Wind Energy Assessment

Course No: M06-002
Credit: 6 PDH

Steven Liescheidt, P.E., CCS, CCPR

CED engineering.com
PDH FOR THE PROFESSIONAL

Continuing Education and Development, Inc.

P: (877) 322-5800
info@cedengineering.com

WIND RESOURCE ASSESSMENT HANDBOOK

Fundamentals for Conducting a Successful Monitoring Program

Prepared By:

AWS Scientific, Inc.
CESTM, 251 Fuller Road
Albany, NY 12203
www.awsscientific.com

April 1997

NREL Subcontract No. TAT-5-15283-01

Prepared for:

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, CO 80401

NOTICE: This document was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

FOREWORD

The *Wind Resource Assessment Handbook* was developed under National Renewable Energy Laboratory (NREL) Subcontract No. TAT-5-15283-01. NREL is a national laboratory of the U.S. Department of Energy managed by Midwest Research Institute under contract No. DE-AC36-83CH10093.

Much of the material presented in the handbook was originally compiled for the preparation of the *U*WRAP Handbook.* This publication was written by AWS Scientific, Inc., in support of the Utility Wind Resource Assessment Program (U*WRAP), and was distributed to interested utilities. The success of the *U*WRAP Handbook* prompted requests from wind energy industry representatives that a similar handbook be made available for the public domain. In response to these requests, NREL contracted with AWS Scientific, Inc. to write a wind resource assessment handbook suitable for any organization or individual desiring to conduct a formally structured wind measurement program.

The principal authors were Bruce H. Bailey and Scott L. McDonald of AWS Scientific, Inc. Contributing authors were Daniel W. Bernadett, Michael J. Markus, and Kurt V. Elsholz, also of AWS Scientific, Inc.

ACKNOWLEDGMENTS

The approval process for this handbook included extensive peer review. The authors would like to extend their appreciation to those who gave time and effort to review chapters and make invaluable suggestions, thereby improving this document: Marc Schwartz, Dennis Elliott, Dave Blittersdorf, Ken Cohn, Rich Simon, Jack Kline, Vaughn Nelson, and Ken Starcher. Special thanks go to Donna Baker for production support.

The authors also express their appreciation to the following individuals for their support of the Utility Wind Resource Assessment Program: Ron Loose, Department of Energy; Bob Thresher, Sue Hock and Marc Schwartz, National Renewable Energy Laboratory; Charles Linderman, Edison Electric Institute; Earl Davis, Electric Power Research Institute; and Robert Putnam, Electrotek Concepts, Inc.

TABLE OF CONTENTS

LIST OF FIGURES, TABLES AND FORMS

LIST OF FIGURES

LIST OF TABLES

LIST OF FORMS

Chapter 1

INTRODUCTION

This handbook presents industry-accepted guidelines for planning and conducting a wind resource measurement program to support a wind energy feasibility initiative. These guidelines, which are detailed and highly technical, emphasize the tasks of selecting, installing, and operating wind measurement equipment, as well as collecting and analyzing the associated data, once one or more measurement sites are located. The handbook's scope encompasses state-of-the-art measurement and analysis techniques at multiple heights on tall towers (e.g., 50 m) for a measurement duration of at least one year. These guidelines do not represent every possible method of conducting a quality wind measurement program, but they address the most important elements based on field-proven experience.

The intended audience for this handbook is any organization or individual who desires the planning framework and detailed procedures for conducting a formally structured wind measurement program. Personnel from the management level to field technicians will find this material applicable. The organizational aspects of a measurement program, including the setting of clear program objectives and designing commensurate measurement and quality assurance plans, all of which are essential to ensuring the program's successful outcome, are emphasized. Considerable attention is also given to the details of actually conducting the measurement program in its many aspects, from selecting instrumentation that meets minimum performance standards to analyzing and reporting on the collected data.

The predecessor of and motivation for this handbook was a similar document—the *U*WRAP Handbook*—developed in 1995 for the Utility Wind Resource Assessment Program (U*WRAP). This program was initiated by the U.S. Department of Energy and is administered by the Utility Wind Interest Group, Inc., to technically and financially support utilities that conduct wind resource assessments. The goal of U*WRAP is to increase the quality and quantity of wind data available to utilities, thereby improving their ability to evaluate and integrate wind energy as an electric generation technology. By establishing standard measurement procedures, this program is compiling high-quality data sets, which enable utility participants to evaluate resource-related wind energy feasibility issues among a large number of dispersed sites. With the present handbook, the non-utility entity can achieve similar benefits.

1.1 OVERVIEW OF CHAPTERS

The handbook contains 10 chapters and an appendix. Following is a brief overview of the contents of each chapter.

