Road Weather Information System Environmental Sensor Station Siting Guidelines, Version 2.0

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16. Abstract
FHWA initiated an effort in 2007 to evaluate and update, as necessary the ESS Guidelines first published in 2004 (FHWA-HOP-05-026). This effort is summarized in a companion report "Implementation and Evaluation of RWIS ESS Siting Guidelines". The consensus of the project was that the original Guidelines covered most of the major issues in the siting of ESS and provided the necessary information in a concise manner. The major change made to this version of the Guidelines involved an update to the metadata table that was included in the original report. Since the original Guidelines were developed a major effort was conducted as part of the Clarus project to define a standard set of metadata for ESS. An expanded metadata table was thus included in the Guidelines showing Clarus metadata in three categories; required, recommended and optional. Other than the modification to the metadata table, most of the additions were limited, and designed to highlight areas of concern noted by DOT's with ESS experience. The feedback from most of the DOT's interviewed was positive and they expressed an interest in using the document for future deployments. Several noted that they would require their contractors to use it.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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Executive Summary

An effort was initiated in 2007 to update the “Road Weather Information System Environmental Sensor Station Siting Guide,” originally published by FHWA in 2004 (FHWA-HOP-05-026). The results of this work are documented in the report “Implementation and Evaluation of RWIS ESS Siting Guide,” produced for FHWA by Mixon-Hill and Cambridge Systematics, and issued in July 2008. A stakeholder process was conducted in order to document experience with implementation of the ESS Siting Guidelines. An initial phone outreach was conducted to nine DOTs. Most of these agencies have extensive RWIS, although most of the systems were implemented prior to issuance of the Guidelines. Three states; Michigan, New Hampshire and Idaho, were selected for site visits and in-depth interviews. The suggested revisions to the Guidelines are based on input from both phases of the stakeholder process.

Those familiar with the Guidelines generally provided positive feedback. The consensus was that the Guidelines covered most of the major issues in the siting of ESS and provided the necessary information in a concise manner. Knowing that there would be a number of recommended additions to the Guide, one important objective identified early in the process was to maintain the Guidelines as a concise and accessible document that stayed focused on the deployment of ESS. Suggested modifications and their disposition is discussed briefly below:

Accepted modifications

- Recommendations were made to cover some additional areas of interest related to ESS deployment including archaeological constraints, soil conditions, and clear zones. One respondent noted that a site had been impacted due to archaeological considerations. References were added in the report in Section 5.4 to alert users that environmental and archaeological review of sites should be conducted to identify any potential impediments to implementation. This section also noted that siting must be subject to safety clear zones.

- The report was revised to note the influence of soil mechanics on ESS siting and recommended the use of the EPA “National Pollutant Discharge Elimination System (NPDES) Stormwater Guide” to evaluate issues related to stormwater runoff. This reference was added in two sections of the report.

- A number of respondents asked that more examples be provided of the tradeoffs required in siting ESS. Two good examples of siting tradeoffs were noted by New Hampshire DOT and included in their report. Both cases illustrated the tradeoffs that must often be considered between infrastructure availability, right-of-way and metrological concerns.

- Several additions were made to the Guidelines to emphasize the importance of ongoing maintenance. Site access and accessibility to major components of the ESS should be considered in order to reduce maintenance costs over the long term.

- Major changes were made to the metadata table that was included in the original report. Since the original Guidelines were developed a major effort was conducted as part of the Clarus project to define an standard set of metadata for ESS. An expanded metadata table was thus included in the Guidelines showing Clarus metadata in three categories; required, recommended and optional. The metadata requirements defined for Clarus were quite extensive and may not be realistic for all ESS installations. Some items in the recommended and optional categories were highlighted as not being critical for most DOT requirements.

Summary

Overall a very limited number of changes were recommended for the guidelines document. Other than the modification to the metadata table, most of the additions were limited, and designed to highlight areas of concern noted by DOT's with ESS experience. It is the case that many agencies are deploying other ITS technologies with ESS; however it was felt that this could greatly expand the document and result in a loss of focus on ESS technology. The feedback from most of the DOT's interviewed was positive and they expressed an interest in using the document for future deployments. Several noted that they would require their contractors to use it as part of their design efforts, as the Michigan DOT is currently doing.

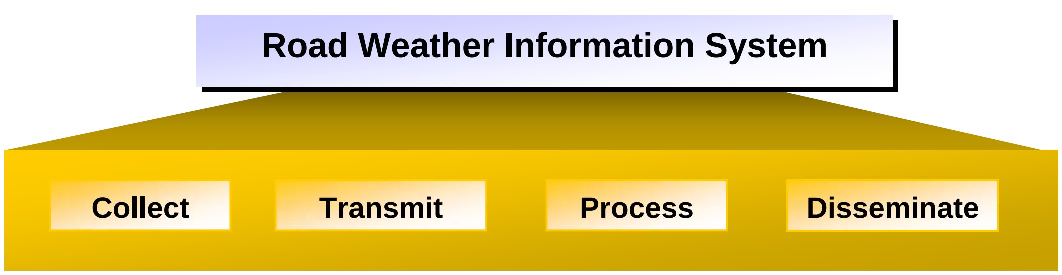
FHWA currently tracks ESS deployment throughout the U.S. on a regular basis. This effort should be expanded to obtain information on whether the Guidelines are being used. Agencies that are using them could be asked for feedback on their effectiveness. This will enable FHWA to obtain continuous feedback and based on that feedback, determine when any future revisions are needed.

1.0 Introduction

■ 1.1 Scope

This document provides guidelines for siting a Road Weather Information System (RWIS) Environmental Sensor Station (ESS) and its associated environmental sensors. The term RWIS has a number of diverse definitions ranging from sensing and processing devices in the field to a composite of all weather and pavement information resources available to highway operations and maintenance personnel. In this document RWIS connotes the hardware, software programs, and communications interfaces necessary to collect and transfer field observations to a display device at the user's location. While the original purpose of the RWIS was to address winter weather conditions, applications have been developed to detect and monitor a variety of road weather conditions impacting road operations and maintenance. As Figure 1 illustrates, the RWIS collects, transmits, processes, and disseminates weather and road condition information. The RWIS may consist of several meteorological and pavement condition monitoring stations strategically located near a highway that help transportation managers make more informed operational decisions. Specialized equipment and computer programs monitor weather and pavement condition elements that help users observe how adverse weather is currently affecting the highways and assess future impacts. For example, winter road maintenance managers may benefit from such a system during winter storms by making optimal use of materials and staff, selecting appropriate treatment strategies, utilizing anti-icing techniques, and properly timing maintenance activities. Traffic managers may use road weather observations to modify traffic signal timing, reduce speed limits, and close hazardous roads and bridges.

Figure 1. Road Weather Information System (RWIS) Functions



This document focuses primarily on the ESS, the "collection" component of the RWIS shown in Figure 1. These guidelines are intended to help establish uniformity in siting

ESSs and to improve the usefulness of road weather information derived from ESS observations. Future revisions to this document may be necessary as environmental sensor technology evolves and research on the characteristics of the roadway environment is completed.

The document is designed to provide siting criteria that satisfy as many road weather monitoring, detection, and prediction requirements as possible. The criteria are based on an analysis of published documents on the siting of weather and pavement sensors, and the results of interviews conducted with nearly two dozen road weather experts representing state Departments of Transportation (DOT), equipment suppliers, and consultants. The individuals interviewed are acknowledged in Section 7 of this document. Roadway and transportation professionals, transportation agencies, researchers, ESS vendors, and meteorologists supporting the transportation community will be able to use these guidelines to aid in siting ESS equipment. ***The guidelines contained in this document do not represent standards for agencies or vendors to follow, but instead offer a set of recommendations.*** A set of RFP's and specifications used by various State DOTs for ESS procurement and maintenance are included on the Aurora program website(http://www.aurora-program.org/matrix.cfm/matrix/survey/matrix/survey/ matrix/survey/installation.pdf).

It should be noted that FHWA does not endorse or recommend any of the approaches taken in these RFP's but they do provide a useful resources for agencies wishing to procure these services.

Section 1 of this document serves as an introduction, providing the scope and purpose and defining the concept of the ESS as it applies to the guidelines that follow. This section also highlights some of the key benefits of employing RWIS ESSs as part of an Intelligent Transportation System (ITS). Section 2 establishes the ground work for deploying an ESS by helping the DOT planning team assess road weather information requirements. To help decide what sensors to deploy as part of the ESS, Section 2, supplemented by Appendix C, provides an overview of the road weather information elements that may be of interest to road operations and maintenance personnel and how these elements can be measured or detected. Additionally, Section 2 differentiates between regional and local ESS sites and discusses the siting criteria of each. Section 2 also encourages the formation of partnerships to share weather observing and road weather resources. These partnerships offer an opportunity to reduce the number of required ESSs and the cost of gathering road weather information. Section 3 builds on the previous section to recommend guidelines for selecting the ESS site and suggests tools to help make siting decisions. Section 4 provides recommendations for siting the ESS tower and individual sensors. Section 5 addresses some additional considerations to include power, communications, safety, security, and ESS metadata. Appendix A contains Acronyms and Definitions while Appendix B contains a list of References in the document. For easy reference, a checklist based on the recommendations in this document is included in Appendix D.

1.2 Purpose

This document provides a set of guidelines to encourage uniform siting criteria designed to help improve the accuracy and usefulness of road weather observation data. There are several compelling reasons for uniform siting guidelines:

- Provide agencies intending to procure additional RWIS equipment with the appropriate information to select and install ESS equipment and instrumentation in order to maximize the return on investment for both its internal user group and external users.
- Help ensure that the investment in RWIS equipment is not compromised by collection of data that does not adequately support the specified purpose of the observing site.
- Foster a better understanding of the effects of the environment on the acquisition of road and weather data, so procuring agencies can better determine whether potential sites are appropriate locations and will remain so for a number of years.
- Improve the comparison and integration of road weather information with other meteorological data. This integration can significantly expand the coverage of useful information for both roadway applications and other weather data uses. Sharing data will enhance both the road weather and general weather observation networks.

While there are many previously established guidelines for siting weather observing equipment,[1,2,3,4] there is limited published siting information[5,6] specifically for the roadway environment. The guidelines in this document are designed to fill that gap and to improve the usefulness of road weather information specifically for the surface transportation community.

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[1] World Meteorological Organization: *Guide to Meteorological Instruments and Methods of Observation*, Sixth Edition, WMO-No. 8, 1996.

[2] Office of the Federal Coordinator for Meteorology - Services and Supporting Research. *Federal Standard for Siting Meteorological Sensors at Airports*. FCM-S4-1994 August 1994.

[3] US Environmental Protection Agency. Meteorological Monitoring Guidance for Regulatory Modelling Applications. EPA-454/R-99-005 February 2000.

[4] US Department of Interior, National Wildfire Coordinating Group. *National Fire Danger Rating System Weather Station Standards*. March 2003.

[5] Boselly, S.E., J.E. Thornes, and C. Ulburg. *Road Weather Information Systems Volume 1, Research Report*. Strategic Highway Research Program Publication - SHRP-H-350, National Research Council, Washington D.C., 1993.

[6] Boselly, S.E., and D.D. Ernst. *Road Weather Information Systems Volume 2, Implementation Guide*. Strategic Highway Research Program Publication - SHRP-H-351, National Research Council, Washington D.C., 1993.

1.3 How to Use this Guide

This Guide and the guidelines contained in it may be useful throughout the life cycle of an ESS. In practice, transportation agencies have used the Guide in two primary modes: as a general reference for ESS information within or in parallel with their own guidelines, and more specifically as a basis for the planning and deployment of ESSs. An ESS is an ITS component recognized within the National ITS Architecture and regional architectures. The systems engineering processes used to plan, develop and deploy ITSs applies to ESSs as well. In that context, the major sections of this Guide align well with the major phases of an ITS deployment.

- Section 1, "Introduction," provides the basic elements of a Concept of Operations.
- Section 2, "Assessing Road Weather Informational Requirements," describes the major classes of requirements to be considered in a Requirements Specification.
- Section 3, "Site Selection," provides a basis for design considerations that might appear in a System Architecture or System Design Description.
- Section 4, "Recommended Siting Criteria," provides a more detailed basis for ESS tower and sensor design needed in a Design Description and associated plan sheets.
- Section 5, "Other Considerations," covers topics related to the power, communication, information, and operational interfaces to the ESS. Aspects of these interfaces may be important throughout the ESS life cycle.

1.4 ESS Description

An ESS consists of one or more sensors measuring atmospheric, pavement, soil, and/or water level conditions. ESSs can be installed *in situ* within or along a roadway, or on a vehicle. This document only addresses stationary, *in situ* sensors.

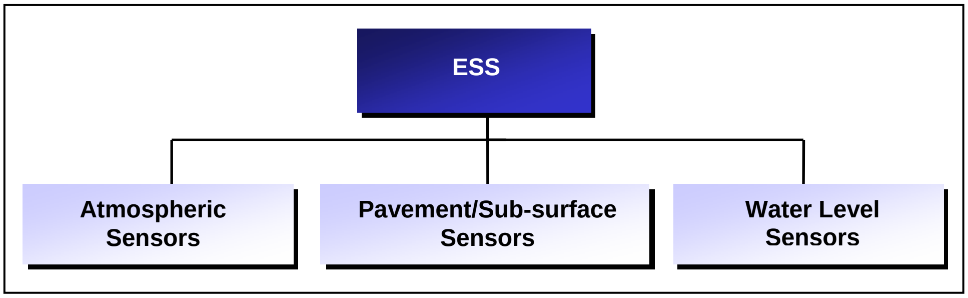
Figure 2. Road Weather Information System (RWIS) Environmental Sensor Station (ESS)

Source: Florida DOT.

Figure 2 is an example of an ESS with multiple sensors located on Route 528, the Beeline Expressway, near Cape Canaveral, Florida.

Figure 3 shows the ESS sensor categories that provide information to identify roadway weather conditions of interest. ESS data are collected in a remote processing unit (RPU) and transmitted to a central processor. Resulting road weather information is used to activate automated warning systems and provide decision support to managers in traffic management centers, road maintenance facilities, and emergency operations centers. By monitoring road conditions using pavement sensors or video, operations and maintenance personnel are able to assess how well their traffic management or winter maintenance strategies are performing, or to determine what additional actions are required. Conditions of interest include pavement condition (e.g., wet, snowy, icy, flooded, plowed), pavement chemical concentration or pavement freeze-point temperature, pavement temperature, soil (sub-surface) temperature, air temperature, wind speed and direction, precipitation (e.g., amount, occurrence, type), humidity, atmospheric pressure, radiation (solar and terrestrial), and visibility. Atmospheric sensors are located above the roadway level and can be used to identify conditions such as strong cross winds or in combination with pavement/subpavement sensors to identify conditions such as icy roads. Some ESSs include water level sensors that are deployed in flood prone areas and on coastal roadways. While not commonly included as part of an RWIS ESS, auxiliary sensors, such as lake webcams and riverbed scouring sensors, can provide opportunities to add sensors that can help monitor and detect events resulting from water-related conditions.

