of the system. The systems are separated into ice-detection systems and high-water detection systems.

2.1 ICE-DETECTION SYSTEMS

Ice-detection systems are sometimes considered synonymous with RWIS's, even though ice-detection systems are just one part of a full RWIS. A full RWIS includes pavement sensors, atmospheric sensors, an RPU, a CPU, weather forecasts, and some type of software to help interpret the data or provide pavement forecasts. Five ice-detection systems are listed below. Three of these systems are full RWIS's.

SSI—SCAN

Surface Systems Incorporated (SSI) has developed SCAN and SCAN for Windows, both of which are full RWIS's. These systems consist of remote sensing equipment, data processing units, telecommunications capabilities, and software. The remote sensing equipment includes pavement sensors, subsurface temperature sensors, and atmospheric sensors. The software enables workstation displays and pavement-specific weather forecasts. SSI also provides training and service of the equipment and software.

SCAN systems are currently installed at over 1,500 sites nationwide, including sites in Minnesota, Iowa, Illinois, Colorado, Michigan, and Wisconsin. SCAN systems are also installed at four bridge sites in Dallas, Texas.

Vaisala—ICECAST

ICECAST is an integrated ice-detection, monitoring, and prediction system. It can be implemented as a full RWIS. It uses Vaisala's MILOS weather stations to provide real-time measurement of the surface temperature and condition at points around the road network. The stations typically consist of one or more pavement sensors, atmospheric sensors, an RPU (MILOS 200), and telecommunications capabilities. The CPU is an IBM PC/386 compatible computer with a color VGA monitor, 40-megabyte hard drive, a printer, and telecommunications cards. The software provides analysis and forecasts of the road surface state. Vaisala also provides thermal mapping as an additional option, which is discussed in Section 3.5.

ICECAST has more than 500 installations worldwide. Current installations include sites in Minnesota, the United Kingdom, the Netherlands, and France. Vaisala has recently installed their system on five bridge sites in Amarillo, and there are plans to install it at new sites in Lubbock. A typical Vaiasala system costs anywhere from $20,000–$30,000 per site, not including software or forecasts.

AANDERAA—RWS 4030

AANDERAA does not supply a complete RWIS. The RWS 4030 consists of a solar cell power module with built-in rechargeable batteries, a sensor arm carrying a suite of atmospheric sensors, road sensors, a data logging unit (RPU), and a VHF radio transmitter. There is no software or CPU associated with this system, although the data from the RWS 4030 could easily be used by another program.

AANDERAA also provides a stand-alone system that consists of a pneumatic ice detector, a solar-powered RPU, signal cable, and message signs. The cost of this stand-alone system is about $2,000, not including installation or the cost of the message signs (provided by a different vendor).

Climatronics—Surface Ice Prediction System

Climatronics offers a four-hour early warning surface ice prediction system that detects and provides advanced warning of slippery road or runway conditions. The system, which can be implemented as a full RWIS or as a stand-alone, includes a number of freezing point sensors embedded in the roadway that are networked with advanced software to communications centers monitored with remote atmospheric sensors. This system warns maintenance crews of icy conditions before the ice actually forms.

Climatronics has a limited number of installations throughout the United States. States using the Climatronics system include Minnesota, Michigan, and California.

Coastal Environmental

Information on the Coastal Environmental Ice Detection System has not yet been received.

2.2 HIGH-WATER DETECTION SYSTEMS

Because most RWIS's do not include water-level sensors, high-water detection systems are treated as a separate entity, even though the concept is similar to that of the traditional RWIS. The high-water detection systems are usually associated with a region's or a city's storm water management department, and they are usually part of a flood warning system. The two systems that we found in Texas are listed below.

RTC—High-Water Detection and Warning Systems

This system is normally installed at low-water crossings where high water may present a hazard. As water rises and reaches a certain point, a submerged optical sensor sends a signal to turn on a flashing yellow light. As water continues to rise, another sensor indicates water above the street. This turns on a flashing red light and actuates a changeable sign stating that the road is closed. The sensor information is transmitted via VHF radio to the warning signs and the control center. The system includes water-level sensors, an RPU, a power source, and a radio transmitter with antenna. The cost of this system installed, with solar power and message signs, is approximately $18,000.

This system is currently installed on Spicewood Springs Road just outside of Austin and is being monitored by the Emergency Operations Center (EOC) in downtown Austin. For more information about the Spicewood Springs installation see Section 4.8.1.

Remote Operating System—Low-Water Crossing System

The Remote Operating System (ROS) basic low-water crossing system provides for a digital level sensor to be installed off the side of the roadway with flashing warning lights and signs installed on both sides of the crossing. The RPU reads data from the sensor and an alarm is set off when the water level reaches a predetermined level (usually 152mm to 305 mm over the road). The lights remain illuminated at least until the water level recedes below the alarm level. The alarm and level information will also be transmitted via radio to a CPU in the EOC Office. The system hardware includes continuous level sensors, a solar powered RPU with radio and antenna, and a stainless steel enclosure for the RPU. The cost of the hardware for this system is approximately $5,000 per installation, not including the cost of the message signs or installation. The message signs are usually provided by a different vendor.

This system has been installed at three low-water crossings in the San Antonio District and are being monitored by the City of San Antonio EOC.

CHAPTER 3. SYSTEM COMPONENTS

3.1 SENSOR TECHNOLOGIES

For road weather information systems (RWIS's), there are three different groupings of remote sensors: pavement (or ice-detection) sensors, water-level sensors, and atmospheric sensors. This chapter discusses each of these system components.

3.1.1 Ice-Detection Sensors

The following four vendors manufacture pavement or ice-detection sensors. All of these sensors, with the exception of FRENSOR, are thermally passive in that they do not alter the temperature or environment they are measuring. Also, all of these sensors are embedded in the roadway.

SSI—FP 2000 Freeze Point Sensor: The SSI pavement sensor uses a thermistor to measure temperature and incorporates a capacitor that measures the dielectric effect of moisture in both liquid and solid forms. The sensor, embedded flush with the pavement surface, provides an output signal that indicates the pavement conditions in its vicinity. The sensor also measures the freezing point of the solution, the percent of ice, and the percent of chemical solution present on the pavement. The SCAN system is well tested and is in widespread use throughout the United States. SSI does not sell its sensors separately.

Vaisala—DRS 12 Road Surface Sensor: Vaisala features the DRS 12 and DRS 12B Road Surface Sensors. The DRS 12B version is designed for bridges having a thin surface layer. The road surface condition is determined by assessing the relative amount of the electrical conductivity and ionic polarizability of the road surface coverage. This sensor, which is embedded into the pavement, has been designed to mirror the road's thermal behavior. It calculates the freezing point of the solution on the road and distinguishes between the following surface states: wet and salty, moist, dew, ice, frost, snow, wet, dry, and black ice. Figure 3.1 is a schematic of the DRS 12 sensor and its various components. The Vaisala system is in widespread use throughout Europe. While Vaisala does not sell its pavement sensors separately, the itemized cost of each sensor is $1,300.

AANDERAA—Road Sensor 3565 and Pneumatic Ice Detector 3428: AANDERAA supplies both a pavement sensor and a pneumatic ice detector. The road sensor is a single combined sensor that measures four parameters: road surface temperature, based on a Pt-element as the sensing element; wet or dry road, determined by sensing whether the road has a conducting moisture film; salinity of the surface moisture (indicating the freezing point); and the presence of snow, determined by detecting infrared light reflected from the snow.

The Pneumatic Ice Detector detects ice by the principle that a porous membrane is permeable to air when dry or wet and impermeable when covered with ice. The sensor outputs all 1's when there is ice present, and all 0's when there is no ice. The Pneumatic Ice

Detector is a relatively new product and is currently under testing at Virginia Polytechnic Institute. The cost of this device is $1,370.

Climatronics—FRENSOR: FRENSOR is an active device that, when buried in the pavement, directly measures the freezing point of the surface using a Peltier cell. The Peltier cell cools and warms the liquid or moisture on its surface in 5-minute cycles under the control of a microprocessor. At the same time, the temperature of the cell is measured. The instant freezing occurs, it is detected and the temperature is reported via digital or analog outputs. Besides freezing point, the sensor also measures pavement temperature near the surface and below the surface. By comparing FRENSOR readings with dewpoint temperature, it is possible to distinguish between dry, wet, frost, and ice conditions. The roadside microprocessor that accompanies FRENSOR can support up to four sensors. The cost of the microprocessor and four sensors is about $7,500.

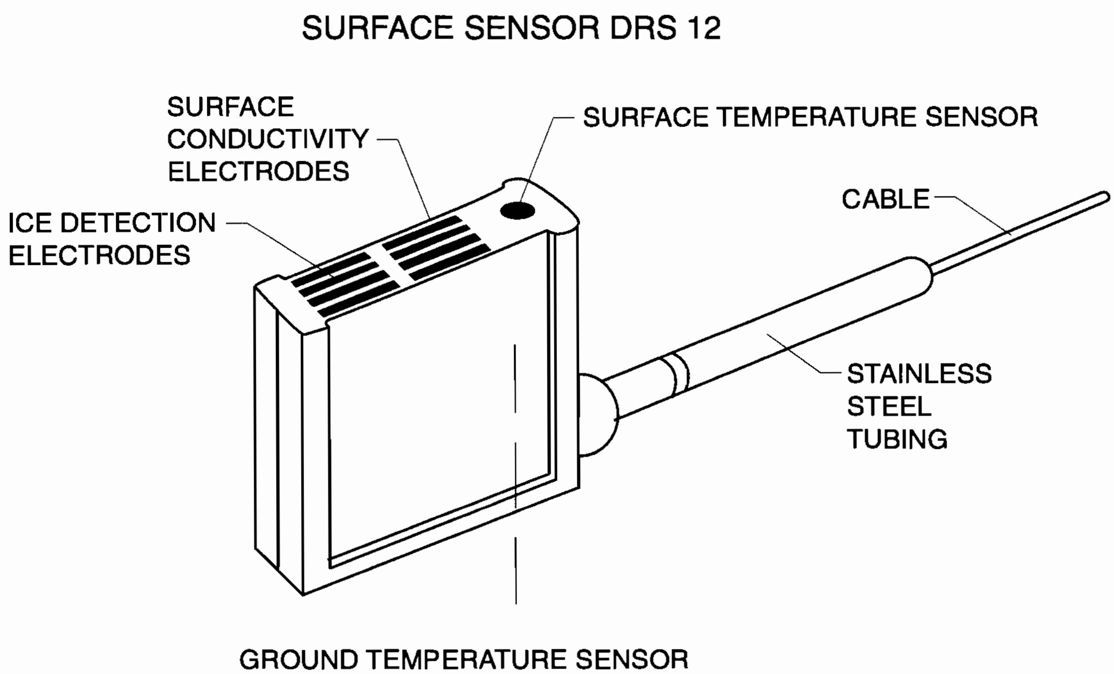

Figure 3.1 DRS 12 Road Surface Sensor

3.1.2 Water-Level Sensors

Remote Operating Systems (ROS) (Model 200 Digital Level Sensor): ROS manufactures a patented, digital multilevel sensor for stream level measurement. It consists of a 47.6 mm sealed center tube surrounded by two circular floats. The sensors are housed in 127-mm-to-152-mm galvanized pipes to protect the float from debris. The sensor never requires calibration and is accurate to 6.35 mm. It outputs a digital signal and communicates with RS485 standard protocol to RPUs. The ROS digital level sensor has been proven in over 4 years of stream flow measurement for the Upper Guadalupe River Authority. Unless there is a major flood, the ROS sensors require maintenance only once a year. This sensor is based on a simple principle, and it seems to be fairly accurate and inexpensive. An enclosed 5-foot sensor costs about $1,000.

RTC (High-Water Sensors): The RTC sensor assembly is installed in a rise tube and consists of two solid-state infrared devices that use light refraction to sense the presence of water. When water reaches the first-level sensor, a caution signal is activated; when water reaches the second-level sensor, an alarm signal is activated. The sensor assembly is connected to the RPU via a two-pair cable. The sensors communicate according to SDI-12 standard protocol. The one drawback of this sensor is that it does not provide a continuous measurement of the water level; consequently, there is no way of telling the rate at which the water is rising.

Other Water-Level Sensors: There are several other water-level sensors that are readily available and could be implemented as part of a statewide RWIS. These include float switch systems, pressure transducers, and ultrasonic sensors.

The float switch systems work much like the float in a toilet. As the water level rises, the float also rises and trips a switch. These systems are simple and fairly inexpensive (about $800), but they are basically on-off switches. While it is possible to install a couple of these at one site to set off different warnings, there is no mechanism that specifically measures the rate at which the water is rising.

Pressure transducers use the hydrostatic pressure of the water to measure its height. This feature allows the user to measure the water height and, thus, the rate at which the water is rising. However, these sensors have reported accuracy problems and should be used with this caveat in mind. Also, the transducers can cost up to $3,000 each.

Finally, ultrasonic sensors have been used to measure water level at low-water crossings. An ultrasonic sensor produces an analog sign based on the height of the water. These sensors measure water-level height and rise rate, but are inaccurate insofar as they are highly temperature dependent. Costing about $2,500 each, they are also more expensive than other options.

3.1.3 Atmospheric Sensors

Most of the vendors that supply turnkey RWIS's also supply a suite of atmospheric sensors to complement the system. These sensors can detect visibility, wind speed and direction, relative humidity, air temperature, and precipitation. The atmospheric sensors send output to the RPU, where the data are processed and transmitted to the CPU. This is usually, but not always, the same RPU that is used to process data from the pavement sensors. The measurements obtained from the atmospheric sensors that are most important for predicting pavement conditions are relative humidity, air temperature, and presence of precipitation. A typical suite of atmospheric sensors costs approximately $3,000. Figure 3.2 shows how a suite of atmospheric sensors are integrated with road sensors and an RPU to make up a typical roadside weather station.

3.2 REMOTE PROCESSING UNITS (RPUs)

The remote processing units (RPUs) receive data from the sensors and transmit these data to the CPU. While these units are usually solar powered, they can also be powered from a main line. Each company has its own version of an RPU, but they all perform basically the same tasks. The RPU acquires the data from the sensors, usually by way of a hardwire link, then transmits the data to the CPU via regular phone lines, cellular phone, radio, microwave, or satellite. It also controls any remote flashing lights or variable message signs at the site. The price of an RPU can vary from $5,000 to $10,000, depending on power source, data handling capability, communications requirements, and enclosure.