Chapter 2: Guiding Principles of a Wind Resource Assessment Program

Discusses various resource assessment approaches and recommends the use of a formal measurement plan, a monitoring strategy, and a quality assurance plan.

Chapter 3: Siting of Monitoring Systems

Summarizes the most commonly used siting techniques and addresses land leasing and permitting requirements for a measurement tower.

Chapter 4: Measurement Parameters

Details the recommended measurement parameters and offers guidelines for incorporating other optional parameters that may benefit your monitoring program.

Chapter 5: Monitoring Station Instrumentation

Describes the instrument components (sensors, data loggers, towers, peripherals) of a recommended wind resource monitoring station, including the performance specifications for basic and optional sensors.

Chapter 6: Installation of Monitoring Stations

Provides guidelines on equipment procurement, inspection and layout, site layout, tower installation, sensor and equipment installation, site commissioning, and documentation.

Chapter 7: Station Operation and Maintenance

Details the key elements of an operation and maintenance program, including scheduled and unscheduled site visits, on-site procedures, checklists and logbooks, calibration checks, and a spare parts inventory.

Chapter 8: Data Collection and Handling

Highlights data issues related to in-field raw data storage, data retrieval and protection, retrieval frequency, and documentation.

Chapter 9: Data Validation, Processing, and Reporting

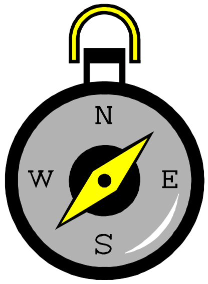
Recommends specific steps to inspect all recorded data values, deal with erroneous values, create validated data files, and generate standard summary reports.

Chapter 10: Costs and Labor Required for a Wind Monitoring Program

Illustrates the approximate cost and labor effort to site, procure, install, and operate a qualified monitoring station for two years.

Appendices

A. Wind Resource Assessment Equipment Vendors
B. Bibliography



Chapter 2
GUIDING PRINCIPLES OF A WIND RESOURCE ASSESSMENT PROGRAM

A wind resource assessment program is similar to other technical projects. It requires planning and coordination and is constrained by budget and schedule limitations. It demands a clear set of objectives so the best assessment approach is selected. Its ultimate success rests on the quality of the program's assembled assets—sound siting and measurement techniques, trained staff, quality equipment, and thorough data analysis techniques.

2.1 APPROACHES AND OBJECTIVES

Several approaches are available when investigating the wind resource within a given land area. The preferred approach will depend on your wind energy program objectives and on previous experience with wind resource assessment. These approaches can be categorized as three basic scales or stages of wind resource assessment: preliminary area identification, area wind resource evaluation, and micrositing.

A. Preliminary Area Identification

This process screens a relatively large region (e.g., state or utility service territory) for suitable wind resource areas based on information such as airport wind data, topography, flagged trees, and other indicators. At this stage new wind measurement sites can be selected. Details on site screening techniques are provided in Chapter 3.

B. Area Wind Resource Evaluation

This stage applies to wind measurement programs to characterize the wind resource in a defined area or set of areas where wind power development is being considered. The most common objectives of this scale of wind measurement are to:

- Determine or verify whether sufficient wind resources exist within the area to justify further site-specific investigations
- Compare areas to distinguish relative development potential
- Obtain representative data for estimating the performance and/or the economic viability of selected wind turbines
- Screen for potential wind turbine installation sites.

C. Micrositing

The smallest scale, or third stage, of wind resource assessment is micrositing. Its main objective is to quantify the small-scale variability of the wind resource over the terrain of interest. Ultimately, micrositing is used to position one or more wind turbines on a parcel of land to maximize the overall energy output of the wind plant. This step is beyond the scope of this handbook. For more information, refer to the sources listed in the bibliography.

2.2 MEASUREMENT PLAN

Common to all monitoring programs is the need for a measurement plan. Its purpose is to ensure that all facets of the wind monitoring program combine to provide the data you need to meet your wind energy program objectives. Therefore, the program's objectives should dictate the design of the measurement plan, which should be documented in writing, and reviewed and approved by the project participants before it is implemented. The plan should specify the following features:

- Measurement parameters
- Equipment type, quality, and cost
- Number and location of monitoring stations
- Sensor measurement heights
- Minimum measurement accuracy, duration, and data recovery
- Data sampling and recording intervals
- Data storage format
- Data handling and processing procedures
- Quality control measures
- Format of data reports.

This handbook provides guidance on all these features.

2.3 MONITORING STRATEGY

How the measurement plan is carried out is the basis for the monitoring strategy. Its core is good management, qualified staff, and adequate resources. Everyone involved should understand the roles and responsibilities of each participant, and the lines of authority and accountability. Everyone should be familiar with the program's overall objectives, measurement plan, and schedule. Communications among the players should be often and open.