Figure 3. Environmental Sensor Station (ESS) Categories



1.5 Additional Benefits

ESS data provide many benefits, in addition to improving road safety, mobility, and productivity, by supplying information on roadway conditions essential for traffic operations, traveler information, road maintenance, and emergency response. Figure 4 identifies several additional operational applications[7]. Benefits derived from these applications include:

- Weather service providers for surface transportation customers use ESS data to develop tailored road weather products (e.g., pavement temperature forecasts).
- Government and university mesonets can include these data to support the development of weather and road weather forecast models.
- National Weather Service (NWS), military, and private weather service providers use these data to develop weather products, short-range forecasts, and forecast verification, and as input to locally run weather forecast models.
- State climatologists can use ESS data for long-term records and climatological analyses.
- Insurance companies can use these data to help determine risks of potential impacts from future weather events.
- Local, state, or Federal disaster assessment and response agencies (e.g., Federal Emergency Management Agency and the Department of Homeland Security) may use these data to manage emergencies and related response actions.

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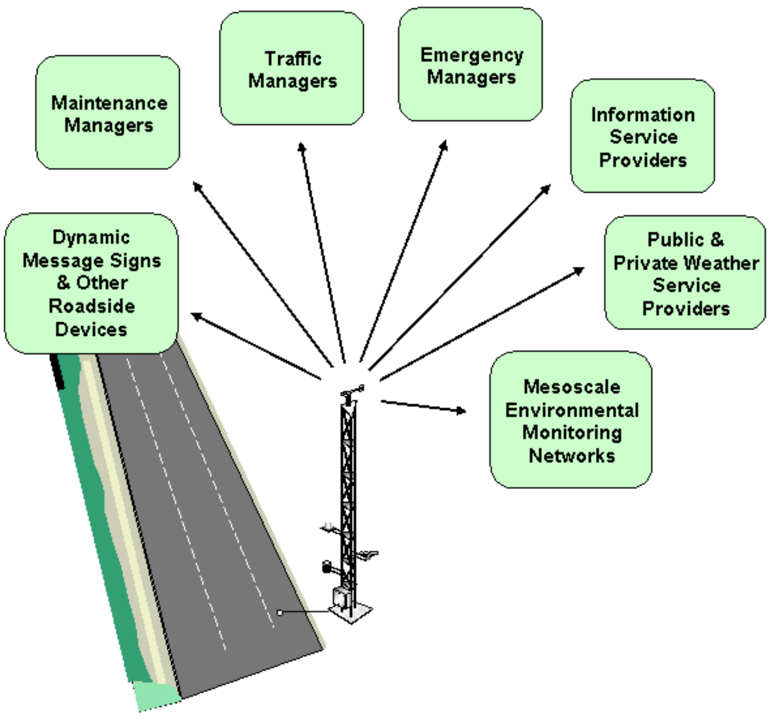
[7] Goodwin, L., *Best Practices for Road Weather Management*, Version 2.0, prepared by Mitretek Systems for the FHWA Road Weather Management Program, May 2003.

- Forensic meteorologists can use ESS data to better understand and reconstruct roadway crashes.

- RWIS ESS data can also be leveraged to support rail, pipeline, and marine operations when such operations are adjacent to or reasonably near the ESS.

Figure 4. Environmental Sensor Station (ESS) Operational Applications



To maximize these benefits, an attempt should be made during the planning process for siting RWIS ESSs to contact other organizations involved in similar data collection that may help both local transportation agencies and other customers (e.g., NWS; Federal Aviation Administration (FAA); U.S. Forest Service (USFS); local TV stations; universities and high schools; and, other city, county, and state agencies). Section 2.3 discusses the potential for establishing information partnerships and/or leveraging the data collected by other organizations. The Siting Checklist in Appendix D provides a reminder to the siting team to consider information partnerships during the siting process.

■ 1.6 Modifications in Version 2.0 of the ESS Siting Guidelines

FHWA sponsored a review of the ESS Guidelines that was conducted in 2007-2008. The project included interviews with a number of State DOT RWIS managers and more detailed reviews with three State DOTs in Idaho, Michigan and New Hampshire. All three states had either recently deployed new ESS or were in the process of doing so. The results of this review are documented in a separate report, "Implementation and Evaluation of RWIS ESS Siting Guide," prepared for FHWA by Cambridge Systematics and Mixon-Hill, November, 2008.

The report documents a number of issues related to ESS Siting and deployment, but the number of changes recommended for the Guide itself were limited. An important objective of FHWA is to keep the Guide a manageable length so it is used in practical by implementing agencies. The following specific changes have been made to the document:

- In Section 2.2, **Regional and Local Site Requirements,** language was added to discuss co-location of other traffic management technologies, such as Dynamic Message Signs with ESS.

- In Section 2.3, **Leveraging Information Partnerships,** language was added discussing the *Clarus* project, and how it provides an opportunity to leverage information from multiple RWIS.

- In Section 3.0, **Site Selection,** a specific example was added to illustrate the tradeoffs between metrological requirements and practical siting considerations such as availability of power and communications.

- In Section 4.1, **Observation Tower,** a reference was added to the U.S. Environmental Protection Agency's Stormwater Guide.

- In Section, 4.2, **Sensor Location,** a note is added that manufacturer's recommendations regarding installation and calibration should be followed.

- In Section 5.4, **Aesthetics, Maintenance, Safety and Security,** a note was added regarding maintenance of clear zones and discussion was added regarding the importance of maintainability. Discussion was also added regarding geotechnical issues and stormwater runoff.

- The most significant change in the document was made in Section 5.6, **Siting Metadata.** Metadata recommendations were modified based on work as part of the *Clarus* project. Because FHWA's goal is to have all State DOT ESS reporting to *Clarus* the metadata recommendations should be similar. However, since the *Clarus* recommendations are extensive, data are divided into Critical (Table 2) and Options (Table 3) categories. Cost considerations may limit the number of data elements that can be collected and reported.

2.0 Assessing Road Weather Information Requirements

Planning for the acquisition and installation of ESSs is best accomplished by a team of road and weather experts. In addition to the DOT team lead, this group should include a meteorologist familiar with road weather requirements and local DOT personnel. The meteorologist can fill the gap between the weather and transportation communities by helping to evaluate road weather information requirements and assess available ESS technologies. The meteorologist can play a key role during ESS site selection by evaluating specific sites for obstructions or weather influences that could compromise the validity of the ESS data. The meteorologist can also consider the broader application of ESS data that may benefit the transportation community and other users. For example, the meteorologist can consider how additional weather observations can be used by high resolution forecast models and can help develop a siting plan that will meet DOT requirements while helping to improve the accuracy of road-specific and general area weather predictions.

The planning team should also include local DOT personnel, especially maintenance personnel. These individuals typically possess a vast knowledge of weather conditions along the road segment they maintain. The maintenance personnel can provide critical input about recurring weather problems such as the locations of frequent slippery pavements, low visibilities, or strong gusty winds that suggest the need for an ESS installation. Additionally, local DOT personnel can often identify areas where an ESS sensor might be vulnerable to large snow drifts, flooding, or pooling water from spring thaws.

Planning the ESS network should include an analysis of the operational requirements for road weather information. This analysis will drive the environmental sensor requirements and lead to decisions regarding sensor selection and siting. Considerations include:

- How will the road weather information be used? For example, will the information be used to monitor roadway conditions as input to winter maintenance decisions or road temperature modeling, or to support weather-responsive traffic management, traveler information systems (e.g., 511 systems) or road construction efforts?

- Will the ESS be used to measure a site-specific condition or to provide information that may represent conditions across a general area? For example, installing a sensor to monitor the visibility along a fog-prone road segment may result in completely different siting decisions than if the requirement is to collect wind and temperature information for input to a road weather model.

- What needs to be measured at each installation? The information in Section 2.1 and Appendix C will help DOTs evaluate their data collection requirements and the sensors available to meet those needs. System designers should keep in mind that several different sensors may be needed in combination to satisfy observing requirements. For example, if a pavement sensor is to be included in an installation, the DOT may also want to install air temperature, humidity, and precipitation sensors to complement the pavement sensor data. The precipitation sensor can help identify whether pavement sensor readings are indicative of new or continuing precipitation, while the temperature and humidity sensors will indicate whether conditions support the formation of frost.

- DOTs may want to create a prioritized list of the road weather elements and sites they need to fulfill their requirements. Such an approach may help in making tradeoffs when data collection needs exceed available funding or when a phased approach to meeting statewide requirements is desired.

- DOTs should also consider other sources of weather and pavement data that may be available to meet road weather information requirements. Developing data-sharing partnerships with other agencies may help satisfy RWIS ESS installation requirements while improving the availability of data to all partners. Leveraging existing weather observing networks is discussed further in Section 2.3.

■ 2.1 Environmental Sensors

The RWIS ESS can consist of a relatively few number of sensors providing basic information such as wind speed and direction and air, pavement, and subsurface temperatures, or it can include the measurements of more complex weather elements such as visibility. Table 1 provides a list of the most common ESS sensors. The sensors chosen for a particular site should reflect the results of the requirements analysis, i.e., how the observations will be used and what the minimum required road weather information is at that specific location.

Table 1. ESS Sensors

Roadway Element	Sensor
Air Temperature	Thermometer
Water Vapor (Dewpoint or Relative Humidity)	Hygrometer
Wind Speed and Direction	Conventional and Sonic Anemometer and Wind Vane or combined sensor (Aerovane)
Pavement Temperature, Pavement Freeze Point Temperature, Pavement Condition, Pavement Chemical Concentration	Pavement Sensor
Subsurface Temperature	Subsurface Temperature Probe
Subsurface Moisture	Subsurface Moisture Probe
Precipitation Occurrence	Rain Gauge, Optical Present Weather Detector
Precipitation Type	Rain Gauge, Optical Present Weather Detector
Precipitation Intensity	Rain Gauge, Optical Present Weather Detector
Precipitation Accumulation	Rain Gauge, Optical Present Weather Detector, Hot-plate Type Precipitation Sensor
Snow Depth	Ultrasonic or Infrared Snow Depth Sensor
Visibility	Optical Visibility Sensor, Closed Circuit Television Camera
Atmospheric Pressure	Barometer
Solar Radiation	Solar Radiation Sensor
Terrestrial Radiation	Total Radiation Sensor
Water Level	Pressure Transducer, Ultrasonic Sensor, Float Gauge, or Conductance Sensor

While sensor selection should always reflect operational requirements, a typical ESS installation frequently includes the following:

- A combined sensor to measure both wind speed and direction (e.g., aerovane or sonic anemometer) or individual wind speed and direction sensors (e.g., conventional anemometer).
- Sensors to measure air temperature and moisture. Typically two sensors located in a single housing provide air temperature and one of the following: dewpoint temperature, wet bulb temperature, or relative humidity.
- Sensors to measure the temperature of the pavement and to indicate whether the surface is dry, wet, or frozen. Active sensors cool and warm surface liquids to determine the freeze point temperature. Passive sensors commonly monitor changes

in roadway surface conductivity as surface changes occur. When road treatment chemicals are in use, the surface conductivity can be an indication of the chemical concentration on the roadway. The presence and concentration of chemicals is important, as it will affect the actual freezing temperature of the road surface.[8] Optical sensors for pavement measurements are also under development.

- Sensors to detect the presence, type, and intensity of precipitation. A single, optical, present weather detector can detect the presence of precipitation and measure intensity. By estimating the water content of precipitation and combining this information with optical forward scatter and temperature measurements, these instruments can also identify precipitation type. Optical present weather sensors capable of differentiating among rain, freezing rain, drizzle, freezing drizzle, mixed rain and snow, snow, and ice pellets are available.

Based on roadway operations and maintenance needs, additional sensors can be added from those listed in Table 1 to provide a more capable ESS. For example, visibility sensors can be extremely useful along roadways prone to low visibility due to fog or manmade pollutants (e.g., smoke). Subsurface temperature and solar radiation sensors can provide information to support forecasts of pavement temperatures. Precipitation, snow depth, and video imagery from an ESS camera can provide the DOTs valuable information for managing traffic and planning road maintenance operations.

Appendix C includes a list of weather elements for DOT consideration during the analysis of road weather information requirements. Automated sensors are not yet available to observe all the weather elements in that list, and some sensors, while available, have inherent limitations that restrict their utility as part of an ESS. During the process of analyzing requirements and potential sensor suite solutions, the DOTs may want to consider these sensor limitations:

- Cameras may be an option for determining the presence of snow and/or drifts on a roadway. There are no reliable instruments to remotely measure many roadway conditions such as roadway snow pack depth or roadway snow or ice accumulation.

- Observations of thunderstorms, tornadoes, and waterspouts are difficult to automate using sensors deployed as part of an RWIS ESS.

- There are no automated sensors for observing sun glare.

- While cloud cover information can be of interest to road maintainers as input to road temperature models and to RWIS data users, automated sensors are limited in their ability to measure cloud cover as an individual standing on the ground sees it (the sensor typically only scans directly overhead while an individual can scan the entire celestial dome). These instruments also tend to require more maintenance than most

[8] Keep, Dale. *Roadway Weather Information Systems (RWIS)*, Ice and Snow Technologies, LLC, Report, 2004.

ESS sensors. For these reasons, cloud cover sensors are not normally installed with an ESS and are not included in the ESS sensor list shown previously in Table 1.

2.2 Regional and Local Site Requirements

An ESS installation can be characterized as either "regional" or "local." A regional ESS site would be one that represents the general weather conditions for a large area or road segment. A local site is one where the weather phenomenon of interest (e.g., icy pavements or tidal flooding) is for a specific short segment of roadway, topographic feature, or designated bridge structure. Differences in the siting requirements between regional and local sites result in different philosophies in the selection of the sensors and the siting criteria of the ESS. In general, regional sites include more types of sensors sited in an unobstructed location. Local sites may consist of a tailored suite of sensors (potentially only one or two) that are located close to the road segment or bridge where the targeted weather event is of interest.

A single ESS can satisfy both regional and local requirements for road weather information. For example, a site considered representative of regional road weather conditions may also include one or more sensors focused on conditions of interest within a short roadway or bridge segment. Similarly, road weather information requirements may dictate installing multiple sensors on a local ESS to monitor road conditions (e.g., including a pavement sensor near a visibility monitoring site). Siting a single ESS to satisfy both regional and local road weather information requirements or multiple local weather information requirements, requires considerable planning. An agency considering new or relocated ESS locations may need to make tradeoffs in sensor selection and siting or may need to install additional sensors or sites to satisfy all regional and local road weather information requirements.