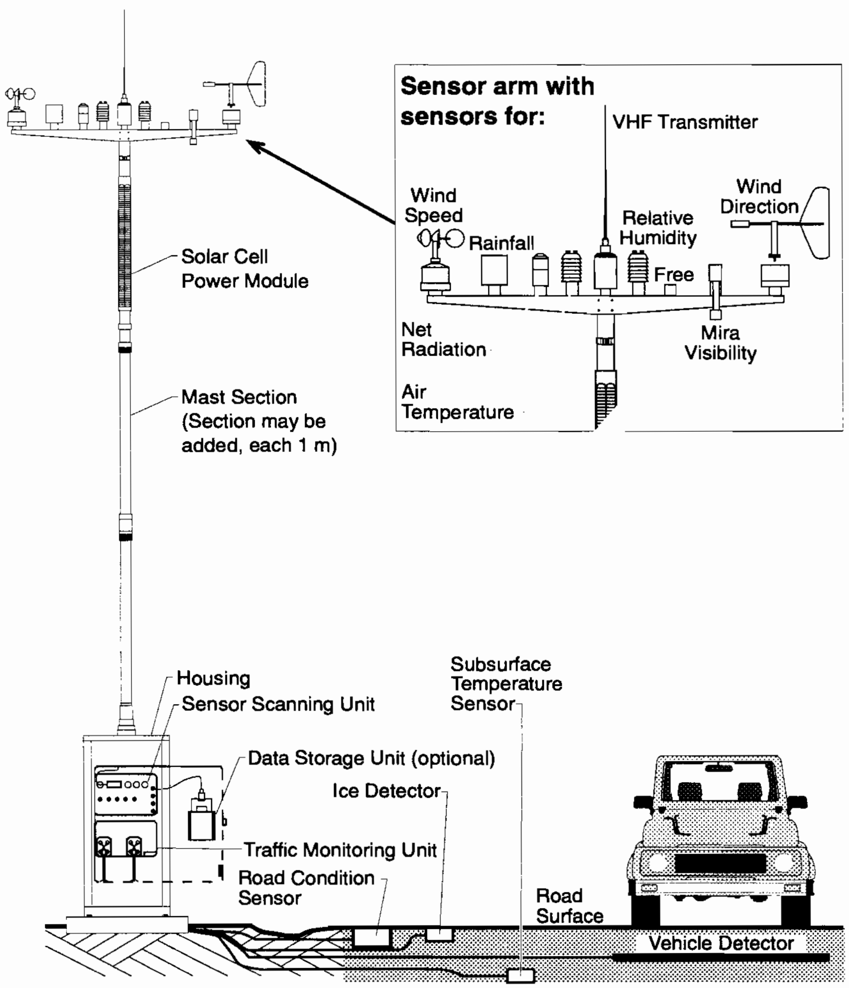

Figure 3.2 Typical Roadside Weather Station

3.3 CENTRAL PROCESSING UNITS (CPUs)

Central processing units (CPUs) receive data from the RPU and process the information. The process includes storing the data for historical purposes, possibly for future prediction purposes. Also, the CPU can display the data graphically, numerically, or by lighting up LEDs on a map. Finally, the CPU disseminates the data to other CPUs, either by request or automatically, to enable others to have access to the data. The user evaluates the data from the CPU and takes the proper actions during inclement weather. As with the RPU, the CPUs are vendor specific.

3.4 COMMUNICATION SYSTEMS

Each part of an RWIS must communicate with at least one other component. This communication flow includes sensor to RPU, RPU to CPU, CPU to CPU, CPU to end users, and finally RPU and CPU to the traveling public.

3.4.1 Sensors to Remote Processing Units

In all of the systems surveyed, the sensors were hardwired to the RPU. The cable is either buried in the ground or run through conduit along bridge supports to the RPU. The sensors transmit either an analog or a digital signal over these wires, where it is interpreted by the RPU for possible transmission to the CPU or to warnings signs.

3.4.2 Remote Processing Units to Central Processing Units

There are several methods of communicating from the RPU to the CPU. Phone, radio, microwave, and satellite are the main forms of communication. Phone and radio are the two major methods at this point, but if one already has the microwave equipment, this could be an excellent option. Satellite technology in the past has been too costly to use. However, it is getting cheaper and is now developing into a viable alternative.

Telephones/Modems: One mode of communication between RPUs and CPUs is a phone line. The RPU sends data via modem to the CPU either automatically when an event occurs or when requested by the CPU. This is performed by using a standard RS-232-C modem connection. If the cost of installing or maintaining a phone line is too high owing to the site not being near enough to a phone line, or if the long-distance charges are too high, cellular phones could be an alternative. Vaisala has installed five sites in Amarillo, all of which use regular phone lines. SSI has four sites in Dallas; two use regular phone lines while the other two use cellular phones.

There are a couple of problems with phone communication. First, there is the cost. Phone lines have a monthly cost associated with them, along with possible long-distance charges or air-time charges if using cellular phones. Also, there is a problem with phones becoming inoperable during a storm, with the consequent disruption of data transmission at a time when it is most needed.

UHF/VHF Line-of-Sight Radio: Another widely used method of communicating between RPU and CPU is by way of UHF/VHF line-of-sight radio transmission. This method requires a radio transmitter in the RPU, a receiver in the CPU, and an FCC license to transmit signals on a certain frequency. It also requires line-of-sight communication. If the devices do not have line of sight, one would have to use a repeater tower or daisy-chaining that involves using a series of repeaters in order to transmit the signal from the RPU to the CPU. The City of Austin and the Kerrville District both use radio communication for their high-water detection systems.

Data radio systems are readily available from companies such as Motorola/RNETS, Johnson, Microwave Data Systems, and Vitel, Inc., among others. The costs of these radio systems range from $500 to $1,000. Radio systems have an advantage over phone systems in that they require only the up-front cost of the transmitter and receiver, with no monthly cost. However, if line of sight cannot be obtained, radios are not a feasible option.

Microwave: Microwave technology is a reliable way of transmitting the data from RPU to CPU, especially over long distances. For this to be feasible, the microwave towers would already have to be in place and available for use by the RWIS. For example, Valero, a natural gas supplier and distributor, has an existing microwave communications network deployed throughout most of Texas. A microwave line could be leased from Valero for a small monthly fee (that would also include maintenance).

The most common method of using microwave for communication includes transmitting by line-of-sight radio to the tower, and then converting the signal to microwaves for subsequent transmission to the CPU. It would be necessary to install a radio receiver/microwave converter on the microwave tower; a microwave receiver would decode the information and send it to the CPU. As mentioned above, this is viable only if the microwave towers are already available, because microwave technologies are considerably more expensive than radio. Microwave Data Systems is a popular vendor of microwave technologies.

Satellite: An emerging communication option is the use of satellites. Once too costly, the price for sending data via satellite is dropping to a level that would be economical for many applications. These systems include a satellite transmitter and a telemetry antenna at the RPU for sending data, and a satellite receiving unit and antenna at the CPU for receiving the data.

ORBCOMM currently has a system that uses its satellites, charging by the length of the data stream transmitted and how often it is to be transmitted. For small data groups that are not transmitted often, this might be practical. Vitel, Inc., has a system that interfaces with the Geostationary Orbiting Environmental Satellite (GOES). For most government organizations, the use of this satellite is free. Thus, one would need to purchase only the telemetry equipment for satellite communications. The Vitel telemetry unit sells for about $2,500.

An advantage to using satellite communication is that it is reliable, since line of sight is not an issue. A disadvantage to using satellites is that there is usually a time lag of 4 to 10 minutes for the signal to transmit from the RPU to the CPU.

3.4.3 Central Processing Unit to Central Processing Unit

Direct Network Transfer: This mode of CPU-to-CPU communication is for CPUs on a local area/wide area network (LAN/WAN) system using TCP/IP. It allows for the transfer of data using file transfer protocol (e.g., ftp, Fetch, etc.); a user can also log on remotely to access the data (e.g., via telnet). TCP/IP is a standard that ensures that machines on the network are addressed properly and that information is routed correctly for the proper flow of data throughout the network. The network could be as small as a couple of machines, or as large as the global Internet. It includes SLIP lines, which are modem connections that appear as physical machines on the network. This is the preferred method for transfer of data in that it tends to be faster than serial connections. Many vendors are working on setting up their systems to use TCP/IP protocols with the Internet, especially the World Wide Web (WWW). In such an arrangement, the data would be viewable by anyone on the WWW. In other words, the general public, as well as the maintenance managers, would be able to see the up-to-date road conditions at any time.

Telephone/Modems: This form of communication is the standard RS-232-C modem communication that has been in use for years. In this method, users on a remote CPU will dial up another CPU. They would then log in and start a session that would involve the uploading and downloading of data to and from the CPU; users could also look at the alphanumerical data remotely without downloading it. When finished, users log off and break the connection. On the remote CPU, there would be some software that could be used to view the data that have been most recently downloaded. This is a well-known and reliable form of data transfer that is currently available with all of the RWIS's. Its widespread acceptance is evidenced by the soon-to-be-adopted American Association of State Highway and Traffic Officials (AASHTO) standards for RWIS CPU-to-CPU communication discussed in Section 3.7.

3.4.4 Remote Processing Unit to the Traveling Public

An RPU alerts the traveling public to possible dangerous road conditions by activating flashing lights, variable message signs, or a combination of both. Generally, when an RPU receives a signal from the sensor that is interpreted as an alarm, it sends a signal to the warning sign either by radio or by a hardwired link. The signal turns on the sign's lights, changes the sign's message, or both. When the RPU receives a message from the sensor that the hazard is over, it sends a signal to the sign to return to its default state. Other methods of alerting the public about hazardous road conditions include television broadcasts, radio advisories, and kiosks located at public rest stops.

3.5 ROAD WEATHER INFORMATION SYSTEM SOFTWARE AND USER INTERFACES

SSI—SCAN for Windows: The SCAN for Windows User Interface is a Windows 95-compatible application. Its workstation contains a map-based graphical user interface for RWIS data display. Current and historical data from pavement and atmospheric sensors, video stills, and the latest SCAN*CAST Pavement Forecast are displayed by SCAN for Windows. For radar and other data, Weather for Windows can be run simultaneously with SCAN for Windows.

Vaisala—ICECAST: The ICECAST road condition monitoring system is designed to collect road and weather information from RPUs, process the collected data in the form needed, and distribute and display the data to users. ICECAST displays both the measured and analyzed data in graphical, tabular, or map format. The software also provides alerts of hazardous conditions according to user-selected criteria. The cost for the first copy of the ICECAST software is about $4,500, with additional software licenses considerably cheaper. Examples of output from ICECAST can be found in Appendix C.

For an additional fee, ICECAST can provide 24-hour pavement forecasts that include a prediction of the pavement temperature and condition. The cost of receiving two pavement forecasts per day at one site is about $600 per month.

Vaisala also provides a thermal mapping feature that shows a climate map of the road network, showing clearly the location of the areas most susceptible to freezing. Thermal mapping can also be used to find the optimal locations for sensor sites. Based on the thermal maps, the ICECAST calculates the surface temperatures between sensor sites.

ROS—Wonderware: The City of San Antonio and TxDOT's Kerrville office currently run Wonderware for use with their high-water detection systems. This software package allows decision makers to view sensor data graphically or textually in order to make timely decisions. This package also allows the user to remotely monitor the status of the system and to make changes to alarm criteria if desired. This software is very user friendly but its ability to handle large amounts of data has yet to be determined. There have also been some complaints of minor bugs in the software. A copy of Wonderware costs about $4,000 for a stand-alone system, or $5,500 for the network version. Appendix C contains examples of output from Wonderware.

Novalynx—Novastar: This is the application software that performs the data acquisition, filing, analysis, forecasting, and warning tasks for the Flood Early Warning System in the City of Austin. This menu-driven program is an upgraded version of the ALERT software that was written by the National Weather Service in the 1970s. The program was written in the C programming language and was compiled for the QNX operating system. QNX is a real-time, multi-user, multi-tasking operating system that runs on Intel platforms. The advantage of multi-tasking is that it enables the system to handle data from a number of sources while performing a large number of tasks at once. This reliability is extremely important when emergency situations like flash floods are involved. The Novastar software costs about $4,400 per copy.

Other user interfaces: Other types of user interface include a physical map mounted on a wall in the Emergency Operations Center (EOC) in Austin. On this map, each site being monitored is represented by an LED that illuminates when alarm criteria have been reached for that site. Many of the warning systems also include some sort of voice message system that automatically dials or pages decision makers to inform them of an emergency situation.

3.6 WEATHER SERVICES

There are a variety of vendors that provide weather forecasts and data services. Most public forecasts are issued by the National Weather Service (NWS) and retransmitted by broadcast media. According to many of maintenance engineers interviewed, public forecasts are often too conservative and rarely provide sufficient details that can be related to specific sites. Such detailed forecasts usually require the services of Value-Added Meteorological Services (VAMS's).

VAMS's use NWS data and forecasts, specialized observations, and meteorological models to provide state agencies with specific weather packages tailored to meet an agency's needs. These packages can also include live radar observations (such as NEXRAD) from the NWS. The cost of these services has dropped dramatically in the last few years — to only a few hundred dollars a month; hence, the majority of state agencies subscribe to some sort of meteorological service.

Ideally, a statewide network would be established so that this type of information would be shared by all of the state agencies that rely on weather information and forecasts. This could significantly reduce the cost of the service. Typical vendors of these services include Weather Services, Inc. (WSI), Weather Data, Inc. (WDI), Marta, Alden, and many others. SSI provides weather packages to complement their SCAN system.

Another vendor, Data Transmission Network Corporation (DTN), supplies unlimited access to comprehensive, time sensitive, weather information via satellite. DTN provides all of the necessary equipment, including a satellite receiver, a compact satellite dish, a high-resolution VGA color monitor, and data storage capability. The satellite technology of the DTN weather center allows the user instant access to in-motion radar maps, current temperature, humidity and sky conditions, severe weather maps and forecasts, regionalized wind speed maps updated hourly, in-motion satellite cloud photos, and over 250 major city forecasts. All of this information is provided for a set monthly fee of $64, with a start-up charge of $318. There are no "on-line" fees or phone access charges associated with this system. DTN currently serves over 94,000 subscribers throughout the United States.

3.7 STANDARD COMMUNICATION PROTOCOLS AND DATA FORMATS

For RWIS's to be fully realized, a standard communication protocol needs to be developed. This protocol would operate on the RPU-to-CPU and CPU-to-CPU level.

Currently, there is not a standard communication protocol available for RPU-to-CPU communication. Thus, each vendor sets up its own protocols for transmitting data from the sensor to the RPU and then on to the CPU. Consequently, if a customer wishes to use one vendor's sensors, the customer must either purchase the RPU, CPU, and software from the same vendor, or write translation software so that the components of one vendor can interface with the components of another vendor.

With a standard communications protocol, sensors and RPUs from different vendors could be linked to a single CPU. However, without a standard, two different vendors' sensors at the same location would currently require two different RPUs speaking with two different CPUs. Even though there is currently not a standard specifically for RWIS RPU-to-CPU protocol, there has been a standard under development for transportation control equipment, such as traffic signal controllers, variable message signs, cameras, etc. This protocol, called the National Transportation Control/ITS Communications Protocol (NTCIP), has been developed by the National Electrical Manufacturers Association (NEMA) to allow for the implementation of a national Intelligent Transportation Systems (ITS) program.

3.7.1 National Transportation Council/ITS Communication Protocol (NTCIP)

NTCIP provides an industrywide standard for dealing with communication among different types of traffic control devices. NTCIP is a complete communications protocol for integrating all of the various components that may be in an ITS. It contains the requirements for allowing controllers and other units in traffic control systems obtained from different vendors to be interchangeable. In addition, it covers the complete end-to-end data handling so that controller units can perform communication tasks between traffic management centers and other equipment.