Because of the complexities of siting and monitoring, the project team should include at least one person with field measurement experience. Data analysis, interpretation, and computer skills are also necessary assets. Available human and material resources must be commensurate with the measurement program's objectives. High standards of data accuracy and completeness therefore require appropriate levels of staffing, an investment in quality equipment and tools, prompt responsiveness to unscheduled events (e.g., equipment outages), access to spare parts, routine site visits, and timely review of the data.

2.4 QUALITY ASSURANCE PLAN

An essential part of every measurement program is the quality assurance plan, an organized and detailed action agenda for guaranteeing the successful collection of high-quality data. The plan should be prepared in writing once the measurement plan is completed.

- **Quality Assurance Policy:** The program manager must first establish and endorse the quality assurance plan. This will lend credence to the party assigned the responsibility of enforcing the plan.

- **Quality Assurance Coordinator:** The link between the plan and the program management should be the quality assurance coordinator. This person should be knowledgeable of the routine operation requirements for collecting valid data. If the quality assurance plan is to be taken seriously, this person must be authorized to ensure that all personnel are properly trained, correct procedures are followed, and corrective measures are taken. In addition, the coordinator should maintain the proper documentation in an organized format.

Data quality is usually measured in terms of representativeness, accuracy, and completeness. The quality assurance plan relies heavily on the documentation of the procedures involved to support claims of data quality. The components of the plan should include the following:

- Equipment procurement tied to the program's specifications
- Equipment calibration method, frequency, and reporting
- Monitoring station installation and operation and maintenance checklists
- Data collection and retrieval forms
- Data analysis guidelines (calculations, etc.)
- Data validation methods, flagging criteria, and reporting format
- Internal audits to document the performance of those responsible for site installation and operation and maintenance, as well as collecting and handling data.

Another goal of quality assurance is to minimize the uncertainties that unavoidably enter into every step of the siting and measurement processes. No site perfectly represents the entire area it describes, no sensor measures perfectly, and no data gathered over an extended measurement period perfectly reflect all future wind conditions a wind plant will experience during its 30-year lifetime. However, if the magnitude of these uncertainties is understood and controlled through a concerted quality assurance plan, the conclusions can be properly qualified to provide useful information.

2.5 MONITORING DURATION AND DATA RECOVERY

The minimum monitoring duration should be one year, but two or more years will produce more reliable results. One year is usually sufficient to determine the diurnal and seasonal variability of the wind. With the aid of a well-correlated, long-term reference station such as an airport, the interannual variability of the wind can also be estimated. The data recovery for all measured parameters should be at least 90% over the program's duration, with any data gaps kept to a minimum (less than a week).

Chapter 3

SITING OF MONITORING SYSTEMS

The main objective of a siting program is to identify potentially windy areas that also possess other desirable qualities of a wind energy development site. There are three steps in the siting effort:

- Identification of potential wind development areas;
- Inspection and ranking of candidate sites; and
- Selection of actual tower location(s) within the candidate sites.

Since the initial analysis region can be quite large, such as a utility service territory or even an entire state, the siting process should be designed so it efficiently focuses on the most suitable areas.

The next two sections discuss several industry accepted siting techniques and tools. These include the use of existing wind data and the analysis of topographic maps. The final three sections outline steps to be taken following initial site identification. These include site surveys, choosing an appropriate tower location, and obtaining necessary permits before the tower is installed.

The following documents contain more detailed discussions of general siting techniques:

- *Recommended Practice for the Siting of Wind Energy Conversion Systems*
- *Siting Guidelines for Utility Application of Wind Turbines*
- *The Meteorological Aspects of Siting Large Wind Turbines*
- *A Siting Handbook for Small Wind Energy Conversion Systems*

See Appendix B for ordering information.

3.1 USE OF WIND DATA SOURCES

Wind data are useful in the early stage of the siting process. These data represent records of actual wind conditions, so they must be evaluated before the windiest areas of a particular region are sought. Unfortunately, most historical wind data were not collected for wind energy assessment purposes. Thus the results often represent the mean conditions near population centers in relatively flat terrain or low elevation areas. Their primary benefit to the analyst, therefore, is to provide a general description of the wind resource within the analysis area, not to pinpoint the windiest locales.

Common sources of wind information include the National Climatic Data Center (which archives weather data from all National Weather Service stations), universities, air quality monitoring networks, electric utilities, the U.S. Forest Service, and various other government and private organizations. Wind information from many of these sources has been synthesized by the Pacific Northwest Laboratory on behalf of the U.S. Department of Energy. You should contact several data sources, as no one particular organization likely possesses full data coverage for the area(s) of interest or provide all statistics used in the wind resource characterization. For example, wind shear data are generally not available from National Weather Service stations because these stations do not use multi-level towers. A better source of information in this instance may be a utility's air quality monitoring tower if it is in a representative location.