Regional sites support broad, real-time monitoring of weather and road conditions across a geographic area. Equally important, these sites can also be used to provide data to improve the accuracy of surface transportation specific forecasts (e.g., pavement temperature forecasts). Installing regional sites across an area lacking sensors helps define the initial environmental conditions necessary to run road weather prediction models. These sites can also provide ground truth for comparing surface transportation specific forecasts with real-time observations to evaluate the accuracy of the forecasts. Additionally, locating a regional ESS in an isolated area where no other weather observations are available or in a location upstream of an area of interest can improve the ability to anticipate changes in the road weather environment in a specific area of interest.

Regional sites include many of the same characteristics as weather observing locations satisfying NWS or FAA weather information requirements. That is, they have a generally uniform suite of weather sensors sited to represent a regional area. A key difference between regional RWIS ESS and NWS or FAA weather observing locations is that the ESS sites may include roadway-specific sensors (e.g., pavement and subsurface sensors). ESS regional sites can successfully augment sites used for general weather applications, and the increased data density they offer can improve the accuracy of NWS analyses and storm forecasts.

The size of the area for which road weather observations from a regional ESS site can be considered representative is influenced by a number of factors including topography, climate, and the time and space scale of the weather event under observation. There are no studies that define the optimal separation between regional ESSs to monitor road weather events and to support weather models. Some weather forecasting models include a grid spacing as low as 2.5 miles (4 kilometers (km)). While installing regional ESSs with a 2.5 miles (4 km) separation may be desirable to contribute to more accurate weather forecasts, doing so may be cost prohibitive. A spacing of approximately 20-30 miles (30-50 km) along a road is recommended as a guide.

Local sites are usually located close to the point of interest on the roadway or bridge deck. A point of interest is typically the result of topographic variations, road construction techniques, pavement types, or roadway geometry, e.g., at an intersection that has some sort of managed traffic control such as a traffic signal. Local sites can also provide predictors for conditions at the site. However, the point of interest may also be subsurface characteristics that influence or are influenced by specific weather situations (e.g., high humidity, low solar heating, residual surface moisture, and high water conditions). Because local ESSs are installed to measure specific events of interest to transportation operations and road maintenance personnel, the resulting observations may be pessimistic as compared to observations representative of a larger area.

By definition, a local site is one where the weather conditions of interest are for a specific short segment of roadway, a topographic feature, or designated bridge structure. An ESS in this context might be deployed, for example, in conjunction with a bridge anti-icing system. However, certain general road and bridge deck sites may be considered representative sites for other similar segments or structures within the same general weather area. For example, a pavement temperature sensor on a bridge deck can be considered representative of conditions on other bridge decks over the same body of water or topographic feature, or of other bridges or ramps in the area.

The need for a local site may also be an indication of an opportunity to leverage investment of related ITS components to fulfill the underlying operational need. If an ESS is being sited to monitor a segment of roadway prone to icing or blowing snow, for example, it may be beneficial to co-locate a dynamic message sign (DMS) for providing information to travelers along that segment. The dual siting provides enhanced safety benefits while reducing deployment costs over an alternative wherein the ESS and the DMS were to be independently deployed.

The characteristics of a local ESS site are analogous to specialized weather observing sites supporting other industries, such as agriculture. These specialized sites contain sensors primarily designed to monitor specific elements or situations. For example, some agricultural weather sites only include wind sensors at low heights, such as 6.5 feet (2 meters) above ground level, an array of subsurface sensors, and a solar radiation sensor.

2.3 Leveraging Information Partnerships

An important consideration during planning of a new RWIS ESS is the opportunity to partner with other agencies and share resources. These resources may be other sensor systems belonging to organizations such as the NWS, FAA, USFS, Water Resource Weather Station Networks, and universities. DOTs may want to contact these organizations to determine the availability of real-time weather observations and to assess whether those observations will meet some road weather requirements. While it is unlikely these sources of other weather information will satisfy many road weather information requirements, DOTs may be able to leverage existing observing capabilities to obtain some weather information to supplement weather data collected from the RWIS network. In some situations, partnerships may avoid the costly duplication of sensors that may already exist in the area. The sharing of data with other agencies can be complicated by different data formats, different weather observing frequency requirements, and communications incompatibilities. Still, it is advisable to develop relationships with other agencies to identify areas of mutual interest for future cooperation. Sharing data can leverage assets between organizations and enhance the overall reporting network supporting all users. A key resource in this regard is the NWS, starting at the appropriate regional office.

The *Clarus* Initiative is an example of the tremendous opportunities for making ESS observations available across larger regions and jurisdictional boundaries. Observations fed to *Clarus* from DOT ESSs are quality checked and disseminated throughout the transportation and meteorological communities for developing value-added products and services. The DOTs providing their observations to *Clarus* then have access to the quality checks performed on their environmental data, to similar data from other jurisdictions, and to the value-added products.

Beyond the benefits of information sharing, other organizations may be able to provide existing towers, power, and communications to support the installation of an ESS. For example, the NWS partnered with the National Ocean Service (NOS) to increase the availability of weather data along U.S. coastlines and bays. The NWS installed their atmospheric sensors on NOS tide gauge platforms already equipped with power and communications. This partnership saved the NWS significant funds that would have otherwise been required to install NWS observing platforms.

3.0 Site Selection

Correctly selecting an ESS site is very important to the overall effectiveness of the sensor suite and the representativeness of its observations. An ESS installed at a poorly chosen location can result in unrepresentative sensor readings, servicing difficulties, and even damage to the ESS from natural runoff and ponding in low lying areas and from road maintenance activities such as snow removal. The site selection objective is to locate the ESS where its observations will be most representative of the area or roadway segment of interest. Meeting this objective requires the DOT planning team to minimize non-weather influences such as those that may result from nearby buildings, billboards, tall vegetation, elevated portions of the highway, bridges, or topography. DOTs making ESS siting decisions should consider the seasonal characteristics of the sites. Site conditions can change significantly from summer to winter when sun angles are low and trees loose their foliage. Unfortunately, the ideal ESS site will rarely be found. The very nature of the roadway environment: narrow rights-of-way, the surrounding terrain, and even the traffic itself can impact the effectiveness of the ESS. Site selections are further complicated by the need to meet ESS power and communications requirements. Consequently, DOT planners will most often be in the position of making tradeoffs when selecting the ESS site and even when making decisions on individual sensor placement. An ESS sited near a maintenance yard, for example, may reduce the costs of providing power and communications to the site, but provide observations that are not typical of the roadways. At the other extreme, an ESS sited in the median of a divided highway because of right-of-way concerns may suffer air turbulence and spray from passing vehicles, again providing atypical observations. The ESS siting guidelines can serve as an effective tool when making these difficult decisions.

■ 3.1 Regional Site Guidelines

Regional sites are designed to provide road weather observations considered to be representative of the conditions along a given road segment. The observations from the regional ESS can support monitoring road conditions throughout the highway system and running road weather forecast models, such as those used in highway maintenance decision support systems. The regional site can also provide additional data for incorporation into more general weather forecast models such as those employed by the NWS. To ensure the regional ESSs provide data representative of the area, they should be located along uniform roadway conditions selected to minimize local weather effects and the influences from outside non-meteorological forces such as local heat and moisture sources and wind obstructions. A regional ESS should be sited on relatively flat, open terrain. To reduce the effects of traffic and road maintenance activities, regional ESS sites should be sought on the upwind side of the road based on predominant wind directions, e.g., on the north side of the road if winter conditions are the primary focus and the prevailing wind is northerly. Deviations from the siting criteria in Section 4.0 should be minimized to reduce the possibility of selecting sites impacted by local effects.

■ 3.2 Local Site Guidelines

Local sites are those that require siting of sensors in areas that are specifically designed to satisfy a road weather information requirement along a short segment of roadway or a bridge. Examples of these requirements include: 1) road surface conditions such as historically cold spots that create slippery conditions or a location where significant blowing, drifting, or heavy snow accumulation occurs, 2) surface flooding on low lying road segments, 3) visibility distance where the local environmental conditions contribute to low visibility (e.g., a large local moisture source), or 4) high winds such as those occurring in hurricanes and terrain-induced crosswinds along a confined valley or ridge top. These local requirements may require the use of additional sensors or the siting of sensors in a location that is specifically selected to detect and/or predict a local roadway condition or weather phenomenon. At local sites, the primary consideration is detecting the road weather condition of specific interest to transportation operations and maintenance activities.

In many cases, local weather conditions or weather-induced road conditions may require a different assortment of measurements and sensors on an ESS. Some examples of these local conditions include roadway segments abnormally susceptible to ice, frost, snow, low visibility, dangerous crosswinds, and roadway flooding conditions. Other phenomena, like mudslides or rockslides, can affect roadways, but these are not covered here due to the lack of adequate sensors that can be used in the roadway environment to detect such events.

3.2.1 Slippery Pavement Conditions

These conditions usually occur in historically cold locations prone to standing water or the development of ice, frost, slush, or snow due to local weather or geographic conditions, e.g., a low spot on the road, elevated roadway or bridge, a predominantly shaded area, or locations susceptible to snowfall, blowing/drifting snow, refreeze, or frost. In these cases, the purposes of the sensors are to detect or monitor the roadway temperature and pavement conditions.

Pavement sensors that monitor roadway or bridge deck temperature, surface condition, or chemical concentration and freeze-point temperature should be installed in locations that experience icing conditions. This may result in the surface sensors being placed in more specialized locations such as multiple traffic lanes, areas subject to blowing snow, or elevated roadways. The addition of dewpoint/frost-point and/or relative humidity sensors will help monitor conditions that may lead to the development of road frost. In areas where road frost is a problem, mounting a dewpoint sensor close to the pavement height should be considered.

3.2.2 Low Visibility Conditions

These conditions usually occur in locations where local moisture, smoke, or dust sources exist or in valleys or road depressions that trap cool moist air. In these cases, the purpose of the sensors is to detect a reduction in visibility or an increase in moisture in the atmosphere, and the speed and direction of the wind. Moisture and particulate matter can be man-made, such as from a power station, waste treatment plant, mining area, plowed field, or vehicle traffic, or can occur naturally from a river or swamp, a sandy or dusty area, or blowing/drifting snow. For locations with frequent low-visibility conditions, DOTs may want to consider providing traffic safety warnings via dynamic message signs.

Visibility, temperature, humidity, and wind sensors should be installed adjacent to the roadway or in areas influenced by local sources of moisture (liquid or solid) or dust, such as on or near bridges or in confined roadway cut areas. The visibility sensors should also be installed such that they represent the atmosphere 6.5 to 10 feet (2 to 3 meters) above the roadway. Siting visibility sensors closer to the roadway may degrade their performance due to the influence of salt spray from snow and ice control practices, or passing vehicles, and they may require more frequent maintenance. A thorough analysis of the particular location characteristics (e.g., source locations, obstructions, etc.) will help find an acceptable siting location.

3.2.3 High Wind Conditions

High winds and strong gusts frequently occur on bridges, confined valleys where channeling occurs, open fields unprotected by trees or structures, or on ridge tops. In these cases, the purpose of the sensors is to monitor and detect the onset and duration of high winds and wind gusts at the height most likely to affect the stability and handling of moving vehicles.

For these conditions, additional wind sensors can be placed where they represent the winds likely to affect motor vehicles. This can be on bridges, open areas with long wind fetches, and rapid wind shear areas (e.g., exit from within road cuts, tree stands, and large structures). For dangerous crosswind conditions, wind measurements normally taken at 33 feet (10 meters) can be supplemented by an additional wind sensor installed at a height of 10 – 16.5 feet (3 – 5 meters) so it will measure winds most likely to affect high-profile vehicles. Care should be taken to avoid siting the wind sensors too close to moving traffic or in wind shadows (i.e., the downwind side of bridges, signs, foliage, or buildings). In cases where wind channeling is caused by valleys or canyons, consideration should be given to installing sensors at the entry and/or exit areas of these features where wind shear can be experienced.

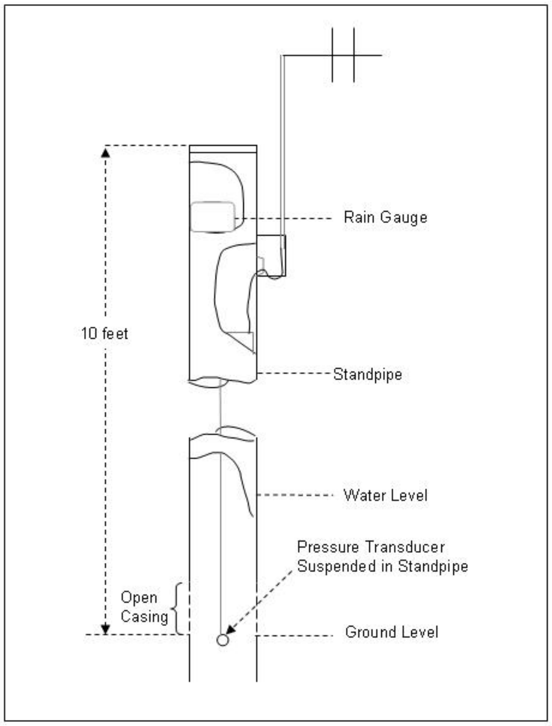
3.2.4 Water Level Conditions

Flooding can occur on bridges, in underpasses, or in other low lying road segments adjacent to permanent or intermittent water bodies. Such conditions may occur during or after heavy precipitation, thawing, tidal, river ice jam, persistent counter-flow winds, or storm surge events. During these events, the sensors monitor water level conditions and detect flooding. These data can support emergency response activities and can result in the closing of roads to prevent loss of property or life.

Sensors including pressure transducers, ultrasonic sensors, and float gauges installed in standpipes can be used to measure the water levels and monitor flooding conditions. The standpipe, as illustrated in Figure 5, is normally a 10-12 foot rugged pipe with a diameter of 12 inches. The sensors and associated electronics are packaged within the pipe. Some vendors offer these sensors with a rain gauge mounted near the top of the pipe. The float gauge can be installed in normally dry areas where runoff and precipitation accumulate. The pressure transducer can be used to monitor water levels in standing bodies of water such as lakes and reservoirs. The ultrasonic sensor monitors water levels in fast moving streams and rivers. If installed on the side of a bridge to measure potential flooding, the sensors should be sited on the downstream side in a location with low water turbulence. Water level sensors can also be installed adjacent to the low point of the roadway or next to any road segment subject to flooding.