NTCIP is designed to provide to the public real-time updates of traffic conditions (perhaps using variable message signs). It is also set up to transmit this information back to the ITS control center. These functions are similar to what an RWIS is meant to do. As of yet, NTCIP has not considered an RWIS, but if RWIS's are going to be involved in ITS development, then RWIS data will need to be incorporated into the NTCIP definition. Of course, this process cannot be enacted without more cooperation among the various vendors.

3.7.2 The American Association of State Highway and Transportation Officials Data Exchange Protocol

On a higher level there is a standard communication protocol being developed for CPU-to-CPU communication that would allow for data exchange between two different vendors' CPUs. The AASHTO RWIS Data Exchange Protocol (DEP) permits the sharing of data between vendors' computers. This DEP allows regions to view data from other regions regardless of the vendor of each region's RWIS. Each region could then be free to choose its own vendor for RWIS without risking incompatibility with the rest of the state.

The AASHTO DEP being considered is an open systems protocol that specifies the connections, log ins, data requests, and data deliveries among RWIS CPUs obtained from any vendor. A brief summary of the data exchange process and file formats for RWIS is presented in Section 3.7.3. For more information, please consult the full AASHTO DEP document (Ref 1).

3.7.3 American Association of State Highway and Transportation Officials Data Exchange Process and File Formats

To explain the AASHTO data exchange process for an RWIS, it is necessary to define certain terms. The *initiator* is the RWIS CPU that calls (or initiates the communication with) another CPU, called the *responder*. The responder answers the initiator's call. Both CPUs can transmit and receive data during the communication process. The RPU is the unit that is responsible for collecting sensor data and transmitting them to the CPU. Current data are defined to be the latest data from an RPU, while history data are older RPU data that have been stored by the CPU.

The data exchange process is a session that contains the following eight steps:

1. **Connecting:** The initiator starts the process by having its modem connect to the responder. The responder, which is waiting for a call from any initiator, answers the call.
2. **Logging In:** The initiator's "username" and "password" are sent after the responder prompts for them. If they are not valid, the responder terminates the connection.
3. **Requesting Data:** The initiator sends a file containing data requests only.
4. **Receiving Data:** The responder sends the requested data in a series of files.
5. **Receiving Requests:** The responder sends a file of data requests only.
6. **Sending Data:** The initiator sends the requested data in a series of files.
7. **Logging Out:** The responder terminates all programs that it is running for the initiator.
8. **Disconnecting:** Both the initiator and the responder hang up their modems.

These steps can be seen in more detail in Table 3.1. The order goes from 1.A to 1.B to 2.A and so on through 8. Some of these steps occur simultaneously.

File DE30, which is sent to the responder, contains all of the initiator's data requests. File DE50 is the same sort of file but has the responder's data requests to be obtained from the initiator. The format for these files is one request per line. If either CPU has no data requests then it will send its file with one empty line. There are two types of requests that can be made: one for current data and one for historical data. The form for current data requests is:

RpuCurrent(dom=*Domain*, sysid=*Sysid*, rpuid=*Rpuid*)

where ***Domain*** is the RWIS domain, such as SSI, ***Sysid*** is an integer that represents the RWIS ID number, and ***Rpuid*** is an integer that represents the specific RPU in the system. The Rpuid starts at zero for the first RPU in a system and goes up sequentially for all of the other RPUs. So, to get a specific RPU, one must specify the Domain, Sysid, and Rpuid. If the Rpuid is left out of the data request, data for all of the RPUs belonging to the given system will be sent.

Table 3.1 DEP Session Sequence (from AASHTO DEP Paper)

Step	Initiator's Action	Step	Responder's Action
1.A	Initiate and wait for connection to Responder	1.B	Receive (respond to) connection from Initiator
2.B	Login	2.A	Prompt for and accept (or reject) login information
3.A	Send data request, filename DE30	3.B	Receive data request, filename DE30
4.B	Receive the requested data, filenames DE40NNN, DE41NNN	4.A	Send data requested by Initiator, filenames DE40NNN, DE41NNN
5.B	Receive data requests, filename DE50	5.A	Send data requests, filename DE50
6.A	Send data requested by Responder, filenames DE60NNN, DE61NNN, DE6Z	6.B	Receive the requested data, filenames DE60NNN, DE61NNN, DE6Z
7	No action	7	End the session
8	Disconnect	8	Disconnect

Here are some examples of current data requests:

RpuCurrent(dom=P, sysid=57, 5)

This would request the current data from RPU 5 in RWIS system 57 in domain P.

RpuCurrent(dom=F, sysid=233)

This would request the current data from all of the RPUs in system 233 in domain F.

There are two forms for requesting history data. One uses the ***StartDate***, which is the date and time of the earliest requested record, and ***EndDate***, which is the data and time of the last record requested. The second form uses ***N***, which is the number of historical records requested counting back from the most recent one available. If the date method is used, the dates are specified in YYYY/MM/DD HH:MM with the time in GMT. The time is assumed to be 00:00 if it is omitted.

The two forms for requesting history appear as follows:

RpuHistory(dom=*Domain*, sysid=*Sysid*, rpuid=*Rpuid*, start_date=*StartDate*, end_date=*EndDate*) and
RpuHistory(dom=*Domain*, sysid=*Sysid*, rpuid=*Rpuid*, n=*N*)

Here are some examples of historical data requests:

RpuHistory(dom=R, sysid=20, rpuid=2, start_date=1994/4/12 09:00, end_date=1994/5/1 23:00)

This requests the historical data from RPU 3 in RWIS system 20 in domain R from 9:00 a.m. April 12, 1994 to 11:00 p.m. May 1, 1994.

RpuHistory(dom=F, sysid=12, rpuid=4, n=100)

This is a request for the last 100 records from RPU 4 of system 12 in domain F.

Once the data requests are made, the other CPU starts transmitting files that contain the requested records. Each separate successful data request causes a separate file to be sent. The files contain only symbols that are represented in both ASCII and EBCDIC character sets. Fields in a line are separated by commas. Each line in the file represents one record of the requested data, except for the first line, which is a description of the data presented below it. The first line contains the field names that apply to all of the data below. The names of the files with the current RPU data are DE40NNN or DE60NNN, with the DE40NNN being data sent from the responder to the initiator and DE60NNN being the opposite. The NNN is replaced with a number starting at 001 for the first file and increasing sequentially for the rest of the files. The historical data files are named DE41NNN and DE61NNN, with DE41NNN representing data from responder to initiator, DE61NNN representing data from initiator to responder, and the NNN representing information similar to that represented by the current data files above. The first few lines of a data file could be:

```
Dom, SyId, RpId, RpDtTm, ApAirT, ApDewT, SfTemp0, SfSubT0, SfTemp1, SfSubT1
S, 180, 2, 1994/05/03 13:45, 2.3, -1, 4.7, 7.2, 4.3, 6.5
S, 180, 2, 1994/05/03 13:50, 2, -0.8, 4.2, 7.1, 4.0, 6.3
S, 180, 2, 1994/05/03 13:55, 1.5, -0.8, 3.5, 7.0, 3.5, 6.1
```

The first line of the file indicates what the rest of the lines represent. The data consists, in order of the Domain Identifier (Dom), the system ID (SyId), the RPU ID (RpId), the date and time (RpDtTm), the air temperature (ApAirT), the dewpoint (ApDewT), and the surface and subsurface temperature data for two sensors labeled 0 and 1 (SfTemp0, SfSubT0, SfTemp1, SfSubT1). The terms in line one are specified in the standard in order to keep the types of data being transmitted standardized as well. Each of these separate pieces of data that are allowed to be transmitted also has its own set format, such as the time and date being in YYYY/MM/DD HH:MM. Items such as type and intensity of precipitation have also been incorporated into the standard.

The Domain Identifier is vendor specific (such as S for Scan Systems Inc.); in order to get an identifier, each vendor must show that its systems are capable of following the protocol as it is set up by AASHTO. This ensures that each vendor that has an identifier can actually use the protocol and be incorporated with other vendors' systems that the customer may already have.

The DEP has set the method of communication to be by asynchronous serial communication using 8 bits, no parity, and 1 stop bit with a speed of at least 1200 baud. The file transfer is prescribed to be Zmodem. As can be seen, the AASHTO DEP standard will cover everything from the file formats and filenames to the actual order of the session and transmission protocol (the above technical information is from the AASHTO RWIS DEP document).

CHAPTER 4. STATE AGENCIES' EXPERIENCES WITH ROAD WEATHER INFORMATION SYSTEMS (RWIS)

This chapter summarizes some of the RWIS-related activities that are ongoing in Texas and in other states. The chapter is divided into sections that correspond to each state contacted. Each section includes a description of the current system in place, plans for expanding the system, how the state uses the system, and its experiences with the system. The information was received through phone interviews with key department of transportation (DOT) personnel. Points of contact for each state DOT are located in Appendix B.

4.1 MINNESOTA DEPARTMENT OF TRANSPORTATION

The Minnesota Department of Transportation (MnDOT) currently has seventeen remote weather stations in the Twin Cities and Duluth area. Four different RWIS vendors are represented among these sites, including SSI, Vaisala, Climatronics, and Coastal Environmental. The SSI stations do not include a weather forecast contract, though the Vaisala stations include a contract with a local company to provide weather and pavement forecasts. Mark Wikelius, the MnDOT representative contacted, mentioned having problems with service and with the Vaisala hardware. MnDOT has published a report (Ref 10) summarizing its implementation plan and its evaluation of different RWIS's.

MnDOT plans to expand its system to sixty to seventy remote stations and integrate the new installations into a centralized system. It is currently working on the requests for proposals (RFPs), which will probably include a specification for the system that will ensure uniform equipment and allow hardware from different vendors to communicate. MnDOT is also looking into the National Transportation Control/ITS Communications Protocol (NTCIP) specifications to ensure uniformity. Finally, Mr. Wikelius stated that knowing the amount of chemicals present in the de-icing mix and having reliable forecasts is very important information for maintenance crews, as it allows for better use of resources.

4.2 IOWA DEPARTMENT OF TRANSPORTATION

The Iowa DOT has twenty-two RWIS sites that it has purchased from SSI since 1988 (it is trying to expand to forty-two total sites). The DOT started out by acquiring three sites per year until it obtained eleven new sites with the FP2000 sensors last year, and then had the old sites retrofitted with the FP2000 at the same time. All of its systems are the full-remote weather stations. The Iowa DOT is generally pleased with SSI, although officials there reported having problems with the new sensors earlier this year. They had concerns about the reliability of the new sensors, insofar as the optical weather identifier could not detect light rain or snow. This caused them to cancel this year's order until SSI addressed the problem. According to the Iowa DOT, SSI corrected the problem and extended its warranty coverage time to make up for the inconvenience.

In Iowa, RWIS information is not frequently used for planning construction operations. It is primarily used for maintenance in de-icing and anti-icing procedures. Anti-icing is a practice whereby chemicals are placed before icing begins. Right now, construction personnel are for the most part treating the system as a curiosity and are mainly looking at the freeze/thaw cycle information. The weather data are also used for spraying herbicides and painting stripes on the road.

Their sensors use a SCANCOM processor to process the information at each location via the remote processing units (RPUs) before it is sent to a central processing unit (CPU) in Ames, Iowa. All of their sites are powered by regular AC power (with no power backup). The data are sent from each RPU to the CPU in Ames every 15 minutes via telephone communication (every hour in remote locations) — unless it is in an alert stage, in which case the data will be sent every minute. This alert stage can be triggered automatically when the temperature drops below a certain point or if moisture is detected. This information is then disseminated to the 115 garages around Iowa every hour by means of satellite communication.

The two different vendors Iowa officials cited for satellite weather information provision included Data Transmission Network (DTN) and Broadcast Partners. According to these state officials, DTN services were cheaper than using phone lines. DTN provides basic weather information, such as Doppler radar and satellite updates, and allows the RWIS data to be included (piggy-backed) with it every hour. There is also dial-up modem service for remote access by maintenance managers. Apparently, DTN downloads the RWIS data from the central site in Ames and transmits the data to all the garages. This DTN system costs Iowa $96,000 to lease equipment for all 115 garages for a year (less than $70/site each month). Iowa DOT provided the installation of the dishes, but all other setup and installation was provided by DTN. Also, DTN is responsible for all maintenance and repair of the sites. Because the equipment is leased, it can be returned to DTN if it becomes outdated or if officials decide that it is no longer needed. According to Dennis Burkeheimer, maintenance engineer for the Iowa DOT, the greatest thing about the system is that it is very easy to use; now that it has been installed, he says, it will be very difficult to get the maintenance people to return it to DTN.

The Iowa DOT representative also mentioned a multistate RWIS conference to be held in Council Bluffs, Iowa, in early August. The conference will provide an opportunity for several of the DOTs to get together and discuss not only the strengths and weaknesses of each RWIS, but also what they would like to see in future RWIS units.

4.3 ILLINOIS DEPARTMENT OF TRANSPORTATION

Three years ago, the Illinois Department of Transportation (IllDOT) started installing SCAN systems throughout the state. The northern two districts (it has a total of nine districts) were outfitted first with the old E sensor, with the department then working its way south. The northern two-thirds of the state started out getting the E sensors, but recently each of these sites has been retrofitted with at least one FP2000 sensor. The rest of the state has only FP2000 sensors at each site. Currently, there are thirty-one sites up and running. Six more sites have been inspected for possible installations in the near future. The department wants to achieve a total of fifty-one sites.

IllDOT officials have had no problems with either sensor. They recorded between 800 and 900 driver observations of the old E sensor and found that the sensor reading was accurate with the driver survey over 80 percent of the time. They found that the FP2000 was able to detect exactly what was happening at the site even during light snow. Thus, they have developed a confidence in the accuracy of their sensors.

Currently IllDOT has nine CPUs, one in each district. The CPU in District 6 collects all of the data from the other districts by calling the other CPUs every hour on the hour. This costs the department approximately $1,800 per month in phone charges. It is currently looking at a way to get the RWIS data transferred on its dedicated Maintenance Management Information System (MMI) line. Currently, the MMI line goes to some 250 terminals at offices throughout the state. It is used for evaluating material usage, vehicles, and employee time sheets. As of March, officials can get the RWIS data from the CPU onto the MMI, but they cannot get the RWIS data from the MMI to the CPU as of yet. The RPU-to-CPU communication is achieved mainly by standard phone lines, though IllDOT has two test sites using radio communication with Motorola and SSI.

In addition, the department currently has thirteen DTN terminals that provide it with radar, satellite data, and forecasts for twenty cities in Illinois. These terminals also have the SCANCAST pavement forecasts along with the statewide RWIS data. IllDOT prefers satellite communication because it provides the department with radar and satellite information that is (at most) 15 minutes old. From DTN, they also get the Iowa RWIS information. IllDOT has also put four DTN terminals in rest areas around the state and has received a positive response from the public (especially from the truckers).

Regarding vendor incompatibility problems, IllDOT representative Dennis File feels that the American Association of State Highway and Transportation Officials (AASHTO) standard will eliminate this problem. The state buys multiple sites at a time for each CPU. Thus, if it has to buy a different vendor's server, it does not affect the cost significantly. As long as the CPUs can communicate, state officials are satisfied.