A. Regional Wind Resource Data

Regional wind resource estimates can be obtained from the *Wind Energy Resource Atlas of the United States.* The atlas integrated pre-1979 wind measurements with topography and landform characteristics to arrive at its wind resource estimates. Data from approximately 270 post-1979 sites, including nearly 200 that were instrumented specifically for wind energy purposes, were used to verify or update the original wind resource values. The updated wind resource values are depicted on gridded maps, 1/4° latitude by 1/3° longitude resolution for the 48 contiguous states. Different resolutions were used for Alaska, Hawaii, and the U.S. territories. Estimates of the wind resource are expressed in wind power classes ranging from Class 1 to Class 7, with each class representing a range of mean wind power density or equivalent mean wind speed at specified heights above the ground. Table 3.1 defines the wind power classes in terms of the upper limits of mean wind power density and mean wind speed at 30 m (98 ft) and 50 m (164 ft) above ground level.

Grid cells designated as Class 4 or greater are generally considered to be suitable for most wind turbine applications. Class 3 areas are suitable for wind energy development using tall (e.g., 50 m hub height) turbines. Class 2 areas are marginal and Class 1 areas are unsuitable for wind energy development. The gridded wind resource estimates were not meant to address the variability in mean wind speed on a local scale but to indicate broad areas where a high wind resource is possible. Therefore, in approaching an area designated as Class 2, for example, the analyst should not rule out the possibility that it may contain smaller-scale features possessing a more energetic (Class 3 or greater) wind resource.

Table 3.1
Classes of Wind Power Density

	30 m (98 ft)		**50 m (164 ft)**	
Wind Power Class	**Wind Power Density (W/m²)**	**Wind Speed m/s (mph)**	**Wind Power Density (W/m²)**	**Wind Speed m/s (mph)**
1	≤160	≤5.1 (11.4)	≤200	≤5.6 (12.5)
2	≤240	≤5.9 (13.2)	≤300	≤6.4 (14.3)
3	≤320	≤6.5 (14.6)	≤400	≤7.0 (15.7)
4	≤400	≤7.0 (15.7)	≤500	≤7.5 (16.8)
5	≤480	≤7.4 (16.6)	≤600	≤8.0 (17.9)
6	≤640	≤8.2 (18.3)	≤800	≤8.8 (19.7)
7	≤1600	≤11.0 (24.7)	≤2000	≤11.9 (26.6)

Certainty ratings were also generated for each grid cell to depict a confidence level in the wind resource estimate. The degree of certainty depends on the following three factors:

- The abundance and quality of wind data
- The complexity of the terrain
- The geographical variability of the wind resource.

The highest degree of confidence (rating 4) was assigned to grid cells containing abundant historical data and relatively simple terrain; the lowest certainty (rating 1) was assigned to data-sparse regions or those within complex terrain.

B. Site-Specific Wind Data

If you wish to closely examine wind data from selected stations, several attributes about the data should be determined including:

- Station location
- Local topography
- Anemometer height and exposure
- Type of observation (instantaneous or average)
- Duration of record.

Data are more representative of the surrounding area where the terrain is relatively flat. In complex terrain, the ability to reliably extrapolate the information beyond a station's immediate vicinity is limited. In recent decades, most airport measurements have been taken adjacent to the runways where the surrounding area is open and unobstructed. Measurements taken from rooftops may be unreliable due to the building's influence on the wind flow and should be used with caution.

Typical airport anemometer heights are in the 6 m to 15 m (20-50 ft) range. When comparing data with other stations, all wind speed data should be extrapolated to a common reference height (e.g., 30 m or 40 m). Wind speeds can be adjusted to another height using the following form of the power law equation:

$$v_2 = v_1 \times \left[\frac{z_2}{z_1}\right]^{\alpha}$$

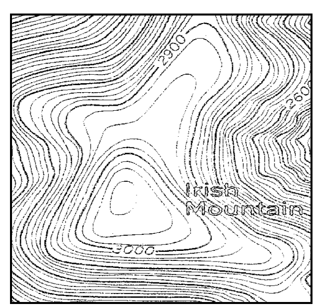
where

v_2 = the unknown speed at height z_2
v_1 = the known wind speed at the measurement height z_1
α = the wind shear exponent.

As a first approximation, the wind shear exponent is often assigned a value of 0.143, known as the 1/7th power law, to predict wind profiles in a well-mixed atmosphere over flat, open terrain. However, higher exponent values are normally observed over vegetated surfaces and when wind speeds are light to moderate (i.e., under 7 m/s or 16 mph).