While not yet widely used as part of an ESS sensor suite, solid state water sensors that detect the presence of conductive solutions can warn of rising water levels. The sensor's electrodes are positioned at a desired water level detection height. When water reaches the electrodes, a warning signal can be sent to an ESS RPU.

Figure 5. Typical Standpipe Configuration



3.2.5 River Bed Scouring Conditions

Scouring of river beds adjacent to a roadway bridge pier or abutment foundation can result in the undermining of the foundations and their eventual failure. Scouring can occur at any time but usually occurs during flooding conditions. The state bridge engineer can be consulted to determine if there are scour susceptible stream beds on the road segment under consideration for an ESS installation. Sensors used to measure scouring can provide warnings of danger to the integrity of the bridge foundation. A liquid-filled load cell buried in the river sediment weighs the sediment, water, and air above it, and an accompanying pressure sensor provides the weight of the water and air. The difference in the weights indicates the weight of the sediment and can be monitored for scouring. Additional optical, conductive, radiometric, and acoustic scouring sensors are under development. Scouring sensors are buried in the sediment adjacent to a bridge pier or foundation. Scouring sensors are not normally included as part of an ESS but are presented here for DOT consideration.

■ 3.3 Siting Tools

Local road maintenance personnel can provide valuable insight into weather-related safety and mobility concerns along the roadway they maintain. In addition to tapping their experience, the site selection team can employ several tools to help identify locations suitable for an ESS installation.

3.3.1 Thermal Mapping

Thermal mapping can be a useful tool in planning the installation of an RWIS ESS network and in selecting ESS sites. Road thermal analysis, or thermal mapping, is the use of vehicle-mounted, downward-pointed infrared radiometers to survey a selected road segment to map the position of warm and cold spots along the roadway. This analysis can 1) better define the thermal characteristics of road segments (e.g., cold spots) and aid in the selection of locations to site roadway sensors for monitoring and forecasting surface icing conditions and 2) help identify locations that are representative of other locations, thereby possibly reducing the number of ESS installations required. The thermal mapping data are usually collected in the early morning, before sunrise, when surface temperatures are the coldest. Data are usually collected under clear sky, cloudy sky, and wet pavement conditions, as roadway temperature patterns differ under each condition.

An analysis of the data (similar to the work accomplished by the Nevada DOT[9] and research conducted by Lee Chapman, John Thornes, and Andrew Bradley[10] and Jorgen Borgen et al[11]) determines where along the stretch of roadway the pavement temperature will be the minimum under the different weather and road conditions. This analysis can be one method for determining points of interest for frost and icy pavement formation and for ESS site determination and roadway characterization. Thermal mapping can help optimize the number of ESSs to be installed. Fewer ESS installations may be needed if the roadway thermal profiles and properties are better known. In cases where it reduces the number of ESS installations, thermal mapping can pay for itself.

3.3.2 Portable Environmental Sensor Systems

While offering limited utility, portable sensor systems can be used to survey potential permanent ESS sites. These portable systems can include a uniform suite of sensors or

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[9] Vaisala, Inc. State of Nevada DOT Thermal Mapping Final Report 2000, 2000.

[10] Chapman, Lee, et al. *Statistical Modelling of Road Surface Temperature from a Geographical Parameter Database.* University of Birmingham, Climate & Atmospheric Research Group website.

[11] Borgen, Jorgen, et al. *The Impact of Screening on Road Surface Temperature*. Meteorological Applications, Vol. 7 pp.97-104. 2000.

may only contain a couple of sensors if the road weather requirement is very specific. Normally portable ESSs do not include road sensors that must be implanted in or below pavements. Portable systems can be used to detect locations of concern or to monitor construction sites and projects. Mobile observing platforms (e.g., vehicles, trailers) can be used in much the same way to assist in locating specific points of interest for future ESSs.

4.0 Recommended Siting Criteria

The following siting criteria can be used to help select an optimal observation site. Criteria are subdivided into siting the observation tower and placing sensors on or adjacent to the tower. These recommendations strike a balance between established atmospheric sensor siting criteria such as those documented in World Meteorological Organization (WMO)[12] and NWS[13] standards and road-specific weather information requirements. The exact suite of sensors installed at a particular site will depend on the road weather information requirements. Mounting the sensors on a tower will require careful planning so the sensors do not interfere with each other. The availability of rights-of-way to install the site should be verified. Surroundings should be assessed for potential obstructions to selected sensors and potential sensor contaminants (e.g., water and dust sources) should be identified. Complete documentation of the tower and sensor location and exposure should be maintained for each location in a metadata file and made available at a central location (e.g., a website). Variations in sensor or tower siting may be unavoidable due to many circumstances, such as:

- Limited road rights-of-way
- Access requirements for power and/or communications
- Ease in access for maintenance
- Geography (e.g., terrain, water bodies) and neighboring structures
- Aesthetic considerations imposed by individuals and agencies
- Security concerns
- City, county, or state codes.

4.1 Observation Tower

Considerations for the structure and siting of an ESS tower are as follows:

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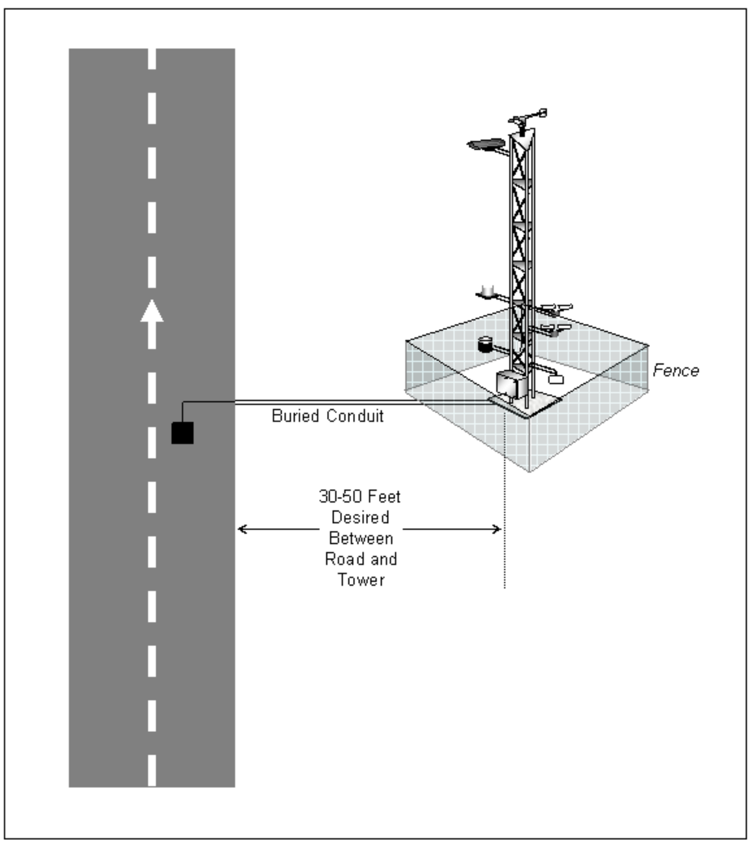
[12] World Meteorological Organization: Guide to Meteorological Instruments and Methods of Observation, Sixth Edition, WMO-No. 8, 1996.

[13] National Weather Service. Operations and Services, Surface Observing Program (Land), Instrument Requirements and Standards for the NWS Surface Observing Programs. Policy Directive 10-1302, October 17, 2003.

- The tower should be sturdy (e.g., open matrix type) using instrument booms to reduce contamination of sensor data by turbulence and wind flow around the tower structure. For water level and road flooding applications, standpipes (i.e., vertical pipes ranging from 3 to 12 inches in diameter and up to 10 feet tall such as shown in Figure 5) are typically used. Masts can be placed above the top of the standpipe to mount wind, air temperature/dewpoint, or other weather sensors. In this situation, the weather sensors may not be consistent with the siting guidelines below; however, the sensors should be installed high enough above the top of the standpipe to eliminate the environmental effect caused by the standpipe.

- At this time, there are no studies that determine the minimum distance the tower should be placed from the roadway to avoid the effects of traffic on the accuracy of the sensors (e.g., heat, wind, splash) or how close it must be to adequately represent the environment over the roadway. Towers are most frequently installed within a range of 30-50 feet (9-15 meters) from the edge of the paved surface. Figure 6 depicts a desired tower location relative to the roadway.

Figure 6. Desired Tower Location Relative to Roadway



- The tower base should be attached to a concrete pad to provide a sturdy platform. The size of the pad should take into consideration the soil conditions, frost activity, and wind loading. If the tower is within the clear zone, a barrier or guard rail should be used.

- The tower base should be at the same elevation as the surface of the road, if possible.

- The tower height should depend on the planned sensors. If a wind sensor is planned, the tower should be tall enough to install it at a height of 33 feet (10 meters).

- Towers should be sited on relatively flat terrain. If possible, avoid steep slopes within 300 feet (approximately 90 meters) that could impact wind measurements. Sites near steep road cuts, swampy areas, and bedrock (a detriment to cable trenching) should be avoided.

- If possible, towers should be placed upwind of the roadway based on the predominant wind direction for the season of most interest. The nearest NWS Forecast Office or State Climatologist can provide predominant wind directions. Additionally, road maintenance personnel can often provide anecdotal information that will help determine the predominant wind direction along a given road segment.

- The surrounding terrain coverage out to at least 50 feet (15 meters) should be low vegetation or native soil.

- Avoid standing water. Many ESSs are installed on the opposite side of a depression adjacent to the road. This depression is a natural collection point for rain and/or water draining off the road. Given the choice of two potential sites, both of which would satisfy other siting requirements, the ESS should be installed in the one less likely to be affected by ponding water. Stormwater management is important to both the accuracy of meteorological observations and site maintenance. The NPDES Stormwater Guide[14] may be used as a reference or basis for stormwater management at the ESS site.

- A fence should cordon off the tower from its surroundings if the threat of vandalism is present. If possible, the distance between the fence and the tower should be at least 15 feet (5 meters). This distance is recommended to minimize the effect of the fence on the sensors readings especially when weeds and/or debris on the fence act as a horizontal obstruction. Limited space in the right-of-way may require the distance between the fence and tower to be reduced. The positioning of the fence and its gate should not restrict access to the equipment or the tower. Careful planning is necessary to assure that fold-over towers with their attached instrumentation may be lowered with sufficient room for a technician to work on the sensors. The fence should not obstruct any sensors on the tower.

- Anti-climb panels can be installed to restrict persons from climbing up the open lattice of towers.

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[14] US Environmental Protection Agency. *Stormwater Guide*. National Pollution Elimination Discharge System. www.epa.gov/npdes/pubs/sw_swppp_guide.pdf.

- Ease of maintenance tasks should be considered in the siting, such as the use of folding towers and the availability of maintenance vehicle pull offs. In some situations, sensor heights may need to be adjusted to accommodate maintenance activities.

- Insufficient space in the right-of-way outside the clear zone may preclude installation of a tower. If requirements for road weather information preclude selecting another site, DOTs may find other options for installing some atmospheric sensors. For example, anemometers can be installed on light standards or utility poles. The anemometer should be placed on top of the pole to minimize disturbances in the air flow. If no pole is available, an anemometer can be mounted on a sign bridge. The mounting site should be selected to minimize disturbances from any signs or from the sign bridge. Consider mounting the anemometer on an instrument boom in the predominant upwind direction. Additionally, long-wave radiation sensors can be installed on a sign bridge to collect data over the road surface for input into road temperature models. Temperature and moisture sensors should not be mounted on top of light standards or utility poles or on sign bridges, as their resulting height would preclude obtaining representative data.

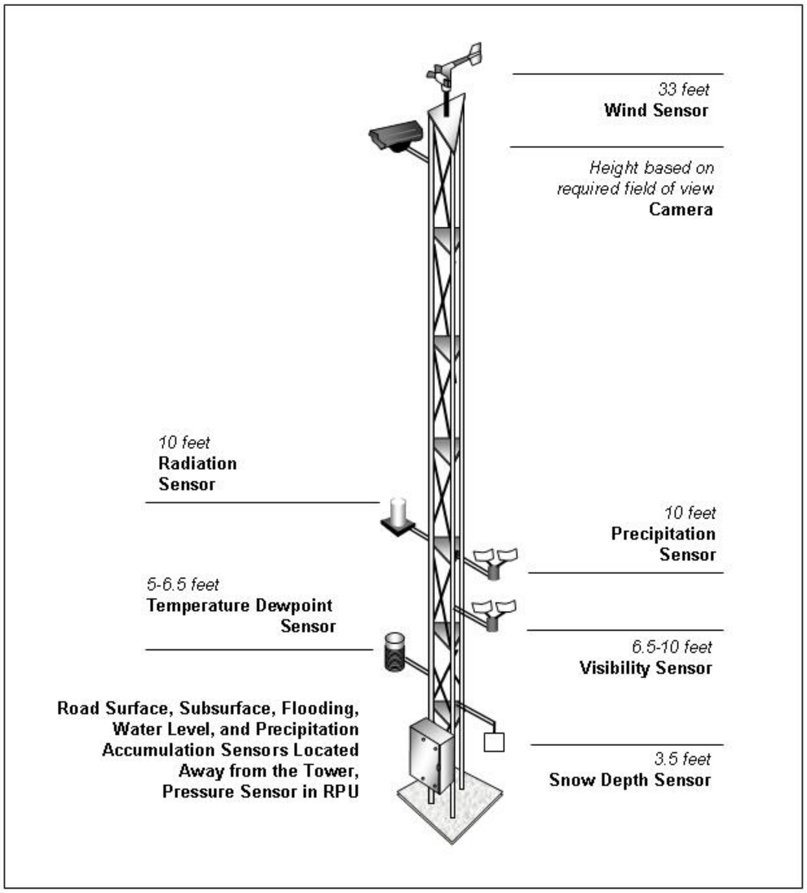
- The positioning of the tower and the height of the sensors on the tower should be included in the metadata file available for the data customers.

- Refer to wind sensor criteria in Section 4.2 for obstruction restrictions.

■ 4.2 Sensor Location

Figure 7 shows the typical locations of sensors mounted on a tower as discussed in the following text. Refer to Section 3.2 for local sensor siting guidelines that differ from the recommended guidelines below. Sensor heights may need to be elevated in areas that receive heavy snow.

Figure 7. Typical Location of Tower-Based Sensors



It is recommended that agencies and their contractors follow the manufacturer's guidance for installation and calibration of all sensors, relying on the guidance below in the absence of more specific instructions from the manufacturers. Different sensors for a given meteorological parameter can also have different location requirements.