IllDOT representatives think the best use of RWIS data is for controlling salting operations. Once a certain stretch of road has been salted, then resalting will occur only after a sensor shows that the salt content has fallen below a prescribed level. The Illinois State Toll Highway staff controls all of their salting based on the salt content readings from the sensors.

All of their systems are powered by standard 110 V AC power with no power backup. They do not need solar power for any of their sites, but they thought it was a good option if it was necessary.

IllDOT relies heavily on the pavement forecasts it receives from SSI, especially for treating the roads. They have experimented with anti-icing using liquid salt. They need good forecasts to know when to start the anti-icing of the roads. Liquid salt is a saline solution with a 22–24 percent salt concentration. It has many benefits that include: no blowover of the salt, one-third as much material gives the same treatment as traditional salting, and the truck can travel at speeds of 40 to 50 miles per hour. Thus, the operator can cover more area in the same amount of time that leaves more time left over for treating other areas. The only problem with liquid salting is that the solution will freeze if the pavement is too cold. So, they use the pavement temperature data from the sensors to tell them whether or not they can apply the solution. IllDOT was so impressed with the liquid salt that they have decided to purchase the necessary equipment for next year.

There are several other applications for which IllDOT uses the RWIS data. For example, it uses it for paint-striping operations. (The paint that is used is a latex water-based paint, which cannot be used when it is wet or if it rains.) The data are also used for herbicide application planning. A third use is for bridge construction, in which the RWIS data are used for concrete pouring operations. The department also hopes to use the RWIS data to predict blowups. A blowup is when the pavement temperature and the subsurface temperature differ sufficiently to cause the pavement to buckle or explode. It is looking at ways to predict when and where this might occur.

According to Mr. File, one of the most important things to do when purchasing pavement ice-detection systems is to obtain a service contract. Illinois negotiated a 5-year service contract with SSI. State officials started off with a 1-year warranty on their equipment. The service agreement gives SSI 24 hours to fix a CPU and 48 hours to fix an RPU, unless there are extenuating circumstances. There is a $100 per day penalty if SSI does not repair the equipment on time. Mr. File said that DOTs should not try to maintain these systems themselves.

Further according to Mr. File, it will take about 2 years for an agency to realize the full benefits of an RWIS. It is a slow, ongoing process. It takes time to train people to properly use the system. IllDOT gives its employees a basic training session and lets them use the system for 2 to 3 months before allowing in-depth training. In this way, the user understands what is being discussed during the in-depth training session.

It was suggested that Missouri would be a good state to contact, since it was handling its weather systems differently. State officials there undertook a 2-year study of weather information systems. From this, they will receive a recommendation for aeronautic, agriculture, water, and transportation weather systems. Missouri will then issue a contract for one integrated weather system for all of its agencies.

4.4 COLORADO DEPARTMENT OF TRANSPORTATION

The Colorado DOT currently has between thirty and forty SSI RWIS installations deployed throughout the state. In general, it is pleased with the way that these systems perform, but state officials are uncomfortable with the fact that SSI dominates the market. While each of their new installations is getting the FP2000 sensor, the older sites have the E sensor, though they are being upgraded when they need to be replaced. The Colorado DOT representative, Dave Woodham, stated that the sensors did require a fair amount of calibration each fall.

Their RPUs communicate with the CPUs by way of radio to a microwave link that then goes to phone lines. They have a problem with the radios going out from time to time. The data from the RPUs are sent to one of the eight district offices, each one of which has its own server/CPU. The CPUs are linked by a network that permits the statewide information to be exchanged.

Most of the state's remote weather sites are AC powered, though a few are solar. According to Mr. Woodham, the solar-powered sites appear to work well.

As far as a DTN-type system, some of the maintenance sites use something like it to obtain regular weather data. However, state officials are not planning to upgrade to a system such as Iowa's, which has all of the state's RWIS data transmitted with weather data to all of the garages. They instead use weather data obtained from the World Wide Web.

They do receive the SCAN pavement forecast, which they find to be fairly accurate and satisfactory. They also use the pavement sensors in the summer for paving operations because they have minimum temperature specifications on their paving materials.

An added feature of the RWIS for them has been the ability to document actions during a storm. They find this especially helpful for litigation purposes. For example, say someone has a wreck on a bridge and claims it had not been de-iced. State officials can look at the pavement data: If they see that the chemical content went from 10 percent to 90 percent, they would know that the bridge had indeed been covered.

4.5 MICHIGAN DEPARTMENT OF TRANSPORTATION

The Michigan Department of Transportation (MIDOT) has approximately eleven SCAN sites and have no known plans for expanding. They had studied several different vendors but had decided that SSI was the best at the time. All of their sites are older, some of which use a SCAN16 board in the RPU. They do not have any of the FP2000 sensors.

Leo DeFrain, the MIDOT representative contacted, reported that the sensors were not very accurate. The pavement temperature was pretty good, but it depends on the installation as to how relevant its temperature reflects that of the road (i.e., in the wheel track or not, how good of a seal there is, etc.). The data reporting icing or no icing were very inaccurate. MIDOT determined this by assigning personnel in the field to describe (in writing) the actual site conditions (along with the time and date). Department officials then compared the written descriptions with the sensor data. They found that if it was dry and sunny, the sensor would report this correctly 98 percent of the time. However, the sensor was correct only 15–20 percent of the time when predicting preferential icing that can occur at air temperatures as high as 36°F. This icing occurs when the pavement temperature remains below freezing, even though the temperature has gone above freezing. Thus, their sensors were not reliable when they needed them the most. This also prompted a legal question as to whether, in the case of an accident suit, the department would be held liable if the technology were available but not purchased and deployed. If it is used and fails, then the department is still liable.

MIDOT also had problems with sensor maintenance. Mr. Defrain mentioned that maintenance was a fact of life that they had to deal with most of the time (MIDOT apparently has no maintenance agreement with SSI). The department has one full-time person who verifies that all of the sensors are working. The problems that must be fixed include defective sensors, cut cables, and corroded RPU boards; in addition, the state has one solar-powered site that is always failing. The solar site's batteries also require frequent replacement (the system will not charge the batteries at times when it should be charging). State officials reported that they are replacing approximately two sensors a year as a result of malfunctions.

Each of the RPUs sends its data to one or two of the maintenance districts, with the exact destination depending on the location of the site. Most sites use leased phone lines, with the monthly rate dependent on the distance and area of the site. Generally, each of these sites cost about $20–30 a month. The other sites use radio, though they have a range of only 20 to 25 miles. The sites are remote from the maintenance offices (they know what the conditions are around the office; they need to know what the conditions are at the far points of their district). The maintenance people have laptops with dial-up access to the pavement data. Much of their de-icing is let out to contractors that will generally also have access to the data. Statewide data are not available because the CPUs are not connected. To combine all the data, one would have to query each district's CPU.

MIDOT does not have any sort of DTN system; nor is it planning to use one. However, all of the PCs in the department have been given World Wide Web access. This allows MIDOT personnel to receive National Weather Service (NWS) forecasts and live radar images via the Web.

Mr. DeFrain also discussed legal issues. MIDOT has about one court case per year relating to an accident on a bridge deck. The plaintiffs usually claim that, since the technology exists, all of the bridges should have sensors installed. MIDOT disagrees and believes it is not reasonable (owing to economic concerns). The department feels that public education is more effective and has, accordingly, provided public service announcements on television and radio, telling drivers that a bridge can freeze before the rest of the roadway.

4.6 WISCONSIN DEPARTMENT OF TRANSPORTATION

Mike Adams is a meteorologist contracted out from Matrix Management to work for the Wisconsin Department of Transportation (WISDOT) on its RWIS. WISDOT will have fifty-one sites in the near future. (As of last year it had twenty-nine sites up and is in the process of adding twenty-two more.) Mr. Adams anticipates Wisconsin will add only nine or ten more full-blown RWIS's. They will look at installing mini-RPUs at other sites. These mini-systems include only the pavement sensors and communications equipment (all provided by SSI).

The new sites have the FP2000 sensor while the old sites have the E sensor. As the old sensors fail, they are being replaced with the FP2000 sensors. WISDOT has an average of three pavement sensors per site, for a total of about 150 pavement sensors. Mr. Adams said that, although a couple of the FP2000 sensors had failed, it was still too early for him to pass judgment on the sensors. WISDOT is experiencing an overall sensor reliability problem though. Of the 150 or so sensors, around 20 are known to be down while others are suspected of sending questionable data. Another problem is that the sensor and cable comprise one unit. If a sensor fails during the winter when the ground is frozen, it cannot be replaced until spring because the cable must be dug up. This is a problem, given that the sensors are most needed *during* the winter. He thinks it would be better if the sensors were more modular: For example, if the devices were modular, a failed sensor could be taken out, unplugged from the cable, and a new sensor plugged into the cable and reinstalled into the pavement. SSI is working to address this problem.

Right now, WISDOT, although slightly behind Iowa in its CPU-to-maintenance-office communication strategy, is moving toward building a system comparable to Iowa's. Currently, all RPU-to-CPU communication is via standard phone line. In the summer, they are going to move twenty-six sites onto their state microwave network, with the expectation that this will reduce costs. Currently, they have seven CPUs throughout the state that are not networked. Each of these CPUs is connected with four to eleven RPUs. To obtain information from a particular site, a user must dial up that CPU. In order to obtain statewide data, a user would have to dial up all seven CPUs.

WISDOT purchases weather forecasts from SSI. SSI calls up WISDOT's CPUs to get the data via modem. They get 24-hour pavement temperature forecasts twice daily. Adams said that if the forecasts are used properly, one can save as much in labor and materials as is spent on the forecasts (i.e., he liked the idea of having them). WISDOT contracts out its road maintenance to the counties. He said that it varies widely from county to county if they use the forecasts well. Some counties use the forecasts all the time. Others use it only during storms. Some counties choose to use only the Weather Channel. The forecasts are needed if one is going to use an anti-icing strategy. A few counties are already doing this. However, Adams said that the forecasts have not been great this winter and if one does not trust the forecast, anti-icing will be ruled out. Adams mentioned that it is a difficult decision to put anti-icing chemicals on the ground 2 hours before it is supposed to freeze because if it does not freeze, then substantial labor and materials are wasted. Thus, the forecasts must be accurate.

He also brought up the problem of lack of communication between systems from different vendors. This lack of communication forces them to stay with the first company they purchased from if they want all components of their system to communicate. This is being alleviated somewhat by the AASHTO standards, and Adams agreed that it would be better if the standard was applicable for RPU-to-CPU as well as CPU-to-CPU communication.

They are also experiencing a problem with the dialing frequencies of some of the CPUs. The data from the RPUs are not being sent regularly. The CPUs are supposed to query each RPU once per hour and get all of the data stored from the last hour by that RPU, but this is not happening for some of the RPUs.

Fifty of their sites are powered by regular utilities. WISDOT is researching using solar power for the fifty-first site because there is no convenient power source. They do not have any battery backups, and he did not think that their cost could be justified (since they lose power so infrequently).

Their construction personnel use the pavement forecasts for planning paving and concrete operations. Most of their counties have DTN for looking at radar and satellite data, but they do not receive the RWIS data from DTN. They are looking into having all of their counties equipped with DTN systems (as is the case in Iowa).

4.7 OKLAHOMA MESONET

Oklahoma currently uses a statewide network to share real-time weather information from hundreds of remote sites spread all over the state. This network, Mesonet, uses the Oklahoma Law Enforcement Telecommunications System (OLETS) to communicate weather information. OLETS is maintained by the Oklahoma Department of Public Safety (DPS).

Each remote site is located within a 15-mile radius of an agency. There are over 200 agencies statewide, each equipped with a terminal. Real-time atmospheric weather data are sent via radio from a remote site to an agency every 15 minutes. All of the agencies are networked to a centralized message switch in Oklahoma City. The Mesonet data are shared by a number of different users, including agricultural-, meteorological-, and transportation-related users.

Oklahoma also has three SSI installations in Oklahoma City and one SSI installation at each airport in Oklahoma; however, RWIS data are not yet available over Mesonet.

4.8 TEXAS ACTIVITIES AND EXPERIENCES

This section summarizes the five Texas field trips taken over the course of this project. The sites visited include a high-water detection system on Spicewood Springs Road in Austin, an Emergency Operations Center (EOC) in Austin, the Texas Department of Transportation's (TxDOT's) Kerrville Office, TxDOT's Dallas District Office, and TxDOT's Amarillo District Office. Each of the descriptions below includes the date of the field trip, the name of the person interviewed (if applicable), and the findings from the field trip. Appendix D includes pictures of the sites.

4.8.1 High-Water Detection System on Spicewood Springs Road—September 20, 1995

The City of Austin and Travis County have recently installed a high-water detection system on Spicewood Springs Road between US 183 and Loop 360. This section of road has a number of low-water crossings that periodically flood when stormwater levels are high. The purpose of this system is, first, to detect when the water has reached a level that is dangerous to motorists, and, second, to pass this information on to the motorists and to the City of Austin EOC.

The system was developed by RTC Manufacturing, Inc., and is marketed by A-TEK. It consists of two sets of flashing warning lights and changeable message signs at either end of Spicewood Springs Road; also included is a pair of infrared photoelectric water-level sensors located in the creek bed of those crossings that flood most frequently among the eight low-water crossings. The sensors are connected via cable to a metal cabinet that houses the battery, with a solar panel used to charge the battery. Atop the sensor cabinet are radio transmitters and an auto dialer used to activate the flasher lights and changeable message signs, and to send messages to the EOC.

Under normal conditions, the lights do not flash and the message sign reads, "WATER OVER ROAD WHEN FLASHING." When the water rises to the level of the first sensor (level of caution), the transmitters send a message that causes two yellow beacons to flash at each end of Spicewood Springs Road; at that point, a radio signal is immediately sent to the EOC in Austin. When the water reaches the level of the second sensor, the second stage of the system is activated. The yellow beacons stop, the red beacons begin to flash, and the message sign opens and reads "DO NOT ENTER, HIGH WATER." There are also gates near each of the flashing light assemblies that can be used to close the road to traffic, though it appears that this must be done manually.

After inspecting the site, we noted a few improvements that could be made to the system. First of all, there were no warning signs other than the two set up at either end of the road. It may be a good idea to have some type of warning device deployed in advance of each of the low-water crossings. Secondly, the sensors detect only water level. It would be useful to have sensors that also detected the water flow, since that is a factor that is likely to cause vehicles to be carried away. Finally, it was unclear what would happen to the residents of Spicewood Springs Road if their road closed. Is there an alternative route for them to take to get into town? Also, how will they know when the water is at a dangerous level if the warning signs are undetectable at the ends of their road?

This site represents a good location for a pilot project, given that the high-water detection system is already in place and that the site is reasonably close to The University of Texas at Austin.