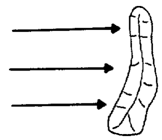
Referenced data sets should be at least one year in duration and possess consistent data for at least 90 percent of that period. A useful format is a time series of hourly wind speed and wind direction measurements, which can be analyzed for a number of user-specified wind characteristics. In many instances, wind data summaries will already be available, which eliminates the need to process the data.

3.2 TOPOGRAPHIC INDICATORS

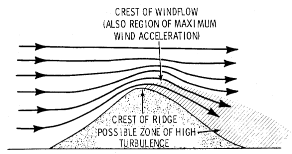


The analysis of topographic maps is an effective means of streamlining the siting process. Maps on a 1:24,000 scale (1 in = 2,000 ft) available from the U.S. Geological Survey (USGS) are the best source of information for identifying suitable terrain features. The topographic screening should attempt to identify features that are likely to experience a greater mean wind speed than the general surroundings. This process is especially important for areas containing little or no relevant historical wind speed data. Features that are likely to be windier include:

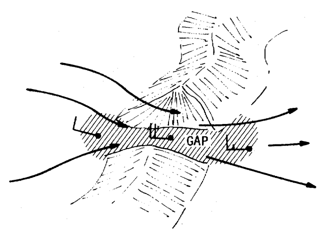
- Ridges oriented perpendicular to the prevailing wind direction



- Highest elevations within a given area



- Locations where local winds can funnel.



Features to be avoided include areas immediately upwind and downwind of higher terrain, the lee side of ridges, and excessively sloped terrain. In each of these situations, increased turbulence may occur.

Topographic maps also provide the analyst with a preliminary look at other site attributes, including:

- Available land area
- Positions of existing roads and dwellings
- Land cover (e.g., forests)
- Political boundaries
- Parks
- Proximity to transmission lines.

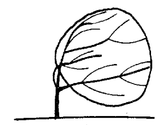
Following the topographic screening, a preliminary ranking can be assigned to the list of candidate sites based on their estimated wind resource and overall development potential.

3.3 FIELD SURVEYS AND SITE RANKING

Visits should be conducted to all potentially suitable areas with the main goal of verifying site conditions. Items of importance include:

- Available land area
- Land use

- Location of obstructions
- Trees deformed by persistent strong winds (flagged trees)
- Accessibility into the site
- Potential impact on local aesthetics
- Cellular phone service reliability for data transfers
- Possible wind monitoring locations.



The evaluator should use a USGS topographic map of the area to note the presence or absence of the above site characteristics. A Global Positioning System (GPS) receiver should be used to record the location coordinates (latitude, longitude, elevation) of the sites. A video or still camera record is useful for future reference and presentation purposes. While at the site, the evaluator should determine the soil conditions so the proper anchor type can be chosen if a guyed meteorological tower is to be installed.

An updated ranking of all candidate sites should be developed following the site visits. This can be obtained by constructing a matrix that assigns a score to each siting criterion. For example, suppose the siting criteria are similar to the bulleted features listed above. The evaluator assigns a numerical score (e.g., 1 to 10) to every criterion for each site that was visited. If some criteria are more important than others, their scores can be weighted accordingly. The weighted scores are then summed and sorted by magnitude to reach a composite ranking.

Field visits also provide an opportunity to make personal contact with landowners. The program's objectives can be presented and questions answered in a friendly face-to-face conversation. The landowners' concerns and interest in the monitoring program or the prospects of a wind turbine project can also be assessed..

While wind turbines are increasingly becoming an accepted part of the landscape, the issues of aesthetics can still present real obstacles to any project. There is no universal or consistent view of what is or is not pleasing to the eye, so the evaluator must rely on his or her judgment based on the character of the land and the proximity of public viewing areas. It is in the project's best interests to investigate this topic in-depth during the evaluation process. A detailed examination of this issue is beyond the scope of this handbook. For more information, refer to the bibliography.