- **Air Temperature/Dewpoint Sensor.** This probe should be located in a radiation shield in a well ventilated area and mounted 5 – 6.5 feet (1.5 – 2 meters) above ground level. The sensor should be on a boom extended from the tower at least 3 feet (1 meter) towards the predominant wind direction. In areas where road frost is a recurring consideration, a second dewpoint sensor mounted lower to the pavement height may help identify the potential for frost formation.

- **Wind Speed and Direction Sensor (anemometer).** This sensor should be positioned 33 feet (10 meters) above ground level. Obstructions to the wind flow should be avoided. A general rule is that the sensor should be positioned at a distance of 10 times the height of the nearest large obstruction, e.g., if the obstruction is 20 feet tall, the wind sensor should be positioned 200 feet away from the obstruction. The wind direction sensor should be set on true north (rather than magnetic north).

- **Optically based Precipitation Sensors (Rate, Type, and Amount).** These sensors should be installed at a height of 10 feet (3 meters) to avoid contamination from debris. Install these sensors away from traffic, as they are susceptible to vibration. Optical sensors should be installed to avoid the sun and stray light sources from entering the receiver element.

- **Visibility Sensors.** These sensors should be installed at a height of 6.5 – 10 feet (2 – 3 meters). This height is lower than the NWS and FAA Automated Surface Observing System (ASOS)[15] minimum height of 10 feet, but above the 1.5-meter height the WMO recommends for non-aviation applications[16]. This height was selected to better represent a driver-level observation. Optical sensors should be installed to avoid the sun and stray light sources from entering the receiver element.

- **Snow Depth Sensors.** These sensors are based on ultrasonic or infrared emissions. They should be installed perpendicular to the surface at a height of approximately 3.5 feet (1 meter). The sensor should have an unobstructed view of the target and should be mounted so as to avoid vibrations.

- **Shortwave Solar Radiation Sensor.** These sensors should be installed at a height of at least 10 feet (3 meters). These sensors should be placed high enough to avoid radiation from reflective surfaces or shading from obstructions.

- **Longwave Radiation Sensors.** These sensors measure incoming and outgoing radiation in the infrared portion of the energy spectrum. The balance of these two radiation processes is extremely important in determining the potential for nighttime cooling. They should be installed at a height of 10 feet (3 meters) to avoid debris contamination. These sensors should be installed on the tower with a clear field of view (i.e., free from obstructions). To measure longwave radiation directly above the road surface, consider placing the sensor on a sign bridge.

- **Cameras, both visible and infrared.** Cameras should be installed where they are able to obtain a clear line-of-sight and not interfere with the operation of any other sensors. If the requirement is for visibility measurements, the camera should be installed as close as possible to the driver's level of view. Continuously imaging cameras may require additional power and communications bandwidth.

- **Pavement Temperature and Pavement Condition Sensors.** The initial consideration in the deployment of pavement sensors is in satisfying the agency needs to monitor or predict pavement conditions. Pavement sensors can be installed where pavement conditions are representative of general road conditions (i.e., part of a regional ESS)

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[15] National Weather Service. Automated Surface Observing System (ASOS) User's Guide. March 1998.

[16] World Meteorological Organization: Guide to Meteorological Instruments and Methods of Observation, Sixth Edition, WMO-No. 8, 1996.

and/or where specific road weather problems are likely to occur. The installation of a pavement sensor meant to be representative of a larger road segment includes slightly different considerations than the installation meant to detect or monitor a specific road weather condition or concern. For example, in most situations pavement sensors should be sited in unshaded areas to represent the surrounding roadway segment under maximum cooling conditions. However, in road segments where shaded pavement is prevalent, such as hilly or mountainous areas, DOTs may consider siting additional sensors in the shaded areas to provide a better indication of local cold weather road conditions.

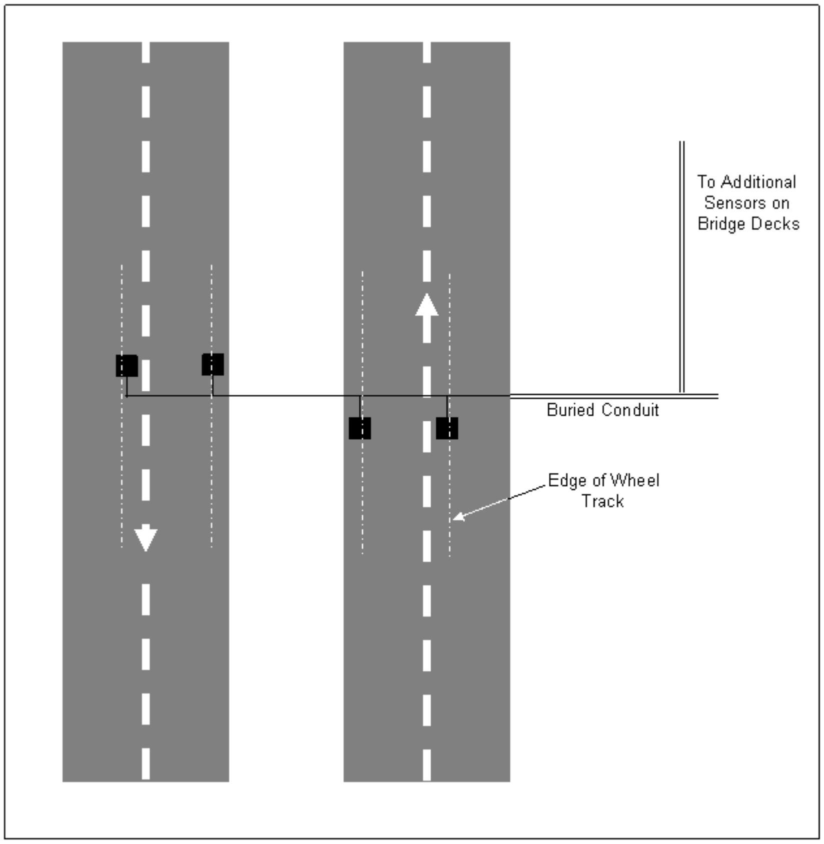
Transportation operations and maintenance practices and concerns define where the pavement sensors should be located. On multilane roadways, consideration should be given to installing several sensors in different lanes. If only one sensor is to be installed, the typical lane selection is the travel lane, the rightmost lane in a multilane roadway. If sensors will not be placed in each lane of a multilane road in an urban environment, consideration should be given to siting the pavement sensors in the travel lane of morning outbound traffic. Icy roads are most often a concern during the predawn and morning hours. Placing the pavement sensor in morning outbound traffic will reduce the influence of heavy vehicle traffic on pavement observations.

In order to optimize the investment in an ESS location, sites are often selected that include installation of at least one sensor in an open road environment and one sensor in a bridge deck. Consider installing the pavement sensors on the second bridge span from the abutment where the flow of air affects the deck temperature and in the approach roadway far enough back from the abutment so that the sensor measures the pavement temperature away from the bridge's effects.

Once a lane is selected, where to install the pavement sensor within the lane becomes the next consideration. In general, pavement sensors should be installed near the edge of the inside wheel track. A typical pavement sensor siting is presented in Figure 8. The sensor location should be adjusted to avoid wheel track depressions, as a depressed wheel track will be susceptible to water ponding that could contaminate sensor readings. For similar reasons, care should be taken in locating the sensor to avoid drainage onto the sensor from the shoulder or median. Pavement temperatures can be as much as 2^{o}F (1^{o}C) higher in lane centers. Accordingly, placing pavement sensors in the center of a lane is not recommended.[17] The sensor should be implanted flush with the pavement. On grooved pavement, the sensors should be implanted flush with the top of the grooves.

[17] Boselly, S.E., J.E. Thornes, and C. Ulburg. Road Weather Information Systems Volume 1, Research Report. Strategic Highway Research Program Publication - SHRP-H-350, National Research Council, Washington D.C., 1993.

Figure 8. Typical Pavement Sensor Siting



- Subsurface Temperature and Moisture Sensors. These sensors should be installed at a depth of 12 or 18 inches (30.5 or 45.5 centimeters), depending on the manufacturer-provided guidelines. Installation at multiple depths should be considered for backup or more detailed analysis. The installation location should be representative of sub grades in the area to include the presence or absence of water, similar soil types, and pockets of foreign materials. For ease of replacement, avoid burying subsurface sensors directly below pavement sensors.

- Precipitation Accumulation Sensor. The tipping bucket and weighing rain gauge are the most common ESS precipitation accumulation sensors. The tipping bucket often underreports rainfall totals in heavy precipitation. A weighing gauge can measure both solid and liquid precipitation and is more sensitive to light precipitation events. Both sensors require a heating device in freezing climates. DOTs may want to consider new technologies such as the hot-plate rain gauge which determines precipitation amounts by measuring the power needed to evaporate precipitation falling on a sensor plate. Additionally, commercially available all-weather precipitation accumulation gauges are being deployed as part of NWS and FAA automated surface observing systems. Exposure is the primary consideration for siting a precipitation sensor. Place the instrument in as open an area as possible and away from the roadway to prevent splashing. Consider the use of a wind shield to increase accuracy of the measurement (not required for a hot-plate rain gauge). Avoid areas of possible blowing or drifting snow. If mounted on a tower, the sensor should have an unobstructed field of view above it. Because the tower itself may influence precipitation measurements, it may be desirable to physically separate the precipitation sensor from the primary tower and remotely transmit the data to the tower RPU or boost the signal for a longer cable distance.

- Barometric Pressure Sensor (barometer). These sensors can be installed at any height but should be encased in a protective shelter to avoid exposure to the elements and any wide temperature changes.

- Water Level Sensors. These sensors typically consist of an ultrasonic, infrared, or float water-level sensor installed in a standpipe. For water-level sensors, the standpipes should be located in a low turbulent (i.e., steady flowing) portion of a flowing creek or river adjacent to a flood-prone road segment or bridge. If installed on or adjacent to a bridge, the sensors should be sited on the downstream side to minimize damage from floating debris. To detect road flooding, the standpipes should be installed adjacent to the low point of a roadway segment prone to flooding. In this situation, the standpipes are normally located in a parking area away from traffic or behind a guardrail.

5.0 Additional Considerations

5.1 Siting Considerations

The primary purpose for siting ESSs near roadways is to measure weather and pavement conditions on or adjacent to the roadway. These measurements are subsequently used to support management decisions and the prediction of future road and weather conditions detrimental to the safe operations of vehicles on the road. There are many obstacles that must be overcome for the proper siting of those stations.

The most difficult aspect of proper siting is to ensure that the sensor locations provide the specific road weather information required. This is not possible in all cases due to physical obstructions, safety, or security issues. In most cases, siting to satisfy the requirements for proper operation of one sensor can be accomplished, but the site may prove inappropriate for measurement of other desired conditions. In such cases, critical compromises or additional actions may be required to locate an ESS. Care must be taken to ensure compromises do not result in locating an ESS or ESS sensor in a location that will not be representative of the required road weather conditions. To avoid such situations, additional sensors or additional sites should be considered.

In addition to close proximity to the roadway, the sensors should be selected relative to the environment being monitored. If the intent is to measure winds of hurricane strength, then the instruments need to be of sufficient durability to handle the expected conditions. Additional actions may include adding sensors of identical types to an ESS in order to satisfy multiple requirements at a single location, e.g., installing a wind sensor on a bridge separate from one sited nearby in an open unobstructed area. The use of additional sensors will help ensure each is representative of the area or location of interest, but this will normally increase system costs and complexity.

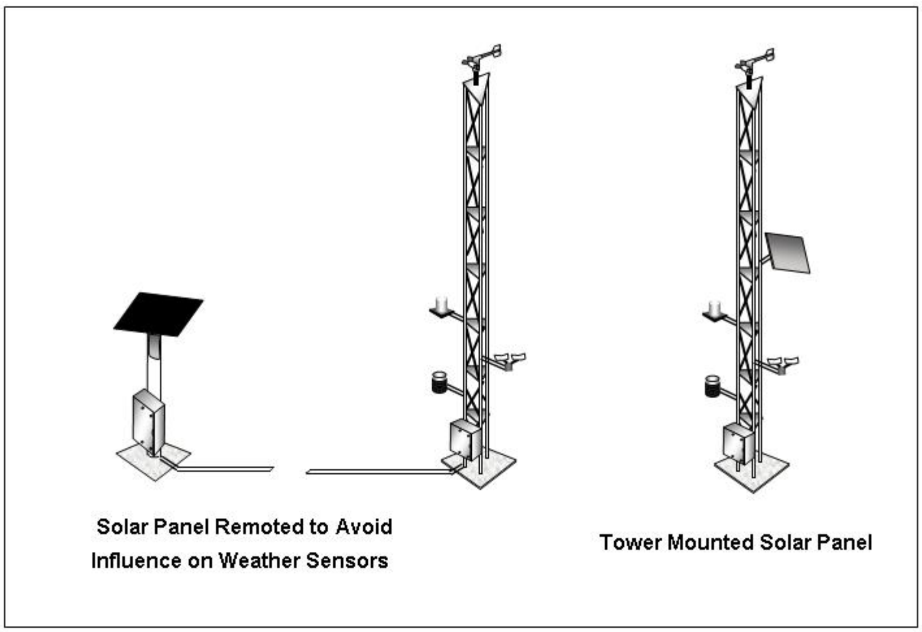
Siting decisions should be based on the need for specific road weather information. Planning should address data requirements first; then address how to satisfy power and communications requirements.

5.2 Power

All sensors require some level of power to operate (e.g., signal voltages, sampling cycles, storage of data, and possibly heating elements). Power is also required for the collection of the data at the RPU and for transmission of the road weather data to its intended users. Power options include commercial power, wind power, or solar power with batteries.

The selection of the appropriate power option is dependent on the availability and dependability of the source. A commercial power connection is usually the most economical and reliable source of power. Solar power can support nominal loads but is typically not capable of sustaining heavy power consumption for heated sensors. Figure 9 illustrates two options for mounting solar panels. Care should be taken to ensure solar panels do not block or interfere with the operation of the atmospheric sensors. If the cost to physically connect to a direct, dedicated electric source is prohibitive, other options must be considered. The actual selection of the power source may subsequently dictate which sensors can be supported.

Figure 9. Options for Mounting Solar Panels



Cost becomes a factor in the decision of whether to install less expensive sensors or communications requiring little power versus more capable sensors or communications requiring more power. Efforts should be made to ensure power considerations do not jeopardize the usefulness of the ESS. The use of solar power is more common in the western and southwestern United States where there is more ample sunlight. Commercial power, requiring less maintenance but considerably more installation costs, is used in most other areas. The use of wind power has been successfully implemented for a number of ESS installations in North Dakota.

■ 5.3 Communications

Similarly, tradeoffs in the method and equipment to support timely and effective data communications (e.g., report frequency versus cost) may also have to be made, hopefully without compromising the usefulness of the ESS.