4.8.2 City of Austin Emergency Operations Center—October 4, 1995

In 1986, the City of Austin purchased an enhanced ALERT (Automated Local Evaluation in Real Time) system for approximately $600,000 from Sierra/Misco of California. This system, named the Flood Early Warning System (FEWS), is operated at the City of Austin EOC. The purpose of this system is to predict when flash floods may occur in the Austin area so that proper authorities and the public can be notified before flooding occurs. This following summarizes the findings of our visit to the EOC. Most of the information was provided by Andy Ruch of the City of Austin Stormwater Management Division.

The FEWS is a network of rain gauges and stream gauges that relays data via VHF radio to a base station, located at the EOC. It is set up to provide real-time weather information and flood forecasting. FEWS covers over 500 square miles of Travis County, including 85 field sensor sites. Each sensor site has a rain gauge sensor equipped with an associated data encoder and radio transmitter. The transmitter sends a radio signal with the site number and the total rain accumulation to the base station via a repeater station. Many of the sensor sites also have stream gauges and battery sensors. The transmitter sends a separate signal for each of these sensors with its associated data to the base station.

Once the data are received at the base station, they are converted to digital format and sent to the computer network over a serial line. The data are filed in a database and saved on two 386 computers. The purpose of having two computers is to share the tasking and to provide a backup in case one fails. The data on the computers are constantly compared with alarm criteria. Once these criteria are exceeded, an alarm task kicks in and the system automatically begins a telephone ring down in an attempt to locate FEWS personnel. If no one can be reached, the system will eventually call 911.

The system offers numerous data viewing options for FEWS personnel. First, there is a City of Austin watershed map with sensor-associated LEDs. When alarm criteria are reached at a sensor site, that site's associated LED begins to blink on the watershed map. This gives FEWS personnel in the EOC office a visual representation of the city's potential flood sites. The sensor information can also be displayed on the computer terminals in the form of either textual maps or raw data for each site. This information can also be accessed by remote workstation via modem.

There are many planned enhancements to the FEWS. The system will eventually be connected to an Ethernet LAN (local area network) so that its information can be more easily shared with offices outside of the EOC. Also, once the QNX operating system is upgraded to version 4 and becomes fully POSIX compliant, the FEWS information will be posted on the Internet. Finally, the EOC is considering two-way communication with the sensor sites. This will allow users to capture data from the sites in case the data have not been transmitted to the base station for whatever reason.

The target system for this project will probably be much simpler and cheaper than what the City of Austin is currently using. Since TxDOT's system will cover a much larger surface area than what FEWS covers, it will not need to be as precise. Also, TxDOT's system will act more as a resource management system, whereas FEWS acts as a crisis management system.

4.8.3 Texas Department of Transportation's Kerrville Office—February 9, 1996

The TxDOT Maintenance Office in Kerrville, run by Wayne Pehl, currently uses a remote operating system (ROS) flood warning system to monitor road conditions throughout Kerr County. The system consists of twenty-two remote sites equipped with rain gauges. Eleven of these sites are also equipped with water-level sensors. The rain gauges and level sensors are connected via cable to a solar-powered RPU at each site. Each RPU reports readings back to a CPU at the District Office every 6 minutes. The RPU-to-CPU communication is via FM radio. The Maintenance Office uses an ROS-developed Wonderware Software Package to monitor the sensor data.

The system is also used by the Upper Guadalupe River Authority (UGRA) and the Kerrville Fire Department. The UGRA originally purchased the system for about $225,000 ($9,000–10,000 per RPU). The Kerrville Fire Chief is in charge of overseeing the system and reporting any major problems to ROS.

The TxDOT Maintenance Office in Kerrville uses the system for flood prediction and flood warning. By knowing the rate of rainfall at specific high locations, Mr. Pehl can predict where the rain will run off and which roads will be in danger of flooding. The system also alerts Mr. Pehl about sites where the water has reached a level that is above the road surface. The continuous level measurement can also be used to predict flooding. Currently, there are no road signs used to warn motorists.

Problems with the system involve mostly minor software bugs (e.g., the date not changing automatically). Mr. Pehl claims that the system hardware is very reliable except for the fact that the rain gauges do not work during freezing rain; he also noted that some of the sensors need to be moved to better locations. He stated that the sensors should be located on the upstream side of the roadway and in an area where they will not become buried with debris. This was a problem with the Turtle Creek level sensor: accumulations of debris led to inaccurate readings. The communication links have been for the most part reliable, though some RPU power sources had been disrupted by lightning. Mr. Pehl also claims that receiving a report every 6 minutes represents far more data than he ordinarily needs, especially when nothing is happening. The system would be more efficient if it sent data every hour except during periods of rainfall, at which time the data could be sent more frequently.

Mr. Pehl claims there is a great opportunity to expand the system in a way that would make it even more valuable. More RPU sites could be installed, some of which could include message signs to warn motorists. Possible locations include the northwest corner of the county that is located 60 miles from the district office, and a section of FM 1338 that includes a very dangerous low-water crossing that has already washed away a number of cars. These expansions could be paid in part by the UGRA, since it also has an interest in expanding the system.

Also needed by TxDOT is a system specification that is tailored to meet TxDOT's needs. This specification should identify a system needing minimal maintenance, and one that takes into account MUTCD guidelines for warning signs (e.g., safe stopping distance and message wording).

4.8.4 Texas Department of Transportation Dallas District Office—February 15, 1996

In 1989, the TxDOT Dallas District Office implemented SSI's SCAN system for bridge ice detection and pavement forecasting. Pavement sensors and weather stations were installed at four bridge sites. A CPU (SCAN server) at the District Office polls the RPUs at the sites every 30 minutes. The data are transmitted from RPU to CPU via modems (two sites use telephone, two sites use cellular link). Once in the CPU, the real-time data can be viewed in graphical or textual format using the SCAN software. Mike Heiss, a maintenance engineer in the Dallas office, is the primary user of the system, though he does not much use the real-time data. Instead, he relies on the SCAN pavement forecast and live radar images provided by WSI.

SSI provides three pavement forecast a day from St. Louis, Missouri (7:00 a.m., 3:00 p.m., 9:00 p.m.). It does this by dialing into the Dallas CPU and having the real-time data sent back to St. Louis. SSI meteorologists use the data, in combination with weather forecasts and forecast models, to provide Dallas with an updated 24-hour pavement forecast. All pavement forecasts are based on real-time data from one site located in the northwest part of the district (the site that has the most frequent problems). The cost of these forecasts is about $400 per month in the winter and $250 per month in the summer, plus a yearly license fee of $200 per year. Mr. Heiss uses the pavement forecasts to predict when snow and ice storms will hit and when he should have crews apply chemicals to the roads.

Mr. Heiss also uses the live radar to predict storms. He receives a live satellite radar image by dialing into a WSI system and downloading the image to his PC. He pays about $100 per month for these images; the cost of each image is $2, with an additional $1.50–$1.89 per minute charged (depending on baud rate) for downloading time. The radar image and the SCAN forecast provide Mr. Heiss with a site-specific forecast that is less conservative than any he would get from the NWS. The information that Mr. Heiss most values pertains to storm approaches/exits and pavement freezing.

Mr. Heiss reported having several problems with the system. Among these: The wind sensors tended to give inaccurate readings; the WSI radar image took too long to pull up and its software is outdated; the pavement sensors sometimes have problems detecting whether the pavement is wet; and occasionally some data are lost owing to a problem with the cellular link. Also, forecasts are used only to predict three to four storms per year. The rest of the time they are used to assist in construction planning.

4.8.5 Texas Department of Transportation Amarillo District Office—March 1, 1996

The Amarillo District Office has had a Vaisala ice-detection system fully operational since November 1995. The primary user of the system is Bruce Nipp of the Amarillo District. The system includes installations at five bridge sites, two with pavement sensors and weather stations with a visibility sensor, and three with just the pavement sensors and weather stations. The total cost of the system, including ICECAST software, twenty-four laptops, three PCs, one CPU, five RPUs, communication, and installation, was $300,000.

The CPU polls the RPUs every 30 minutes for real-time data. The RPU-to-CPU communication is performed via modem. All laptops and workstations are able to dial into the CPU to retrieve real-time data at any time. Twenty-four hour pavement forecasts are received via modem from a different vendor in Boston twice a day (5:00 a.m. and noon). These forecasts are used to predict pavement temperatures, pavement freezing points, and pavement conditions (wet, dry, icy, etc.). The real-time data, which can be viewed both graphically and textually, include air temperature, humidity, dew point, presence of precipitation, pavement temperature and freezing point, and condition of pavement. Unlike Dallas, Amarillo actually uses the real-time data extensively to identify trends, monitor real-time conditions at the bridge sites, and predict future events. Mr. Nipp also uses the pavement forecasts to treat bridges before they freeze. Because this pretreatment requires fewer chemicals than are used to treat the bridges after they have iced over, TxDOT realizes a substantial savings.

Although Mr. Nipp has identified few problems with the system, he occasionally notices gaps in the data that are the result of missed pollings. These gaps may occur because the communications did not properly link. Also, his monthly communications costs are somewhat high, since the system is making 240 phone calls a day to poll the sites for data (144 of these calls are long distance). This cost may be reduced by increasing the polling time. Finally, after his 6 months of free forecasts are up, he may want to reconsider whether they are worth the $3,000 per month he will be paying for them.

CHAPTER 5. LIFE-CYCLE COST ANALYSIS

This chapter summarizes two recent benefit-cost analyses performed on the implementation of road weather information systems (RWIS's). The analyses were performed by the Strategic Highway Research Program (SHRP) and Pilli-Sihvola and Toivonen of Finland.

5.1 SHRP BENEFIT-COST ANALYSIS

In 1988, SHRP initiated a project to evaluate the effectiveness of an RWIS in reducing the costs of highway snow and ice removal. The investigation included a benefit-cost analysis of implementing road technologies. A 1991 article by S. Edward Boselly III describes the statistical model used by SHRP to perform the benefit-cost assessment (Ref 2). The model results show that the use of RWIS's can be cost effective if used proactively and in conjunction with accurate pavement and weather forecasts.

The model takes into account indirect and direct benefits and direct costs. Indirect benefits include improved traffic flow, reduced fuel consumption, reduced accident rates, and reduced insurance premiums. Direct benefits include reduced expenditures for labor, equipment, and materials. Direct costs were acquired from records of expenditures for snow and ice control.

5.2 FINNISH BENEFIT-COST ANALYSIS

There is also a 1992 article that describes a benefit-cost analysis performed for a nationwide RWIS implemented in Finland (Ref 13). This article categorizes benefits in terms of savings in accident costs, vehicle costs, and time costs. Total savings for a single district were estimated at $980,000 per year. By incorporating yearly RWIS investment costs ($60,000/district) and recurring costs ($140,000/district) into the model, a benefit-cost ratio of 5:1 was obtained.

It should be noted that in the few years since these studies were performed, the costs of RWIS hardware and services have declined significantly. Therefore, if a benefit-cost ratio were performed now, the results would probably prove even more cost effective.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

6.1 PROPOSED IMPLEMENTATION ALTERNATIVES

There are basically three options for statewide implementation of road weather information systems (RWIS's). These options include: (1) having two turnkey systems used throughout the state (one for high-water detection and one for ice detection); (2) using multiple proprietary systems statewide (could be different for each district); and (3) combining components of various proprietary systems into a new system. Each of these alternatives is discussed below.

6.1.1 Have Two Proprietary Turnkey Systems for Statewide Use

This alternative involves selecting a single ice-detection system and a single high-water detection system for statewide use. Both of the systems will be turnkey systems and will act independently of each other. All of the districts will use the same system and a statewide wide area network (WAN) will be established so that the districts are able to share information.

One advantage of this alternative is that the turnkey systems will be easy to procure (since they already exist). Acquiring the systems would involve merely establishing the number of remote processing unit (RPU) stations, the number of sensors, the mode of communications, and the method of data access for decision makers. Also, adding additional sensors or RPUs to the system would be easy since there is only one vendor.

Disadvantages are that each district would have to purchase the same system, making any existing RWIS technology obsolete unless it is from the same vendor. Also, using just one vendor limits the agency's capabilities to those offered by that particular vendor. Finally, use of a proprietary system may make it difficult to exchange data with other sources or state agencies, unless a standard protocol is established for CPU-to-CPU communication.

6.1.2 Use Multiple Proprietary Systems Statewide

This alternative involves having each district use whatever ice-detection system or high-water detection system they wish but still making it possible for districts to share RWIS information. Each district's CPU will be able to communicate to CPUs at other districts through standard protocols and data formats. Because this standard CPU-to-CPU protocol already exists, this is a feasible option. Figure 6.1 presents the schematics for a statewide CPU-to-CPU communication system.

The advantage of this alternative is that it enhances interoperability and connectivity among RWIS's from different vendors. It also allows each district to use its existing RWIS equipment, obviating new system purchases. Finally, each district has the flexibility to choose the system that meets its needs, while still being able to share information with other districts or state agencies.

One disadvantage with this alternative is that it requires an agency to establish standard communications protocols and standard data formats for CPU-to-CPU communication. This may require working with the selected vendor in order to ensure successful implementation. As mentioned earlier, a standard American Association of State Highway and Transportation Officials (AASHTO) protocol already exists, so all that needs to be done in this case is to establish a standard data format. Another disadvantage with this system is that it requires each district to purchase the sensors, RPUs, CPU, and software all from the same vendor. Also, with this alternative, the communications link between each of these RWIS components will be somewhat of a "black box" to the agency.