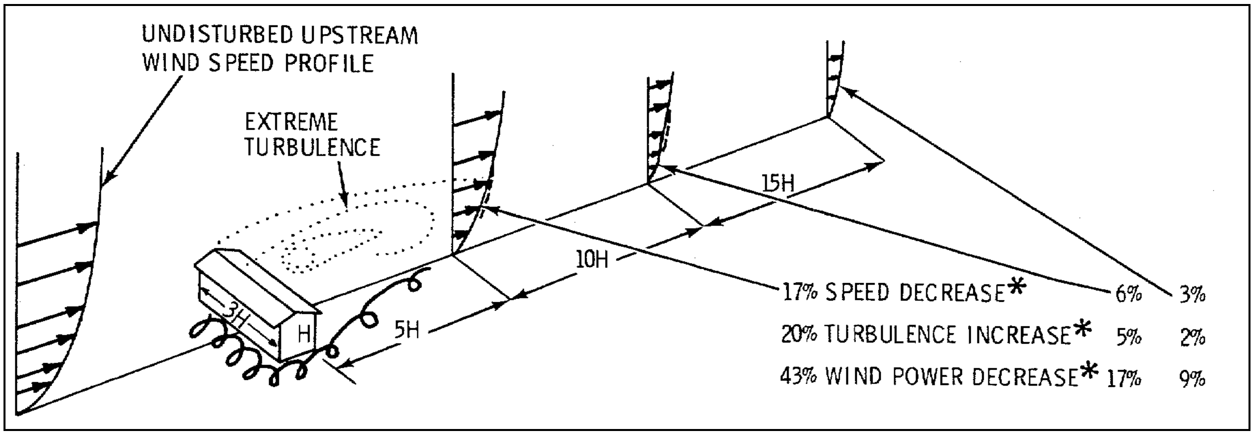
3.4 TOWER PLACEMENT

Two important guidelines should be followed when choosing an exact location for the monitoring tower:

- Place the tower as far away as possible from local obstructions to the wind
- Select a location that is representative of the majority of the site.

Siting a tower near obstructions such as trees or buildings can adversely affect the analysis of the site's wind characteristics. Figure 3.1 illustrates the effects of an undisturbed airflow that encountering an obstruction. The presence of these features can alter the perceived magnitude of the site's overall wind resource, wind shear, and turbulence levels. As a rule, if sensors must be near an obstruction, they should be located at a horizontal distance no closer than 10 times the height of the obstruction in the prevailing wind direction.

Figure 3.1 Obstruction Effects on Airflow

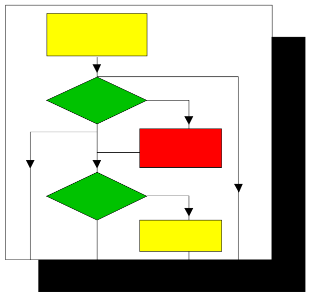


3.5 LAND LEASING AND PERMITTING

Inquiries must always be made to determine whether permits are required before a tower is installed. Tilt-up towers usually fall into the category of temporary structures, so permitting requirements are generally minimal. Jurisdictions normally require a standard building permit, which should be displayed at the site during the installation period. Building permits can be acquired from the town clerk or directly from the town building inspector. Fees are usually $10-$100 range.

Formal lease agreements should be negotiated between the utility and the landowner to protect the parties involved. They should include:

- The tower location
- Total area required for monitoring
- Duration of monitoring period
- Liability
- Insurance
- Title to data and equipment
- Access to premises
- Payment schedule.



Chapter 4

MEASUREMENT PARAMETERS

This chapter details the basic recommended measurement parameters and provides guidelines for incorporating optional parameters that may benefit your wind resource monitoring program.

4.1 BASIC PARAMETERS

The core of the monitoring program is the collection of wind speed, wind direction, and air temperature data. A description of each parameter, its purpose, and appropriate monitoring height(s) is presented below and summarized in Table 4.1. These nominal parameters are recommended to obtain the basic information needed to evaluate resource-related wind energy feasibility issues.

A. Wind Speed

Wind speed data are the most important indicator of a site's wind energy resource. Multiple measurement heights are encouraged for determining a site's wind shear characteristics, conducting turbine performance simulations at several turbine hub heights, and for backup. Heights typical of recent NREL-affiliated wind measurement programs are 40 m, 25 m, and 10 m.

Table 4.1
Basic
Measurement Parameters

Measured Parameters	Monitoring Heights
Wind Speed (m/s)	10 m, 25 m, 40 m
Wind Direction (degrees)	10 m. 25 m, 40 m
Temperature (°C)	3 m

- **40 m:** This height represents the approximate hub height of most utility-scale wind turbines. Actual hub heights are usually in the 50 m to 65 m range.
- **25 m:** This level approximates the minimum height reached by the blade tip portion of a rotating turbine rotor and will help define the wind regime encountered by a typical turbine rotor over its swept area.
- **10 m:** This is the universally standard meteorological measurement height. However, in locations where the interference of local vegetation (e.g., forest) at this height is unavoidable, an alternative low-level height of 10 m above the forest canopy may be used.

These significant measurement heights are becoming commonly observed and will be referenced for the balance of this handbook. You may select additional or alternative heights.

B. Wind Direction

To define the prevailing wind direction(s), wind vanes should be installed at all significant monitoring levels. Wind direction frequency information is important for identifying preferred terrain shapes and orientations and for optimizing the layout of wind turbines within a wind farm.

C. Temperature

Air temperature is an important descriptor of a wind farm's operating environment and is normally measured either near ground level (2 to 3 m), or near hub height. In most locations the average near ground level air temperature will be within 1°C of the average at hub height. It is also used to calculate air density, a variable required to estimate the wind power density and a wind turbine's power output.