Communications options include hardwired telephone, cellular, copper wire, fiber optic cable, wireless, radio, microwave, or satellite. An important factor in the selection of the communication method and equipment is the amount of data that will be required to pass from the RPU. This will be a function of how much data are included in each observation (e.g., bandwidth considerations) and how often observations are transmitted (e.g., report frequency). For sites with low bandwidth requirements (i.e., no video camera and infrequent reporting), a polling system using telephone lines or some type of wireless communication may be more economical than hardwired options. In some cases, ESS siting decisions will be affected by line-of-sight and terrain shadowing considerations. For high data volumes, a hardwired communication system (wire or optical fiber) appears more appropriate, although installation costs could be increased considerably. DOTs should consider using "historical" polling of road weather data, if the RWIS RPU can support it. With historical polling, road weather data are stored in the RPU and are retrieved at set times (e.g., at the top of the hour and every 15 minutes thereafter). This process differs from polling the RPU to get only the current road weather observation. Employing historical polling enables the DOT to recover earlier road weather observations if communications' failures interrupt the polling process.

A complete analysis of communication options and possible interfaces with the present or planned ITS should be performed early in the siting process. In some cases, ESSs can be located near other ITS devices (e.g., traffic counters, dynamic message signs, traffic signal controllers, bridge anti-icing systems) to share power and communications costs. For critical sites, backup sources of power or communications may be needed. An analysis of communications should also consider the weather information requirements of partnering agencies, such as NWS. Partnering agencies may need weather observations at a greater reporting frequency than the DOT. Such requirements may influence the communications solution.

■ 5.4 Aesthetics, Maintenance, Safety, and Security

In some cases, ESSs have been moved or painted in order to minimize how much they stand out from the surrounding terrain and vegetation. Unfortunately, following the siting criteria related to maintaining adequate distances from obstructions can result in a sensor tower that is very obvious. Pre-siting discussions with the surrounding stakeholders can possibly forestall any aesthetics problems.

Pre-siting analysis should also review potential sites for environmental and archaeological significance.

Siting must, in all cases, acknowledge and be subject to safety clear zones.

Geological considerations may impact siting. Soil mechanics may affect placement of access ways, base pads, and subsurface sensors. Stormwater management is important to both the accuracy of meteorological observations and site maintenance. The National Pollutant Discharge Elimination System (NPDES) Stormwater Guide[18] may be used as a reference or basis for stormwater management at the ESS site.

Maintainability of the ESS should be a consideration in both site location and design. Siting too close or too far from the roadway may seriously complicate maintenance procedures or unnecessarily jeopardize maintenance personnel safety. Installations too close to the pavement may make the data more representative of the actual roadway conditions, but increase the hazard to maintenance personnel. Installations too far from the roadway may decrease the value of the data by making the data unrepresentative of the roadway environment. Site design must also include analysis of access to sensors for either fixed-base towers within the enclosure or along the length of a fold-over tower. Maintainability may be enhanced by including remote ESS site monitoring capabilities as part of the RWIS.

Extra security measures should be taken in areas where the threat of vandalism is present. These may include a security fence around the ESS, anti-climb panels, or even security cameras.

■ 5.5 Periodic Siting Reevaluation

An important consideration of any ESS is the periodic reevaluation of the site. Over the years, construction projects, both on and off the roadway, and vegetation growth can change the representativeness and usefulness of ESS locations. A periodic reevaluation of the site is needed to ensure that the observation data from the site are still valid and that the metadata on the site are still correct. Obstructions should be reevaluated for interference and, if required, a new site should be determined or obstructions removed. Any changes resulting from this reevaluation should be included in updated entries to the site and sensor metadata in order to maintain a valid history of the site and its sensors. This reevaluation can be accomplished as part of an annual preventive maintenance program needed for sensor maintenance and calibration.

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[18] US Environmental Protection Agency. *Stormwater Guide*. National Pollutant Discharge Elimination System. www.epa.gov/npdes/pubs/sw_swppp_guide.pdf.

5.6 Siting Metadata

An important aspect of the effective use of road weather data from ESSs is the documentation and distribution of the site's metadata. Metadata is basically defined as "data about data." In the case of the RWIS ESS, metadata should include the station and sensor locations, the history of any changes in the metadata, and a representative index for the particular location and its sensors. The metadata is used to document the characteristics of each sensor and its siting to provide users a better understanding of what the sensor data really represent. The Federal Geographic Data Committee (FGDC) has developed standards for digital geospatial metadata[19]. The referenced document provides "a common set of terminology and definitions for the documentation of digital geospatial data." A companion document[20] describes how and why a uniform set of criteria or standard was developed and presents it in more detail. David Hart and Hugh Phillips also have published a primer on metadata use[21]. Currently, there are no corresponding uniform recommendations for RWIS ESS location and sensor metadata.

Various forms of metadata currently exist for ESSs that are not components of RWIS. The National Climatic Data Center (NCDC) maintains metadata for a number of its datasets. These datasets include: 1) Climate Reference Network dataset[22], 2) NCDC Station History Database with approximately 30,000 stations and part of the NCDC Station History Information Processing System (SHIPS)[23], and 3) NWS Cooperative dataset[24]. The elements for the NCDC station metadata, accessible through their Master Station History Report, include station identification with a number of identifiers; location (e.g., country and state); latitude/longitude; station name; period of record; elevation; and, station type. Elements for the cooperative sites include exposure, topography, and driving directions. The SHIPS database also contains more detailed information about the observations and instrumentation for some locations. In addition, development of a common set of metadata requirements for the NWS National Cooperative Mesonet, a part of the NWS Integrated Surface Observing System (ISOS) Program, is currently underway. The ISOS program may include RWIS as part of the national mesonet. To be included, RWIS data

[19] Federal Geographic Data Committee, *Content Standard for Digital Geospatial Metadata*, FGDC-STD-001-1998.

[20] Federal Geographic Data Committee, *Content Standard for Digital Geospatial Metadata Workbook*, Version 2.0 May 1, 2000.

[21] Hart, D and H. Phillips, Metadata Primer – A "How To" Guide on Metadata Implementation, University of Wisconsin website.

[22] US Department of Commerce, National Climatic Data Center, United States Climate Reference Network (USCRN) Metadata Management – Survey to Operations (Draft). June 2003.

[23] US Department of Commerce, National Climatic Data Center, *Data Documentation for Data Set 9767B, Master Station History Report.* December 31, 2002.

[24] Viront-Lazar, A. and P. Seurer, *Metadata for Climate Data, A Geographic Data Base Model for Station History*, First IEEE Metadata Conference, April 16-18, 1996.

will need to have a minimum set of metadata for each site. Although still being finalized, this metadata set includes platform owner, station name and identifier, station coordinates, station elevation, observed elements with their units, station reporting frequency, and an observation timestamp description. All of these metadata items are included in the recommended ESS metadata set listed in Table 2. As metadata requirements become finalized for the NWS ISOS Program, RWIS metadata managers may want to adjust their metadata archive accordingly.

Currently procedures for archiving ESS metadata vary from state to state. To maximize the application of ESS data within the transportation community and by other potential users, uniformity in metadata content and formats is encouraged. At a minimum, those items with a history of changes should be collected, centrally stored, and backed up whenever a change occurs. In addition to the collection and storage of the metadata, the metadata should also be readily available to any individual or agency that uses the data. The effective distribution of metadata is just as important as the distribution of the sensor data. This distribution of metadata is necessary to ensure that the user understands the characteristics of the road weather data, e.g., whether it is designed to monitor the conditions at a specific site for a specific local purpose or whether that data is designed for general surface transportation weather observing and forecasting.

Recommended metadata items for ESSs are listed in Table 2. Additional metadata items, listed in Table 3, can provide more useful information to road weather data users. Some items in the metadata sets in Tables 2 and 3 correspond directly to identification objects listed in the National Transportation Communications for ITS Protocol (NTCIP) Standard for ESS objects.[25]

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[25] US Department of Transportation. National Transportation Communications for ITS Protocol (NTCIP) – Object Definitions for Environmental Sensor Stations NTCIP 1204. November 23, 2001. Release of Version 2 is expected in 2005.

Table 2. Critical ESS Metadata

Field Name	Field Description	Data Type	Example
climateRecord			
minObsRecord	The minimum observed value of this observation type for this period (month). Precision & bounds dependent on data type Critical – but not necessarily owner provided	real	Minimum Monthly Temp (in Deg c) = -2.9
maxObsRecord	The maximum observed value of this observation type for this period (month). Precision & bounds dependent on data type Critical – but not necessarily owner provided	real	Maximum Monthly Temp (in Deg c) = 38.2
period	The month to which this climate record applies (1=Jan... 12=Dec) Critical – but not necessarily owner provided	integer	May = 5
collector (data access to the RWIS)			
protocol	Description (in lower case) of the protocol used to retrieve observations (examples of input include: ftp, http, or https)	text(10)	https
hostName	The network DNS name or IP address of the collector host server	text(50)	www.fhwa.dot.gov or 64.126.107.233
hostPort	The logical network address port on the collector host server Critical – if required by owner	integer	http = 80, ftp = 22, https = 443, or owner defined integer
fileLocator	The logical directory path to the observation file	text(50)	path = /stateDOT/RWIS/obs/
filename	The filename or the rule for generating file names that contain the observations	text(50)	ESS_Observations.txt
username	The identifier name that is used to log into the collector host server Critical – if required by owner	text(50)	username = Name
password	The password that is used to log into the collector host server Critical – if required by owner	text(50)	password = iHavePermission

Field Name	Field Description	Data Type	Example
obsCollFreq	The number of minutes between collection cycles at the agency's collector host server (when a new file is ready for retrieval). Maximum allowed is 60 minutes.	integer	minutes = 13
obsCollOffset	The number of minutes after midnight UTC that the first collection occurs (for *Clarus* retrieval purposes). Minutes range from 0-60.	integer	minutes = 2
UTCOffset	The number of minutes offset from UTC for the agency's collector host server in Standard time. Areas in the U.S. (west of Greenwich) use negative values. Valid range is -720 to +720 minutes.	integer	minutes = -240
DST	Daylight Savings Time on the server is observed (True or False)	bit	1=True, 0=False
startDST	Starting date and time for DST Critical – only if DST field is TRUE	datetime	4/12/2006 2:00
endDST	Ending date and time for DST Critical – only if DST field is TRUE	datetime	10/15/2006 14:15
collectorConfig Describes the format of the DOT weather data file; one set of entries is required for each observation type in the file			
headerIndex	The positional order (comma delimited) of observation type in the collected observation file (leftmost column = 1)	integer	the temperature column = 5
receiveUnits	Type of units for conversion purposes; Most 1204 units are included	text(50)	Degrees Celsius
receiveLabel	Column label name from collected observation file	text(50)	column = AirTemp
unitsMultiplier	The multiplier used to adjust the decimal position (e.g., multiply 209 by 0.1 to get 20.9 Deg C)	real	times 0.1
metadata contact information (from agency)			
name	Contact person Critical – administrator access only	text(50)	Mr. Fred Flintstone
title	Contact person title Critical – administrator access only	text(50)	Owner of the Bedrock Mesonet
phonePrimary	Contact phone (including area code) Critical – administrator access only	text(10)	2025551301 (no dashes)

Field Name	Field Description	Data Type	Example
e-mail	Contact e-mail address Critical – administrator access only	text(50)	Fred.Flintstone@bedrock.com
contributor			
name	Name of the contributing agency or group within the agency providing observations Critical – administrator access only	text(50)	Bedrock Quarry Company
contactName	Contact person Critical – administrator access only	text(50)	Mr. Barney Rubble
title	Contact person title Critical – administrator access only	text(50)	Bedrock Mesonet Operator
phonePrimary	Contact phone (including area code) Critical – administrator access only	text(10)	2025551302 (no dashes)
e-mail	Contact e-mail address Critical – administrator access only	text(50)	Barney.Rubble@bedrock.com
organization			
name	Organization name Critical – administrator access only	text(50)	Loyal Order of Water Buffalo
contactName	Contact person Critical – administrator access only	text(50)	Mr. Slate
title	Contact person title Critical – administrator access only	text(50)	Organization that owns the Bedrock Quarry
phonePrimary	Contact phone (including area code) Critical – administrator access only	text(10)	2025551300 (no dashes)
e-mail	Contact e-mail address Critical – administrator access only	text(50)	Slate@bedrock.com
sensor-specific information			
obsType	Type of observation collected by this sensor; based on NTCIP 1204 types (see 1204 worksheet)	text(50)	essAirTemperature
sensorIndex	The order of like sensors; used to distinguish one of a set of like sensors associated with a particular station	integer	when multiple sensors are involved at one station: puck 0, puck 1, puck 2, puck 3
minRange	Minimum value for sensor range (hardware) test, as defined by the sensor manufacturer or the instrument owner	real	minimum sensor range temp = -160.0 Degrees or the minimum sensor range temp set by the operator = -100.00 (whichever is most restrictive)

Field Name	Field Description	Data Type	Example
maxRange	Maximum value for sensor range (hardware) test, as defined by the sensor manufacturer or the instrument owner	real	maximum sensor range temp = 220.0 or maximum sensor range temp reporting = 150.0 (whichever is most restrictive)
distGroup	Identifies distribution group to whom data from this sensor can be provided	integer	1 = DON'T distribute, 2 = distribute to everyone, etc.
ratePos	Maximum positive rate of change during the time period defined by rateInterval, and as used by step test Critical – but not necessarily owner provided	real	20.0 degrees
rateNeg	Maximum negative rate of change during the time period defined by rateInterval, and as used by step test; reported as a negative number Critical – but not necessarily owner provided	real	-20.0 degrees
rateInterval	Interval of time, in seconds, over which ratePos & rateNeg apply in the step test Critical – but not necessarily owner provided	real	3600.0 seconds or 1 hour
persistInterval	Amount of time, in seconds, that the observed value can remain constant (not change). Used for the persistence test Critical – but not necessarily owner provided	real	14000.0 seconds or 4 hours
persistThreshold	Smallest amount of change that is allowed between observations. Used for the persistence test Critical – but not necessarily owner provided	real	0.2 degrees
likeThreshold	Largest observed difference that is permitted among like instruments. Used during the like instrument test Critical – but not necessarily owner provided	real	1.0 degree
sensorType			
mfr	Manufacturer of sensor	text(50)	Vaisala
model	Manufacturer's model number of sensor	text(50)	DSC111
site-specific information			
description	Description of site, as used by the contributor (e.g., "Seward Highway @ Portage Glacier Road")	text(50)	Fairfax County Parkway @ Reston Avenue