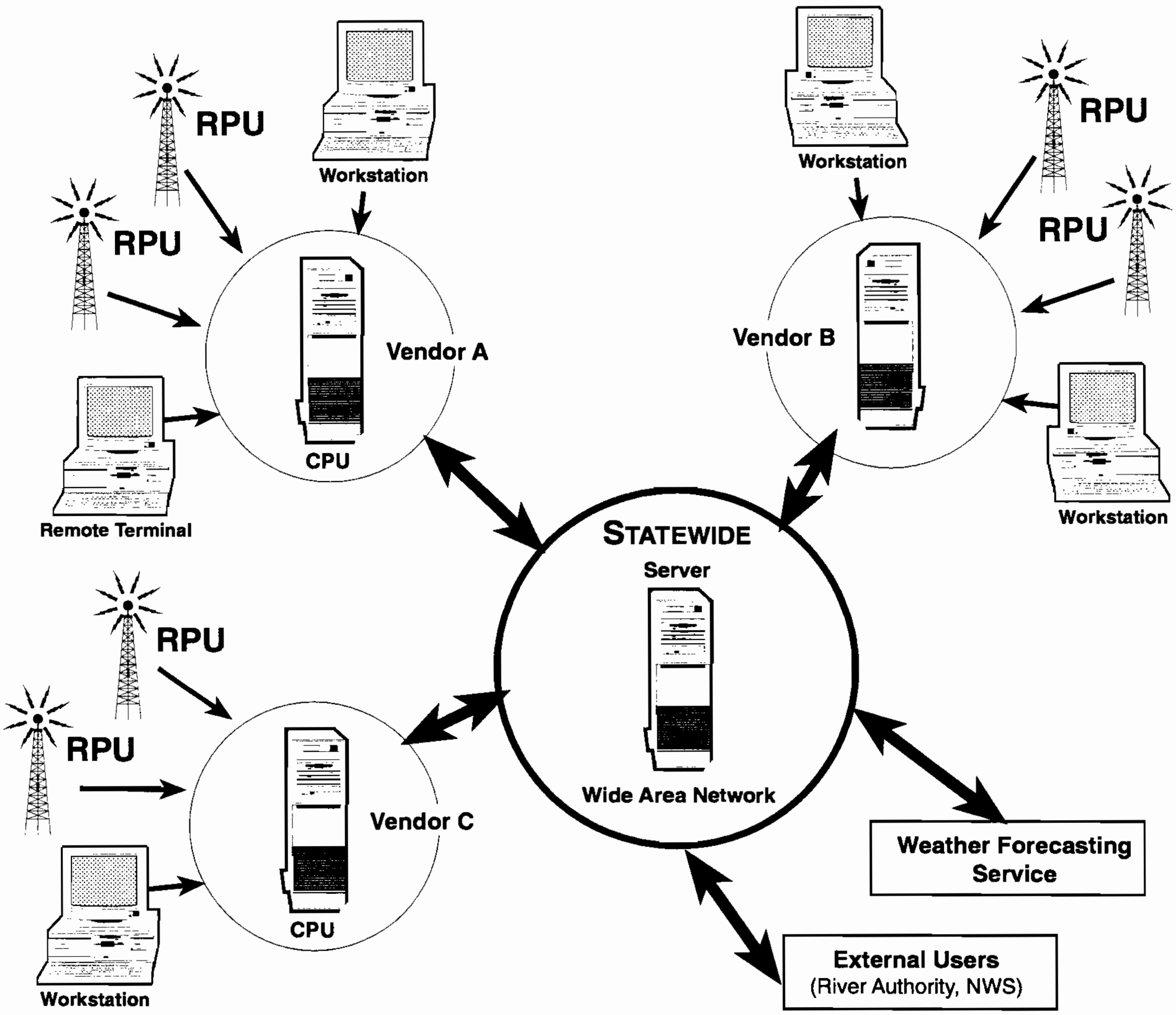

Figure 6.1 Statewide CPU-to-CPU communication system

6.1.3 Combine Components of Various Proprietary Systems into a New System

This alternative allows the agency to combine various RWIS components from different vendors to make up a new system. For example, the system could include road sensors from one vendor; water-level sensors, an RPU, and a CPU from another; and communication systems from yet another vendor. In order for it to work, there must be an open systems architecture in place. Specifically, there must be standard protocols for sensor-to-RPU, RPU-to-CPU, and CPU-to-CPU communications and standard data formats.

The advantage to this system is that it will provide more flexibility in acquiring RWIS technologies. If a highway agency wants to mix different types of pavement sensors or RPUs, replace obsolete sensors, or tie the system with other intelligent transportation system (ITS) technologies, the opportunity to do so is enhanced with this open systems environment. Also, this open systems environment will encourage more competition from smaller vendors that may specialize in just one RWIS component (which will drive down costs). This may also help to eliminate the monopoly that some of the larger vendors (e.g., SSI) have on the market, thus increasing the highway agency's purchasing options.

Unfortunately, there are a number of problems with this alternative. Currently, there is no standard protocol for RPU-to-CPU communication, though AASHTO is in the process of developing one. If the highway agency is forced to develop such a protocol, this could increase the initial cost and the time required to acquire the system. Second, there seems to be some reluctance among a majority of the vendors to accommodate this option. Liability may be an issue here, with some vendors not wanting to be held responsible for another vendor's product. Finally, having all of these components from different vendors may complicate system maintenance and drive up costs.

6.2 RECOMMENDED PATH FORWARD

This section reports a recommendation of what needs to be done for the remainder of this project. This includes a performance evaluation of candidate ice- and high-water detection systems, the development of a statewide implementation plan, and the drafting of specifications for the statewide system.

6.2.1 Performance Evaluation

The next step in this process is to identify potential sites where the ice- and high-water detection systems can be tested for performance and reliability. Ice-detection systems are currently installed in Amarillo and Dallas and there has recently been a request for ice, and possibly high-water, detection systems to be installed in Lubbock. Also, there are high-water detection systems already in place in Austin, San Antonio, and Kerrville. Any of these sites would be a good candidate test site. Lubbock, in particular, could be a good test site given that we could test a system there that uses both the ice and water-level sensors. SSI and ROS have expressed interest in combining their sensors into a single system that performs both of these tasks. It would also be helpful to have two competing systems installed at the same site so that their performance and reliability could be compared objectively. This last task would require cooperation from the vendors, since there is little funding available in this research project to pay for a new installation site.

6.2.2 Develop Statewide Implementation Plan

The next step will be to develop a statewide implementation plan. First, a survey will be sent out to all of the District Maintenance Offices and Metropolitan Planning Organizations in Texas asking them to provide estimates on the number of low-water crossings and freezing-prone bridges in their district. This survey will then be followed up with telephone contacts. Once this information has been gathered, we will develop a criteria for prioritizing which sites should have an RWIS based on weather, traffic, hydrological, and accident data.

Next, we will develop an economic analysis model based on Texas Department of Transportation (TxDOT) priorities and budgetary constraints to determine what the extent of implementation should be for each district. There may be two or even three different levels of RWIS implementation to choose from, and it will be up to each district to determine which level of implementation it wishes to deploy. From these findings, a staged statewide implementation plan will be developed. This implementation plan will include a set of procedures that will guide a district through each stage of the implementation process.

6.2.3 Draft Specifications for System

This step involves determining the type of information that needs to be available at TxDOT's traffic management centers and field offices. This document will also address communication requirements for the system, with special emphasis on standard protocols and data formats. Finally, the specifications will include any additional information, other than road spot-hazardous conditions, that may be incorporated into the system. This could include remote traffic counters, weigh-in-motion systems (WIMS's), or any other types of ITS's.

APPENDIX A:
ANNOTATED BIBLIOGRAPHY

APPENDIX A: ANNOTATED BIBLIOGRAPHY

1) American Association of State Highways and Transportation Officials (AASHTO) Subcommittee on Maintenance Work. *AASHTO Road Weather Information Systems Data Exchange Protocol.*

2) Boselly, S. Edward III. "Benefit-Cost Assessment of the Utility of Road Weather Information Systems for Snow and Ice Control," *Transportation Research Record 1352*, p. 75-82, 1992.

This article describes the statistical model used by SHRP to perform a benefit-cost assessment of the potential effectiveness of an RWIS in reducing costs of highway snow and ice control. Model results show that the use of weather technologies can be cost effective when decisions become proactive with the use of weather information. This article is a very good source of information relating to the economic benefits of an RWIS.

3) Boselly, S. Edward III. *Road Weather Information Systems Volume 1: Research Report*, Strategic Highway Research Program, Washington, D.C., 1993.

The volume 1 research report provides an overview of the types of RWIS currently available, the means for communicating road weather information, and the uses for such information in roadway snow and ice control. The report also presents conclusions and recommendations for the use of RWIS by state and local highway agencies in support of snow and ice control activities. There is a great deal of detailed information in this report ranging from the recommended location of road sensors to standard communication protocols.

4) Boselly, S. Edward III. *Road Weather Information Systems Volume 2: Implementation Guide,* Strategic Highway Research Program, Washington, D.C., 1993.

The Volume 2 implementation guide supplements the Volume 1 research report. Volume 2 describes RWIS technologies available, sources of weather information, communication requirements, guidance on siting RWIS's, and sample RFPs for obtaining the necessary equipment and services.

5) Boselly, S. Edward III. "Road Weather Information Systems: What Are They and What Can They do for You?" *Transportation Research Record 1387*, p.191-195, 1993.

This article describes the various RWIS technologies available. In addition, the article discusses the communications aspects of providing information effectively to highway agencies. Finally, cost analysis results of the research are highlighted *to point out potential cost-saving benefits from implementing RWIS technologies. This article is a good source of background information.*

6) "Developments Improve Road Weather Information Systems," *Better Roads*, October 1995.

This article presents descriptions of the state-of-the-art technologies in ice detection systems. The two vendors whose systems are described in the article are SSI and Vaisala.

7) Eck, Ronald W. "Reducing Tort Liability on Low-Volume Roads Through Analysis of Case Law," *Transportation Research Record 898*, p.115-122, 1983.

This document explores how highway agencies can reduce their liability risk on low-volume roads by using highway case law in conjunction with standard procedures such as record-keeping and warning systems. This document provides some relevant background information regarding tort liability on low-volume roads.

8) Kelly, J. R. "Road Weather Information Systems for IVHS Applications and Improved Maintenance Procedures," Proceedings of the IVHS America 1994 Annual Meeting.

This paper provides an overview of remote pavement weather sensing technology and pavement temperature forecasting for maintenance and Intelligent Vehicle-Highway Systems. The components of RWIS are explained and proposed products and applications from RWIS are presented. This paper provides useful background information and explains the various RWIS components; the paper, however, lacks specific guidance for implementing an RWIS.

9) Kuennen, Tom. "South Carolina Gets Year Round Sensor Use," *Roads and Bridges*, June 1991.

In 1989, the South Carolina Department of Highways and Public Transportation purchased an RWIS from SSI. This article points out some of the savings that South Carolina has seen one year after adopting the SCAN system.

10) Minnesota Department of Transportation. *Road Weather Information System Task Force Report to New Technology Research Committee*, June 1993.

This report provides a literature search of RWIS technology, examines the feasibility of implementing a total RWIS for MnDOT, and recommends solutions for how to implement a total RWIS in Minnesota. The report also examines *different implementation scenarios and seeks agreement on appropriate funding approval. This report may act as a good model for TxDOT—with one exception: TxDOT does not wish to implement a total RWIS, but rather something a little less costly.*

11) National Research Council. Transportation Research Board. *NCHRP Synthesis 186: Supplemental Advance Warning Devices*, Washington, D.C., 1993.

This synthesis presents the results of a literature review and state-of-the-art survey conducted to provide useful information on advanced warning devices that are not specified in MUTCD. More specifically, the report shows some of the devices used to warn motorists of wet roads or icy conditions. These devices may be used in conjunction with our high-water and ice-detection systems.

12) "Out of the Ice Age into the Space Age," *Roadtalk*, December 1994.

This article discusses MTO's recent plans to expand its implementation of bridge ice detection systems throughout Ontario. The system chosen for expansion was the SSI system.

13) Pilli-Sihvola, Yrjo, and Toivonen, Kimmo. "Road Weather Service System in Finland and Savings in Driving Costs," *Transportation Research Record 1387*, pp 196-200, 1993.

This article describes an RWIS that is being used in Finland and calculates its savings in driving costs. There is a great deal of technical information regarding the system configuration, information gathering, communication and alarm handling that may be useful if we are going to design a network. I believe the RWIS mentioned in the article is a Vaisala system.

14) Ring, Stanley. "The Design of Low Water Stream Crossings," *Transportation Research Record 1106*, pp 309-318, 1987.

This document describes the major steps and considerations involved in the design of a low-water stream crossing. This is a useful source of background information regarding what a low-water stream crossing is and when it should be built.

15) U.S. Department of Transportation. Federal Highway Administration. *Environmental Sensor Systems for Safe Traffic Operations*. October 1995.

This report provides the results of a detailed investigation of environmental sensors and their applicability in highway operations. It describes the functional *requirements for weather condition detection devices in highway applications based upon current guidelines of various state and federal agencies. It also examines the state of the art in environmental sensing systems.*

16) Wiltse, Marty. "Kansas' High Tech Turnpike," *Better Roads*, February 1993.

This article describes the new RWIS that has been adopted by the Kansas Turnpike Authority. This system includes a weather monitoring system from SSI called Surface Condition Analyzer (SCAN). SSI has recently upgraded its system to SCAN for Windows.

17) Wright, James L. "Guiding Lights for Minnesota," *Intelligent Highway Systems*, March 13, 1995, pp 11-12.

This article summarizes the results of a research project completed by Minnesota Guidestar that identifies the needs of Minnesota's rural highway users and assesses the potential for implementing RWIS's in Minnesota.

APPENDIX B: RWIS CONTACT INFORMATION

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Contacts for Other States:

Colorado

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John Whited
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Vendor Contacts:

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Richard Butler
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A-TEK
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Climatronics
David Katz
Phone: 215-579-4292

Data Transfer Network
Don Wilmes
Sales Director
Phone: 1-800-485-4000 EXT. 8045

Remote Operating Systems
Bill Dunne
434 W. Nakoma
San Antonio, TX 78216
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FAX: 210-530-9611

Surface Systems Incorporated
Jerry Waldmen
Phone: 1-800-325-7226

Vaisala
Dave Sakelaris
Phone: 1-800-408-9457

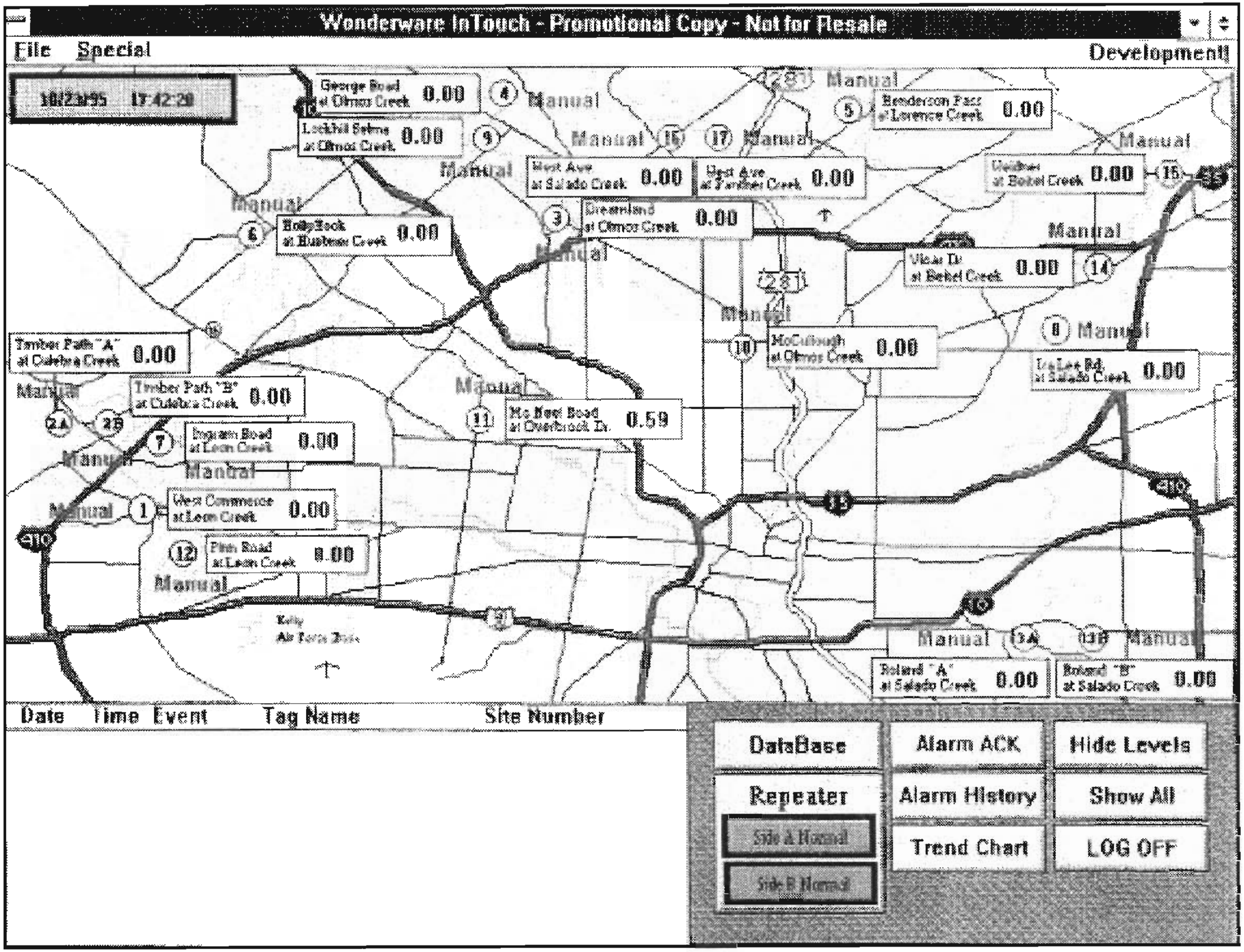
Other Contacts:

Matrix Management
    Bill Higham
    Phone 206-621-1977

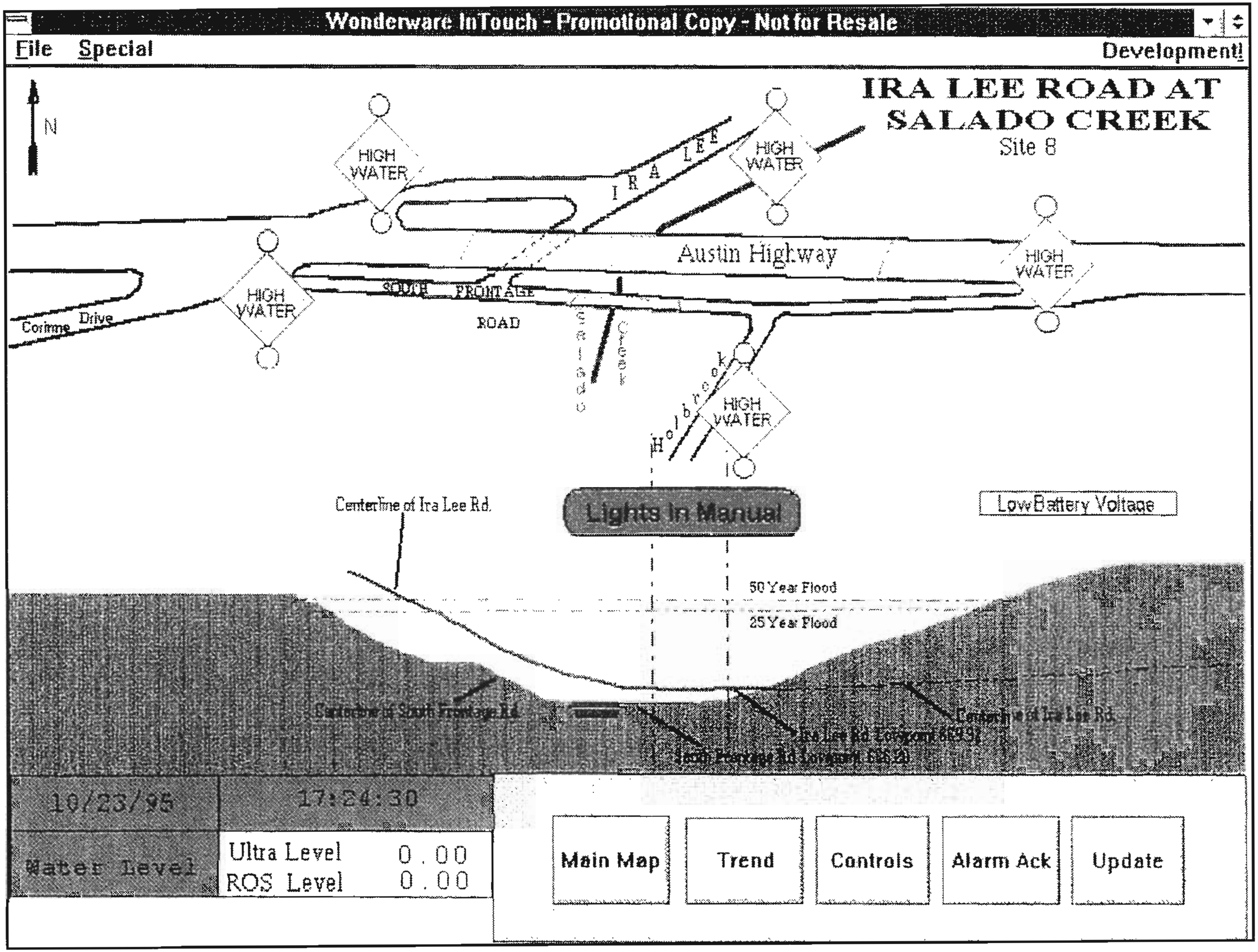
NEMA Committee (Standard Protocols)
    Ed Seymore
    Phone: 214-691-8124

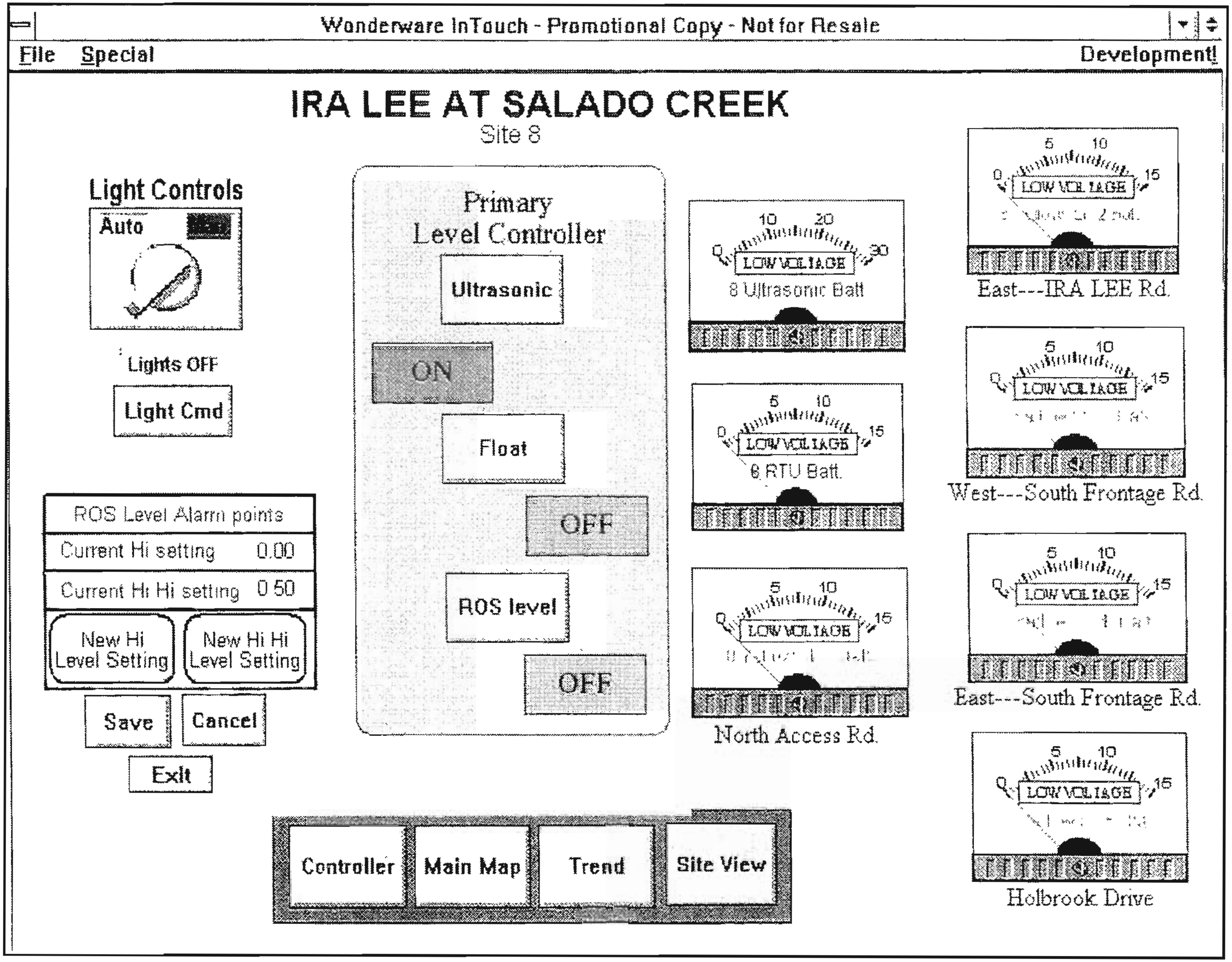
APPENDIX C:

SAMPLE OUTPUT FROM WONDERWARE AND VAISALA'S ICECAST

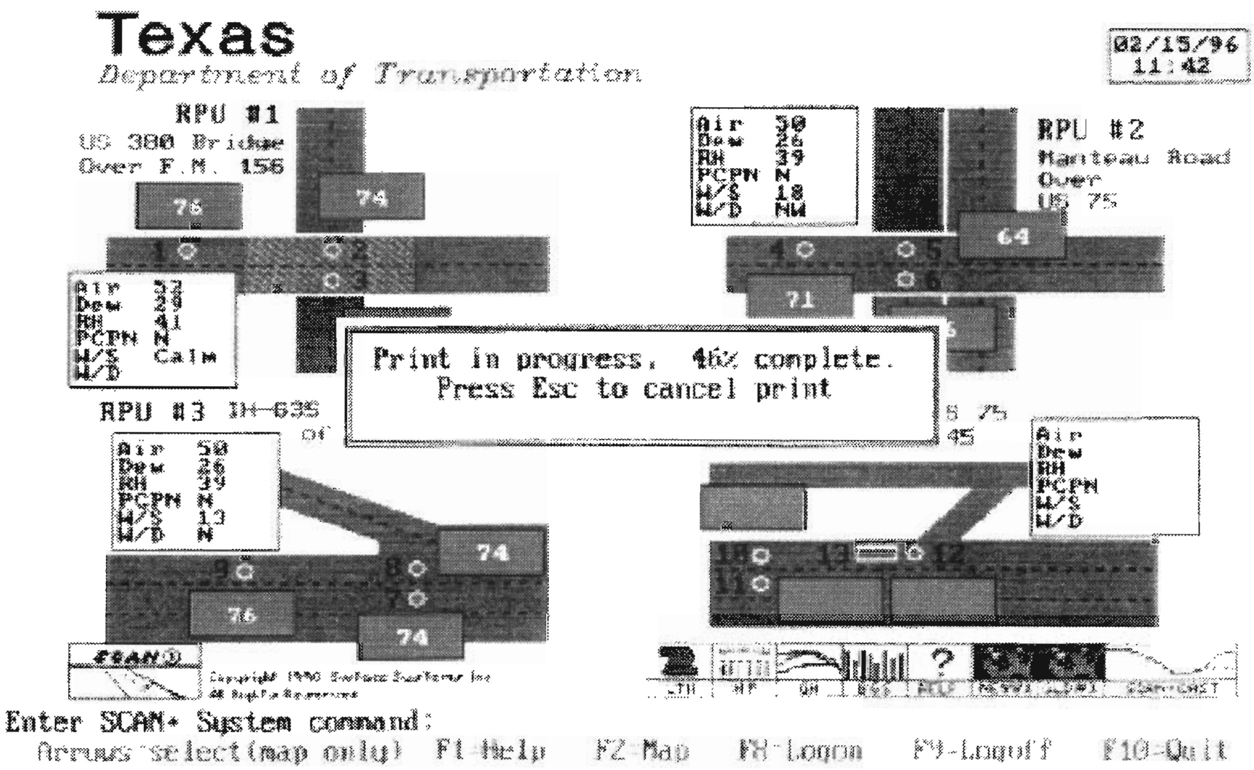


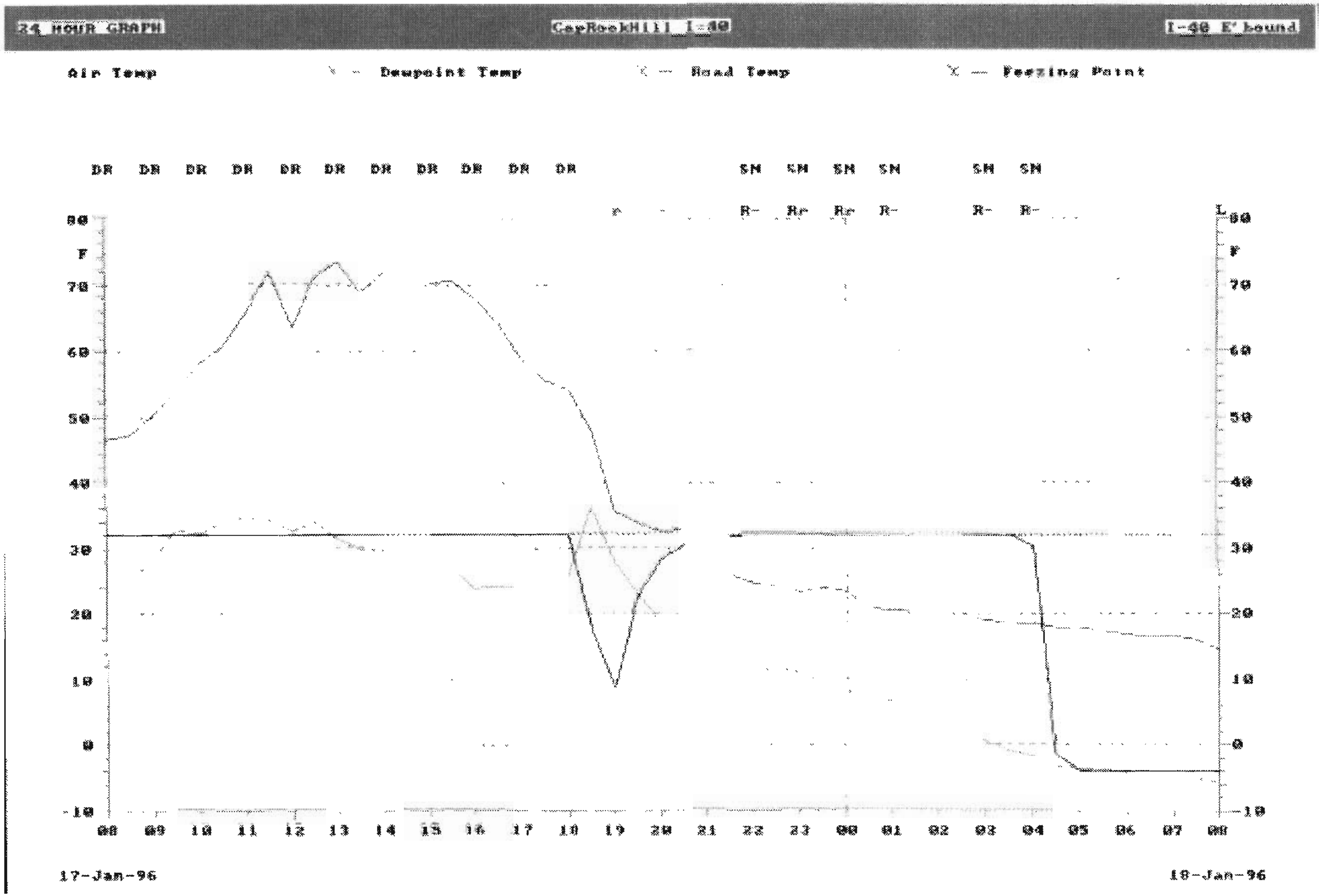
SAMPLE OUTPUT FROM WONDERWARE


Wonderware InTouch - Promotional Copy - Not for Resale
File
Special
Development!
IRA LEE ROAD AT SALADO CREEK
Site 8
N
HIGH WATER
HIGH WATER
HIGH WATER
HIGH WATER
HIGH WATER
IRA LEE
Austin Highway
SOUTH FRONTAGE ROAD
Corinne Drive
Salado Creek
Holbrook
Lights in Manual
Low Battery Voltage
Centerline of Ira Lee Rd.
50 Year Flood
25 Year Flood
Centerline of South Frontage Rd.
Centerline of Ira Lee Rd.
10/23/95
17:24:30
Water Level
Ultra Level 0.00
ROS Level 0.00
Main Map
Trend
Controls
Alarm Ack
Update