4.2 OPTIONAL PARAMETERS

You may expand your monitoring effort to include additional measurement parameters. Possible optional parameters are presented in detail below and summarized in Table 4.2.

A. Solar Radiation

You may want to take advantage of your wind monitoring program to measure the solar resource for later solar energy evaluating studies. Solar radiation, when used in conjunction with wind speed and time of day, can also be an indicator of atmospheric stability and is used in numerical wind flow modeling. The recommended measurement height is 3 to 4 m above ground.

Table 4.2
Optional Measurement Parameters

Measured Parameters	Monitoring Heights
Solar Radiation (W/m^2)	3 - 4 m
Vertical Wind Speed (m/s)	38 m
Delta Temperature (°C)	38 m 3 m
Barometric Pressure (kPa)	2 - 3 m

B. Vertical Wind Speed

This parameter provides more detail about a site's turbulence and can be a good predictor of wind turbine loads. Historically this parameter has been a research measurement, but as wind energy development spreads into new regions of the country, regional information on vertical wind velocity may become important. To measure the vertical wind component (w) as an indicator of wind turbulence, a "w" anemometer should be located near the upper basic wind speed monitoring level (but not exactly at that level to avoid instrument clutter).

C. Change in Temperature With Height

This measurement, also referred to as delta temperature (ΔT), provides information about turbulence and historically has been used to indicate atmospheric stability. A matched set of temperature sensors should be located near the lower and upper measurement levels without interfering with the wind measurements.

D. Barometric Pressure

Barometric pressure is used with air temperature to determine air density. It is difficult to measure accurately in windy environments because of the dynamic pressures induced when wind flows across an instrument enclosure. An indoor or office environment is a preferred setting for a pressure sensor. Therefore, most resource assessment programs do not measure barometric pressure and instead use data taken by a regional National Weather Service station that is then adjusted for elevation.

4.3 RECORDED PARAMETERS AND SAMPLING INTERVALS

The measured parameters presented in this section represent internal processing functions of the data logger. All parameters should be sampled once every one or two seconds and recorded as averages, standard deviations, and maximum and minimum values. Data recording should be serial in nature and designated by a corresponding time and date stamp. The recorded values will be the basis for the data validation procedures presented in Chapter 9. Each is presented below and summarized in Table 4.3.

A. Average

The average value should be calculated for all parameters on a ten-minute basis, which is now the international standard period for wind measurement. Except for wind direction, the average is defined as the mean of all samples. For wind direction, the average should be a unit vector (resultant) value. Average data are used in reporting wind speed variability, as well as wind speed and direction frequency distributions.

Table 4.3
Basic and Optional Parameters

Measured Parameters	Recorded Values
Wind Speed (m/s)	Average Standard Deviation Maximum/Minimum
Wind Direction (degrees)	Average Standard Deviation Maximum Gust Direction
Temperature (°C)	Average Maximum/Minimum
Solar Radiation (W/m^2)	Average Maximum/Minimum
Vertical Wind Speed (m/s)	Average Standard Deviation
Barometric Pressure (hPa)	Average Maximum/Minimum
Delta Temperature (°C)	Average Maximum/Minimum

* Shaded parameters are optional

B. Standard Deviation

The standard deviation should be determined for both wind speed and wind direction and is defined as the true population standard deviation (σ) for all one or two second samples within each averaging interval. The standard deviations of wind speed and wind direction are indicators of the turbulence level and atmospheric stability. Standard deviation is also useful in detecting suspect or erroneous data when validating average values.

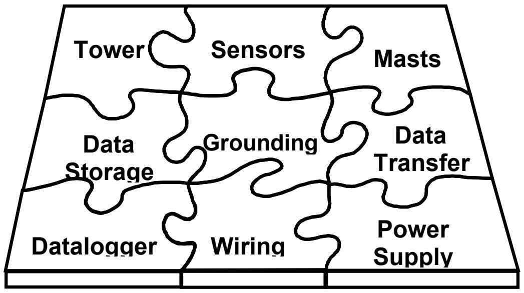
C. Maximum and Minimum

Maximum and minimum values should be determined for wind speed and temperature at least daily. The maximum (minimum) value is defined as the greatest (lowest) one or two second reading observed within the preferred period. The coincident direction corresponding to the maximum (minimum) wind speed should also be recorded.

4.4 SUPPLEMENTAL PARAMETERS TO CLASSIFY WIND ENERGY SITES

The primary purpose of the wind measurement program recommended thus far is to collect data for use in basic wind resource assessment applications. However, additional processing of these data to include recorded ten-minute maximum wind speeds and wind speed differences between measurement levels would provide new information for use in the detailed classification of wind energy sites. As described below, these classifications comply with the new International Electrotechnical Commission (IEC) standards for both wind sites and wind turbines.