Field Name	Field Description	Data Type	Example
stateSiteId	Contributor's identifier for the site Critical – but not necessarily owner provided	text(50)	stateSiteId = 315
station-specific information			
category	The category of station – "P" permanent, "T" transportable, "M" mobile, "O" other	text(1)	P
stationCode	The contributor's station identifier; this may be different than the stateSiteID to allow more than one station at a given site	text(50)	stationCode = 48
rpuUTCOffset	The number of minutes offset from UTC for the remote processing unit (RPU). Areas in the U.S. (west of Greenwich) use negative values. Range from -720 to +720	integer	-60
rpuDST	Does the RPU need adjustment for Daylight Savings Time(DST)? [(0=no, 1=yes]	bit	1
rpuStartDST	Starting date and time for DST (for the RPU) Critical – only if rpuDST field is TRUE	datetime	4/12/2006 2:00
rpuEndDST	Ending date and time for DST (for the RPU) Critical – only if rpuDST field is TRUE	datetime	10/15/2006 14:15
locBaseLat	The latitude location of the base of the station tower or RPU stand, in decimal degrees (e.g., 34.567); positive values are North latitudes. Value can hold up to 9 digits of precision	real	37.4821
locBaseLong	The longitude location of the base of the station tower or RPU stand, in decimal degrees (e.g., -123.456); negative values are West longitudes. Value can hold up to 9 digits of precision	real	-113.22
locBaseElev	The elevation location of the station base (tower or RPU stand) in meters from mean sea level	real	135.5

Table 3. Supplemental ESS Metadata

Field Name	Description	Data Type	Example
collector (data access to RWIS)			
description	Description of collector	text(50)	This collector will work with all ESS on the XX DOT network
maintInstallDate	Date of initial installation	datetime	5/4/2003 12:24
mfrName	The name of manufacturer	text(50)	Facundo Computing
mfrProduct	The name of the product	text(50)	JF Blade Series 1000
mfrModel	The model number or software version	text(50)	123456HH0JM2
Supplemental contact information (Network Owner)			
phoneAlt	Contact phone alternate (including area code)	text(10)	2025551212 (no dashes)
phoneMobile	Contact mobile phone number (including area code)	text(10)	2025554444 (no dashes)
fax	Contact phone fax (including area code)	text(10)	2025553333 (no dashes)
pagerId	Contact pager identifier	text(10)	2025551111 (no dashes)
pager	Contact pager number	text(10)	556687
radioUnit	Contact radio unit identifier	text(50)	2025555555 (no dashes)
address1	Contact mailing address line1	text(50)	123 1st Street
address2	Contact mailing address line2	text(50)	Suite 450
city	Contact mailing address city	text(50)	Apple
state	Contact mailing address state	text(2)	OR
zip	Contact mailing address zip	text(10)	99999-4444
country	Contact mailing address country	text(3)	USA
Contributing organization			
location	Organization location	text(50)	MODOT
purpose	Organization purpose	text(50)	To provide a world-class transportation experience that delights our customers and promotes a prosperous Missouri.
centerId	Organization center identifier	text(50)	4
centerName	Organization center name	text(50)	KC Scout
updateDate	Organization information last updated	datetime	10/23/2005 14:25
contactId	Contact identifier	integer	Contact name for organizational issues that is

Field Name	Description	Data Type	Example
			included in the contact list – the id of the contact name will be put here
Sensor-specific information			
calibDate	The last date of calibration of the sensor Recommended for owner maintenance records	datetime	9/3/2006 10:30
maintDate	The last date of maintenance performed on the sensor Recommended for owner maintenance records	datetime	9/4/2006 4:00
serial	Manufacturer's serial number for sensor Recommended for owner maintenance records	text(50)	55335668
resolution	The smallest increment or measurement that can be obtained from a particular sensor	real	tenths of degrees =.1
accuracy	The known potential variation of the observation	real	0.05
minDisplay	Minimum value for sensor display	real	-52.85
maxDisplay	Maximum value for sensor display	real	120.22
nsOffset	The north/south distance from the station reference location in meters	real	15.0 meters
ewOffset	The east/west distance from the station reference location in meters	real	8.0 meters
elevOffset	The vertical distance from the station reference location in meters	real	3.0 meters
surfaceOffset	The vertical distance from the pavement surface in meters	real	0.5 meters
embeddedMaterial	Description (including depth) of material sensor is embedded in.	text(100)	rubber cement
outputAvgInterval	Milliseconds used to describe average interval of observations	integer	300,000 milliseconds = 5 minutes
outputInternalUnits	Internal units reported to data logger	text(8)	Celsius
maintInstall	Initial installation date for sensor Recommended for owner	datetime	2/8/2003 8:45

Field Name	Description	Data Type	Example
	maintenance records		
maintBegin	Date sensor is taken out of service; sensors for which maintBegin < currentDate < maintEnd will not be checked for data quality. Use if sensor will be out of service for a significant period of time.	datetime	10/15/2006 14:15
maintEnd	Date sensor is put back into service; sensors for which maintBegin < currentDate < maintEnd will not be checked for data quality	datetime	10/15/2006 18:15
samplingInterval	Interval time, in seconds, between consecutive sensor readings	real	15.0 seconds
sensorDescription	Plain text description of the sensor (e.g., thermometer, CCTV camera)	text(100)	PTZ fixed IR camera
linkURL	Link to CCTV images Optional – unless the sensor is a CCTV then mandatory	text(255)	Direct URL link to a CCTV image
Site-specific information			
roadwayDesc	Name/number of the highway nearest to the site (e.g., “Interstate 35,” “U.S. Hwy 59,” “State Hwy 81,” “Haines Highway”)	text(50)	State Hwy 81
roadwayMilepost	Nearest mile marker to the site	integer	45
roadwayMilepostUnits	Units reported for roadwayMilepost Optional – but must be included if roadwayMilepost is used	text(50)	Miles
roadwayOffset	The distance, in meters, between the closest point on the center surface of the roadway to the site reference point (e.g., base of an RWIS station)	real	37.53 meters
roadwayHeight	The elevation difference, in meters, between the closest point on the center surface of the roadway to the site reference point (e.g., base of an RWIS station)	real	22.8 meters
county	The county or jurisdictional name of the site location	text(100)	Fairfax County or Centreville Township
state	State of the site location (2 letter	text(2)	VA

Field Name	Description	Data Type	Example
	postal ID)		
country	The country of the site location (e.g., USA, CA, MX)	text(3)	USA
accessDirections	Directions to access the site from a major roadway Recommended for owner maintenance records	text(50)	Turn left at the cow, proceed three miles to Joe's Grocery, turn right on State Hwy 81, go 3 miles, on left
representativeness	Describe any unique meteorological or topographical feature(s).	text(255)	Between 2 & 4 PM during the summer months, the ESS is shaded
obstructions	Description of physical properties (e.g., trees, buildings) that might affect the accuracy of observations	text(100)	Large outhouse parked on SW side of ESS
landscape	Description of surrounding landscape	text(100)	sandy area except for obstruction of oak tree and outhouse
accessControlled	Ability for contributor to access the site (e.g., locked fence around site)	bit	0 = no access, 1 = full access
terrainSlope	The grade of the surrounding land, in whole degrees from horizontal	integer	10 degrees
terrainSlopeDirection	The direction of the grade, in degrees from North (e.g., slope down from west to east is noted as 270)	integer	85 degrees
windRoughnessClass	Roughness of the wind in four directions (expressed in whole percent)	text(50)	24 percent
soilType	The type of soil on which the site is located, as described by the USDA National Resource Conservation Service soil texture classification (e.g., sandy loam, silt) or by percent sand, silt, and clay	integer	Full enumeration list is not yet available
stateSystemId	Site identifier used by the State DOT (or other data contributor)	text(45)	22
linearReference	Linear reference marker number	real	4.3
Station-specific information			
description	The description of the station	text(100)	The ESS has a 30 m tower with 10 sensors
type	The type of station – "0" data collected electronically/mechanically, "1"	integer	0

Field Name	Description	Data Type	Example
	collected by humans, “3” type of station is unknown		
locBaseDatum	The datum geocoordinate referencing model	text(10)	WGS 1984
powerType	The type of power for the station – “B” battery, “L” line Recommended for owner maintenance records	text(1)	B
doorOpen	The status of the door (0=closed, 1=open)	bit	0
batteryStatus	The percentage of full charge of the battery (101 = error)	integer	78
lineVolts	The typical voltage for the power source (0 to 100)	integer	12 volts
maintArea	The description of the maintenance group for this station (for the site maintenance personnel)	text(50)	Substation 52
maintPrevFreq	The description of preventative maintenance intervals Recommended for owner maintenance records	text(50)	The station is serviced every year in the spring or when the station fails completely
maintCalibFreq	The description of the calibration maintenance intervals Recommended for owner maintenance records	text(50)	The station is calibrated every spring and fall
maintStatus	The maintenance status of the station – “0” out of service, “1” in service Recommended for owner maintenance records	bit	0
maintInstallDate	The initial installation date of the station Recommended for owner maintenance records	datetime	3/8/2004 8:00
rpuNumCards	The number of sensor interface devices	integer	2
rpuCommType	The communication type for the station – “1” phone, “2” IP address Recommended for owner maintenance records	integer	2
rpuPhoneNum	The phone number to contact the rpu	text(10)	2025555555

Field Name	Description	Data Type	Example
	Recommended for owner maintenance records		
rpuIPAddress	The IP address to contact the rpu	text(15)	64.126.107.233
	Recommended for owner maintenance records		
rpuMfr	The manufacturer of the rpu	text(50)	XYZ Manufacturer
obsCollFreq	The number of minutes between collection cycles (rpu to agency server)	integer	2 minutes
obsCollOffset	The number of minutes after UTC midnight that the first collection occurs	integer	1 minute
obsTransFreq	The number of minutes between transmission cycles	integer	15 minutes
obsTransOffset	The number of minutes after UTC midnight that the first transmission occurs	integer	16 minutes
obsTransFormat	The description of the transmission format from the station to the network data logger	text(50)	The ESS will communicate with the data logger by way of remote control
maintContactId	The contact person for maintenance from contact table; is implemented in the database as a link to a contact person	integer	Contact name for maintenance issues that is included in the contact list – the id of the contact name will be put here
Image information			
description	Description of image	text(50)	The image represents the Cumberland Pass in southwest Virginia
linkURL	URL for image	text(255)	www.i70ess248.gov
	Optional – but must be included if image description is provided		

By establishing, maintaining, and sharing a robust metadata archive for ESS sites and their sensors, both transportation and other users will be able to effectively apply the ESS data to their particular weather and road weather information requirements.

6.0 Conclusion

The collection of road weather information can provide decision support to transportation managers and contribute to more accurate weather forecasts. The recommendations in this document are designed to satisfy as many road weather monitoring, detecting, and prediction requirements as possible. The recommendations encourage uniformity in ESS siting and in the application of the road weather observations. Many of the recommended criteria include a range of values. These ranges reflect both the complexity of the roadway environment and the need for additional research. The recommendations suggest siting decisions are best made by a team of transportation operations, road maintenance, and weather experts.

7.0 Acknowledgments

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Appendix A – Acronyms and Definitions

Term	**Definition**
ASOS	Automated Surface Observing System
°C	Degree(s) Centigrade
DMS	Dynamic Message Sign
DOT	Department of Transportation
ESS	Environmental Sensor Station
°F	Degree(s) Fahrenheit
FAA	Federal Aviation Administration
FGDC	Federal Geographic Data Committee
ISOS	Integrated Surface Observing System
ITS	Intelligent Transportation System
kms	kilometers
Metadata	Specific information about site characteristics
NCDC	National Climatic Data Center
NOS	National Ocean Service
NPDES	National Pollutant Discharge Elimination System
NTCIP	National Transportation Communications for ITS Protocol
NWS	National Weather Service
ODOT	Ohio Department of Transportation
RPU	Remote Processing Unit
RWIS	Road Weather Information System
SHIPS	Station History Information Processing System
SHRP	Strategic Highway Research Program
USCRN	United States Climate Reference Network
USFS	United States Forest Service
WMO	World Meteorological Organization

Appendix B – References

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Appendix C – Road Weather Observation Requirements

Table C1 contains a list of weather elements for DOT consideration during the analysis of road weather requirements. This list was adapted from Appendices B-1, B-1.1, and B-5 in the report on surface transportation national needs by the Office of the Federal Coordinator for Meteorology – Services and Supporting Research[26]. A weather element is a particular weather condition or a consequence of weather conditions affecting road operations or the safety, economic value, or efficiency of transportation or road maintenance activities. Table C1 also indicates the thresholds at which the weather element affects road operations and maintenance activities. In some cases any occurrence of a weather element has impact and may require action. For other elements, the thresholds are variable based on the specific needs of users.

The shaded weather elements in Table C1 deserve primary attention during the requirements analysis and the development of ESS plans. Not all the highlighted weather elements can be measured by an automated ESS; however, they all provide insight into important ESS deployment considerations. For example, an ESS cannot directly measure roadway ice accumulation in inches. If roadway ice accumulation is an important consideration, other sensors discussed in Section 2.1 should be selected that will indicate icing conditions. Identifying the highlighted elements for primary consideration is only a recommendation. The actual elements considered when planning an ESS installation must reflect the DOT's operational requirements for road weather information.

[26] Office of the Federal Coordinator for Meteorology - Services and Supporting Research. *Weather Information for Surface Transportation, National Needs Assessment Report*. FCM-R18-2002. December 2002.