Wonderware InTouch - Promotional Copy - Not for Resale
File
Special
Development!
IRA LEE AT SALADO CREEK
Site 8
Light Controls
Auto
Lights OFF
Light Cmd
ROS Level Alarm points
Current Hi setting 0.00
Current Hi Hi setting 0 50
New Hi Level Setting
New Hi Hi Level Setting
Save
Cancel
Exit
Primary Level Controller
Ultrasonic
ON
Float
OFF
ROS level
OFF
LOW VOLTAGE
8 Ultrasonic Batt
8 RTU Batt.
North Access Rd.
East---IRA LEE Rd.
West---South Frontage Rd.
East---South Frontage Rd.
Holbrook Drive
Controller
Main Map
Trend
Site View

SAMPLE OUTPUT FROM ICECAST




24 HOUR GRAPH
CapRockHill I-40
I-40 E'bound
Air Temp
Dewpoint Temp
Road Temp
Feezing Point
DR DR DR DR DR DR DR DR DR DR DR
SM SM SM SM SM SM
R- Rr Rr R- R- R-
80
F
70
60
50
40
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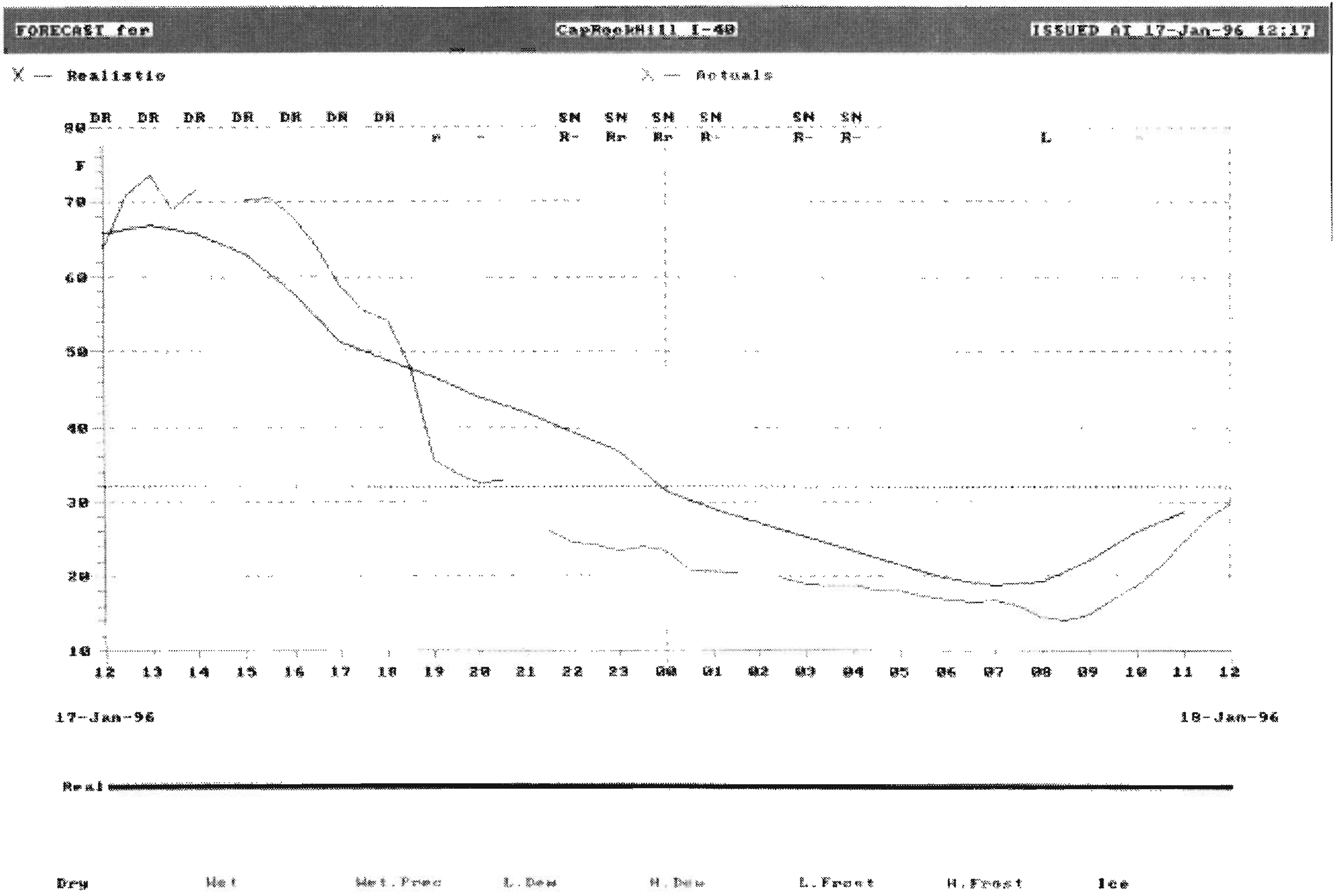
17-Jan-96
18-Jan-96


FORECAST for
CapRockHill I-40
ISSUED AT 17-Jan-96 12:17
Realistic
Actuals
DR DR DR DR DR DR DR
SN SN SN SN SN SN
R- Rr Rr R- R- R-
L
F
80
70
60
50
40
30
20
10
12 13 14 15 16 17 18 19 20 21 22 23 00 01 02 03 04 05 06 07 08 09 10 11 12
17-Jan-96
18-Jan-96
Real
Dry
Wet
Wet.Prec
L.Dew
H.Dew
L.Frost
H.Frost
Ice

APPENDIX D:

PICTURES FROM FIELD TRIPS

Figure D.1 ROS solar-powered RPU at Turtle Creek site in Kerr County

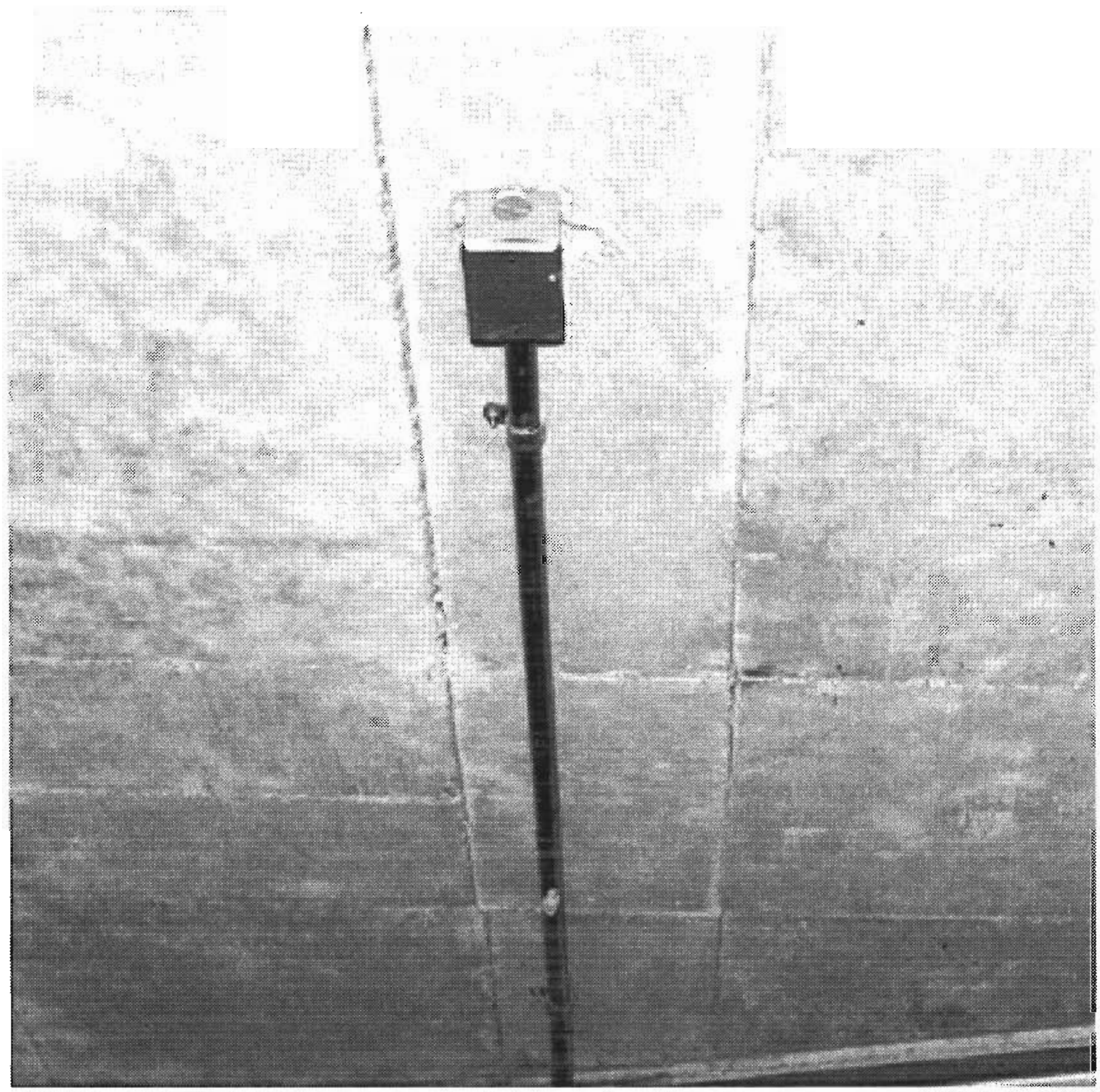


Figure D.2 Vaisala pavement sensor and conduit underneath bridge in Amarillo

Figure D.3 A-TEK water-level sensor on Spicewood Springs Road in Austin

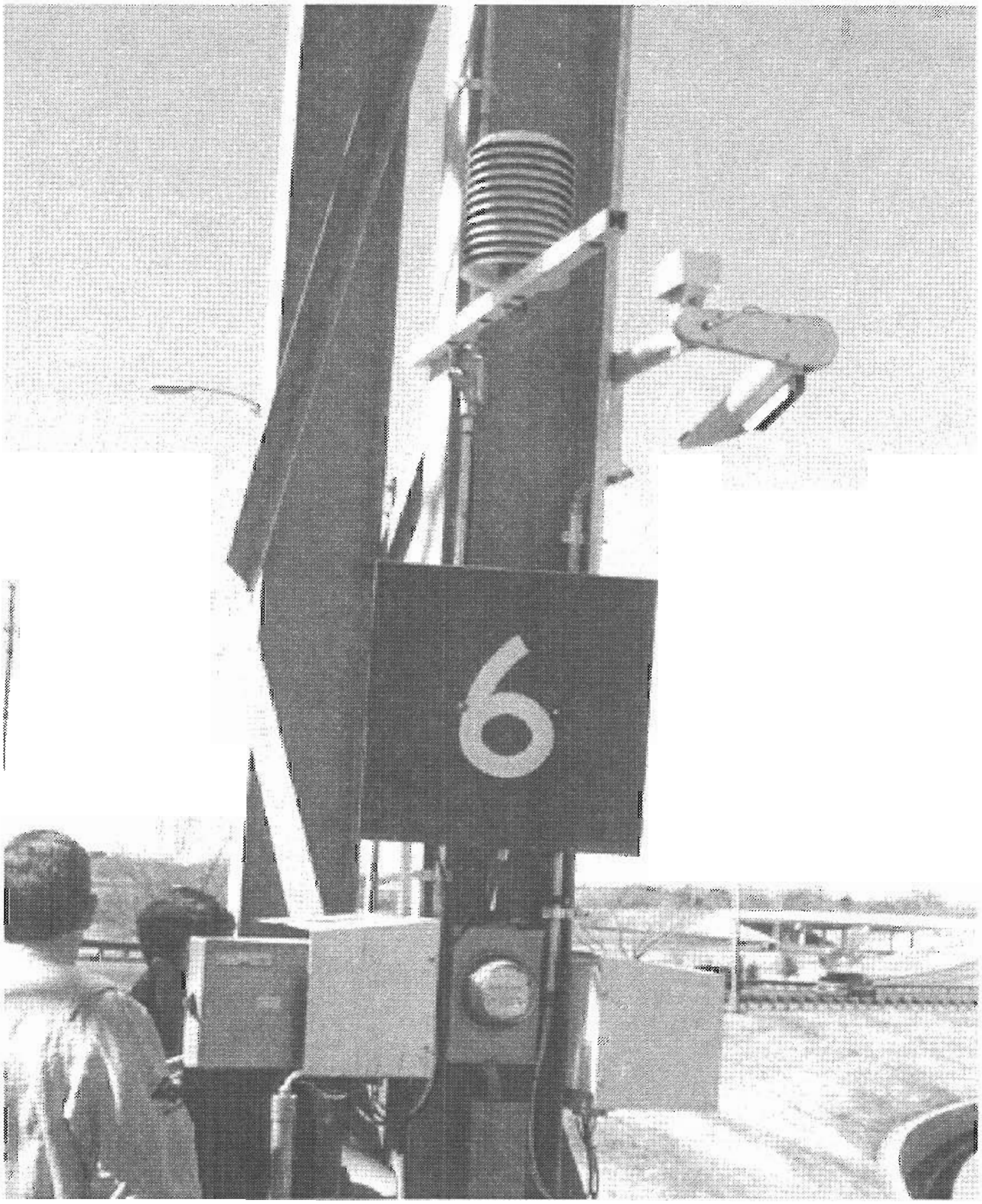


Figure D.4 Vaisala RPU in Amarillo

Figure D.5 A-TEK changeable message sign on Spicewood Springs in Austin

Figure D.6 ROS water-level sensor at Turtle Creek site in Kerr County