Table C.1. Weather Element List

Weather Element (Shaded weather elements are recommended for primary consideration during ESS requirements analyses.)	Threshold
Freezing Precipitation Occurrence	Any
Structure Ice Accumulation (inches)	Any
Pavement Ice Accumulation (inches)	Any
Frozen Precipitation Occurrence	Any
Snow Accumulation Observation (inches)	Any
Snow Drift Level Observation (inches)	Any
Roadway Snow Depth Observation (inches)	Any
Roadway Snow Pack Depth Observation (inches)	Any
Adjacent Snow Depth Observation (inches)	Any
Snow/Ice Bonding Observation (inches)	Any
Liquid Precipitation (inches)	Any
Precipitable Water Vapor Observation (inches) (amount of moisture in a vertical column of air)	Any
Air Temperature (degrees Fahrenheit (°F))	Variable, based on impact criteria
Air Temperature Change Rate (°F per 24 hours)	Variable, based on impact criteria
Air Temperature and Time Values (heating/cooling degree days)	Variable
	24 hour
Dewpoint Temperature (°F) (Also referred to as the frost point when this temperature is below 32 °F)	Variable, based on temperature and impact criteria
Wet Bulb Temperature (°F) (used to measure moisture in the air, similar to Relative Humidity and Dewpoint)	Variable, based on temperature and impact criteria
Relative Humidity (percent) (Can be derived from air temperature and either dewpoint or wet bulb temperatures.)	Variable, based on impact criteria
Wind Chill (°F)	$\leq$ 32 °F
	$\leq$ 20 °F to 32 °F
Heat Index (°F)	Variable, based on impact criteria
Atmospheric Pressure	Variable, based on impact criteria

Weather Element (Shaded weather elements are recommended for primary consideration during ESS requirements analyses.)	**Threshold**
Total Sunlight (hours)	All
	Total hours
Cloud Cover	Scattered, broken, overcast or tenths or octal of sky covered
Subsurface Temperature (°F)	Variable, based on other contributing factors such as wind, shade, sun
Soil Moisture	Saturated, unsaturated
Soil Temperature (°F)	Variable
Pavement Freeze Point Temperature (°F)	≤ 32 °F with moisture (observation and forecast)
Pavement Temperature (°F)	Variable, based on impact criteria
Pavement Condition	Wet/dry, snow, snow pack, slush, ice
Occurrence of Road or Bridge Frost	Any
Chemical Concentration	Variable, based on application, residue
Visibility, Including Restricting Conditions such as Precipitation, Fog, Haze, Dust, Smoke (statute miles)	< 1/4 to ≤ 1/2 mile
Sun Glare	Any
Wind Speed to include Gusts (miles per hour)	Variable, based on impact criteria
Surface Wind Direction (degrees)	Any
Thunderstorms with Lightning (proximity to route or operational area in miles)	≤ 5 miles
Thunderstorms with Hail (hail size, proximity to route or operational area in miles)	Any size, ≤ 5 miles
Thunderstorms with Tornado or Waterspout (proximity to route or operational area in miles)	≤ 10 miles and ≤ 5 miles
Blizzard – sustained wind or frequent gusts greater than or equal to 35 miles per hour accompanied by falling and/or blowing snow, frequently reducing visibility to less than ¼ mile for 3 hours or more (proximity to route or operational area in miles)	≤ 50 miles
Flooding (the occurrence of flooding or a measurement of a water level above a flood stage)	Any
Water Course Flow Volume (cubic meters per second)	Variable, based on impact criteria

Weather Element **(Shaded weather elements are recommended for primary consideration during ESS requirements analyses.)**	**Threshold**
Water Body Depth (feet)	Variable, based on impact criteria
Hurricane Storm Surge	Any
Air Stability (determination of vertical motion or mixing in the atmosphere)	Stable/Unstable

Some weather elements in Table C1 can be determined using the sensors or a combination of ESS sensors. For example:

- Winds associated with blizzards are observations of wind speed and gusts under these high wind conditions.
- Wind chill temperatures are numerically derived from air temperature and wind speeds.
- Heat index is numerically derived from air temperature and relative humidity.
- Air temperature change rate is derived from air temperature.
- Wet bulb temperatures can be derived from dry bulb and dewpoint temperatures.
- Relative humidity can be derived from air temperature and either dewpoint or wet bulb temperatures.

This appendix presents two additional analyses of road weather observation requirements. These analyses supplement the data presented above and are included to help state DOTs evaluate their needs for road weather observations. The first analysis, based on a Strategic Highway Research Program (SHRP) RWIS implementation guide[27], identifies the road weather requirements of highway agencies, as well as those of meteorological organizations and the traveling public. The results are presented in Table C2. A "Y" indicates the users identified a requirement for the associated observation. Requirements are presented for both snow and ice control activities and for other road maintenance activities.

[27] Boselly, S.E., and D.D. Ernst. *Road Weather Information Systems Volume 2, Implementation Guide*. Strategic Highway Research Program Publication - SHRP-H-351, National Research Council, Washington D.C., 1993.

Table C.2. Road Weather Information Systems Weather Observation Requirements

Types of Observation and Associated Weather Elements			Road Agencies		Meteorological Organizations		Travelers	
			Snow	Other	Snow	General	Alert	General
Pavement								
	Temperature							
		Surface	Y	Y	Y	N	N	N
		Subsurface	Y	Y	Y	N	N	N
	Surface condition		Y	Y	Y	N	Y	Y
	Chemical concentration		Y	N	N	N	N	N
Weather								
	Wind							
		Speed	Y	Y	Y	Y	Y	Y
		Direction	Y	Y	Y	Y	N	N
	Temperature							
		Air	Y	Y	Y	Y	N	Y
		Dewpoint/Humidity	Y	Y	Y	Y	N	N
	Solar radiation		Y	Y	Y	N	N	N
	Pressure		N	N	N	Y	N	N
	Visibility		Y	Y	Y	Y	Y	N
	Present weather		Y	Y	N	Y	N	Y
	Precipitation							
		Amount	Y	Y	Y	Y	N	N
		Rate	Y	Y	Y	Y	Y	N
		Begin/end times	Y	Y	Y	Y	Y	N
		Type	Y	Y	Y	Y	Y	Y

<u>Legend</u>

Snow = Snow and ice control activities.

Other = Road maintenance activities other than snow and ice control.

General = Weather and/or road condition information used for other than snow and ice control or severe conditions alert.

Table C3 presents another list of road weather observation elements adapted from an Ohio University study.[28] These data are based on responses from users and administrators from three state DOTs and a European country. Study participants were asked to evaluate the importance of sensors by comparing them in pairs using a scale of 1 to 10, such that the sum of the rankings of the two sensors totaled 10. If two sensors were equally important, they would each be given a score of 5. The evaluator might give a very useful sensor a score of 9 and a sensor not useful to that evaluator a score of 1.

The inputs for all comparisons were used to compute the relative importance of the types of measurements. The results shown in Table C3 provide a prioritized list of the sensor measurements, with the precipitation type considered the most important and wind gusts the least important. While this table may help state DOTs prioritize their sensor requirements, it should be noted that the results were based on a single study with a limited sample size. Table C3 should be considered just another tool in evaluating sensor requirements. The final decision for sensor selections should reflect DOT operational requirements for road weather information.

Table C.3. RWIS Sensor Measurement Rankings

Sensor Measurement
Precipitation Type
Surface Temperature
Surface Status (dry/wet)
Precipitation Rate or Intensity
Visibility
Precipitation Accumulation
Chemical Percentage or Factor
Dewpoint
Air Temperature
Ice Percentage
Freezing Point Temperature
Depth of Water Layer
Wind Speed
Relative Humidity
Wind Direction
Barometric Pressure
Subsurface Temperature
Wind Gusts

[28] Zwahlen, H.T., et al. Evaluation of ODOT Roadway/Weather Sensor Systems for Snow and Ice Removal Operations Part I: RWIS. Human Factors and Erg0onomics Laboratory, Ohio University. June 2003.

Appendix D – ESS Checklist

This checklist is a synopsis of the siting criteria contained in the main document. The checklist provides an organized list of considerations for uniform siting of ESSs. Section numbers refer to locations in the main document.

Identify Road Weather Data Requirements and Uses (Section 2.0)

- ☐ Detect or monitor roadway conditions.
- ☐ Support winter maintenance decisions.
- ☐ Support road temperature modeling.
- ☐ Support improved weather forecasts.
- ☐ Warn travelers of road conditions.
- ☐ Help manage traffic.
- ☐ Support road construction.
- ☐ Other uses.

Identify Basic Requirements for the Site

- ☐ Regional site to provide road and weather data representative of a general area. Generally used to monitor the onset or existence of predicted conditions and to provide information used to forecast weather and road conditions. (Section 2.2)
- ☐ Local site used to detect existing or changing conditions at a specific site or to provide a predictor for the condition and site. (Section 2.2)
- ☐ Site with other associated ITS components (DMS, anti-icing system). (Section 2.2)

Identify Candidate Locations for the Site

- ☐ Choose candidate locations based on site requirements.
    - ☐ For a regional site, select relatively flat, open terrain removed from local non-weather influences. (Section 3.1)
    - ☐ For a local site, select candidate locations close to the road weather condition or road segment of interest or in a position specifically selected to detect and/or predict a local roadway condition (e.g., smoke or dust sources, canyon entrances, sources of road flooding). (Section 3.2)
- ☐ Identify power source options and challenges (type, access, cost). (Section 5.2)
- ☐ Identify communications options and challenges (type, capacity, frequency of access, cost). (Section 5.3)
- ☐ Other considerations (Section 5.4)
    - ☐ Identify aesthetic constraints.
    - ☐ Identify environmental and archaeological restrictions.
    - ☐ Identify maintenance worker safety issues.

    - Identify traffic safety issues and clear zones.
    - Identify geological limitations (soil, stormwater).
- Investigate opportunities to partner with other agencies (Section 5.3).
    - Identify other sites or sensors to provide weather data that can be used to monitor or predict road weather conditions.
    - Identify infrastructure resources (power, communications, sensor platforms) that can support ESS installation.
- Verify the availability of rights-of-way to install the site. In some cases, easements or other permits may be required. (Section 4.0)
- If multiple sites are being considered, assess and prioritize sites according to data requirements and uses.

Identify Sensors Needed

- Choose sensor suite-based requirements.
    - For a local condition or regional site. (Section 2.1)
        - Consider how the observations will be used.
        - What are the required weather parameters at the site of interest and what sensors can measure them directly or provide an indication of their occurrence?
    - For a regional site. (Section 2.1)
        - Select a minimum suite of initial sensors for area coverage based on agency needs.
            - Wind Speed and Direction.
            - Temperature/Dewpoint.
            - Pavement surface conditions.
            - Precipitation presence, type, and intensity.
- Consider additional sensors. (Sections 2.1 and 4.3 and Appendix C.)
    - Assess requirements, usefulness, sensor reliability/maintainability, and cost.
        - Atmospheric Pressure.
        - Subsurface Temperature.
        - Visibility.
        - Precipitation Accumulation.
        - Solar/Terrestrial Radiation.

Select a Specific Site

- Assess surroundings. (Section 4.0)
    - Identify potential obstructions to selected sensors.
    - Identify potential sensor contaminants.
        - Nearby water/dust sources, tree/terrain shadowing.
- Identify tower site (tradeoffs required). (Sections 4.0 and 4.1)
    - Assess distance from obstructions/contaminants.
    - Assess specific power/communications access.
    - Assess ease of maintenance and safety considerations for road traffic (clear zones) and maintenance personnel.

- Identify pavement surface sensor locations and lane placement to meet operations and road maintenance requirements. (Section 4.2)
- Identify site(s) for additional sensor(s) separate from tower. (Section 4.0)

Tower and Sensor Siting Recommendations

- Site tower. (Sections 4.1 and 4.2)
  - Flat terrain, not bedrock or swampy, no steep slope within 300 feet (approximately 90 meters).
  - Low vegetation/native soil for 50 feet (15 meters).
  - Upwind of roadway for season of interest.
  - Avoid standing water.
  - Position 30 to 50 feet (9 to 15 meters) from edge of paved surface.
  - Height of tower depends on selected sensor suite; at least 33 feet (10 meters) for wind sensors.
  - Tower base at the same elevation as road surface, if possible.
  - Barrier or guardrail.
  - Security fence.
  - Avoid neighboring structures, signs, and trees or tall vegetation. Towers with wind sensors should be located away from obstacles at a distance of at least 10 times the height of the nearest large obstacle, if possible.

- Site sensors.
  - Determine availability and applicability of manufacturer's siting criteria.
  - Atmospheric Temperature/Dewpoint. (Sections 3.2.2 and 4.2)
    - Shielded, well ventilated sensor.
    - Height of sensor 5 to 6.5 feet (1.5 to 2 meters).
    - Boom extended from tower at least 3 feet (1 meter).
    - For local low visibility conditions, consider alternate siting closer to the road or local sources (moisture/dust) to capture local effects.
  - Wind Speed and Direction. (Sections 3.23 and 4.2)
    - Locate the sensor away from obstacles at a distance of at least 10 times the height of nearest obstruction, if possible.
    - Height of sensor 33 feet (10 meters).
    - For high wind conditions, consider:
      - Siting additional sensors at a 10 to 16.5 feet (3 to 5 meters) height to capture local effects.
      - Locating sensors at the entry and/or exit of valleys or canyons to measure high winds due to channeling.
  - Optically-based Precipitation (Rate, Type, and Amount). (Section 4.2)
    - Height of sensor 10 feet (3 meters).
    - Avoid sun or stray light sources.
  - Visibility. (Sections 3.2.2 and 4.2)
    - Height of sensor 6.5 to 10 feet (2 to 3 meters).
    - Avoid sun or stray light sources.

    - For local low visibility conditions, consider alternate siting closer to the road or local sources (moisture/dust) to capture local effects.
  - Snow Depth. (Section 4.2)
    - Height of sensor approximately 3.5 feet (1 meter).
    - Ensure proper field of view and orientation.
  - Shortwave Solar Radiation. (Section 4.2)
    - Height of sensor at least 10 feet (3 meters).
    - Avoid reflective surfaces and shading.
  - Longwave Radiation. (Section 4.2)
    - Height of sensor at least 10 feet (3 meters).
    - Ensure clear field of view.
  - Cameras. (Section 4.2)
    - Site as high as possible to obtain clear line-of-sight or at driver's level, depending on requirement.
    - Ensure non-interference with other sensors.
  - Pavement Temperature and Pavement Condition. (Sections 3.2.1 and 4.2)
    - For local slippery pavement conditions, select location to capture critical condition.
    - In user-specified lane near edge of wheel track, flush with surface.
    - Avoid pavements with ruts or depressions that cause ponding.
    - Avoid shade, unless specific requirement dictates.
    - Utilize junction and pull boxes for ease of installation and replacement.
  - Subsurface Temperature/Moisture. (Section 4.2)
    - Depth of sensor 12 or 18 inches (30.5 or 45.5 centimeters).
    - Avoid burying under pavement sensors.
  - Precipitation Accumulation. (Section 4.2)
    - Place in as open an area as possible.
    - Consider separating from other sensors rather than mounting on the tower.
    - Consider power requirements for winter operation.
  - Barometric Pressure. (Section 4.2)
    - Avoid exposure to elements and wide temperature changes.
  - Water Level Sensors. (Section 4.2)
    - Place in low turbulent (i.e., steady flowing) portion of the flowing creek or river.
    - If installed on or next to a bridge, locate on the downstream side.
    - For roadway monitoring, place the sensor adjacent to the low point of the road segment subject to flooding.

Metadata (Section 5.6)

- Document site specific installation details.
  - Prepare appropriate databases.
  - Populate databases as metadata becomes available during deployment.
  - Provide metadata to RWIS users as needed.
- Update these data whenever changes are made to the ESS installation.

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