- The maximum one-second value of wind speed and the coincident wind direction corresponding to that speed would be recorded for each ten-minute interval
- The wind speed difference between two anemometers installed at different heights would be determined. The average, standard deviation, and maximum values of one-second speed differences would be recorded for each ten-minute interval. For anemometers installed at heights of 10 m, 25 m, and 40 m, speed differences would be determined for three height layers: 10 m to 40 m, 10 m to 25 m, and 25 m to 40 m.



Chapter 5

MONITORING STATION INSTRUMENTATION

The instrumentation used in a wind resource assessment program should meet all your data monitoring objectives. For example, the equipment should reliably measure the selected parameters at the prescribed heights for the full monitoring duration and at the specified levels of data recovery and accuracy. It should also be tailored to the environment of the intended location (e.g., weather extremes, dust, salt) and the remoteness (i.e., whether data will be retrieved manually or via communication link). The equipment should also be proven, affordable, and user-friendly. Complete monitoring systems can be purchased from a single vendor or components combined from different ones (see Appendix A).

This chapter describes the instrumentation components of a wind resource monitoring station. It provides details on a station's major components (sensors, tower, and data logger) as well as the peripheral parts such as power supplies, wiring, earth grounding, data storage devices, software, and communication systems. All guidelines are consistent with accepted industry standards for meteorological monitoring (see AWEA Standard 8.1 - 1986: *Standard Procedures for Meteorological Measurements at a Potential Wind Turbine Site*).

5.1 BASIC SENSORS

Meteorological sensors are designed to monitor specific environmental parameters. This section describes instruments for measuring wind speed, wind direction, and air temperature. Table 5.1 lists the nominal specifications for these sensors.

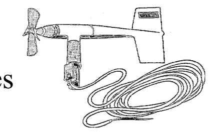
A. Wind Speed

Cup or propeller anemometers are the sensor types most commonly used for the measurement of near-horizontal wind speed.

1. **Cup anemometer:** This instrument consists of a cup assembly (three or four cups) centrally connected to a vertical shaft for rotation. At least one cup always faces the oncoming wind. The aerodynamic shape of the cups converts wind pressure force to rotational torque. The cup rotation is nearly linearly proportional to the wind speed over a specified range. A transducer in the anemometer converts this rotational movement into an electrical signal, which is sent through a wire to a data logger.

The data logger then uses known multiplier (or slope) and offset (or intercept) constants to calculate the actual wind speed.

2. **Propeller anemometer:** This instrument consists of a propeller (or prop) mounted on a horizontal shaft that is oriented into the wind through the use of a tail vane. The propeller anemometer also generates an electrical signal proportional to wind speed.



Although the two sensor types differ somewhat in their responsiveness to wind speed fluctuations, there is no clear advantage of one type over the other. In practice, the cup type is most commonly used for resource assessment.

Table 5.1
Specifications for Basic Sensors

Specification	Anemometer (Wind Speed)	Wind Vane (Wind Direction)	Temperature Probe
Measurement Range	0 to 50 m/s	0° to 360° (≤8° deadband)	-40° to 60°C
Starting Threshold	≤1.0 m/s	≤1.0 m/s	N/A
Distance Constant	≤4.0 m	N/A	N/A
Operating Temperature Range	-40° to 60°C	-40° to 60°C	-40° to 60°C
Operating Humidity Range	0% to 100%	0% to 100%	0% to 100%
System Error	≤3%	≤5°	≤1°C
Recording Resolution	≤0.1 m/s	≤1°	≤0.1°C

When selecting an anemometer model, the following should be considered:

- **Intended Application:** Anemometers intended for low wind speed applications, such as air pollution studies, are usually made from lightweight materials. These are probably not suited for very windy or icy environments.

- **Starting Threshold:** This is the minimum wind speed at which the anemometer starts and maintains rotation. For wind resource assessment purposes, it is more important for the anemometer to survive a 25 m/s wind gust than to be responsive to winds under 1 m/s.

- **Distance Constant:** This is the distance the air travels past the anemometer during the time it takes the cups or propeller to reach 63% of the equilibrium speed after a step change in wind speed. This is the "response time" of the anemometer to a change in wind speed. Longer distance constants are usually associated with heavier anemometers; inertia causes them to take longer to slow down when the wind decreases. Anemometers with larger distance constants may overestimate the wind speed.

- **Reliability and Maintenance:** Wind sensors are mechanical and eventually wear out, although most have special long-life (two years +) bearings.

The most popular wind sensor for wind resource measurements is the NRG Maximum #40 three-cup anemometer. It has demonstrated long-term reliability and calibration stability. The cup assembly is made of molded black polycarbonate plastic. The assembly is attached to a hardened beryllium copper shaft that uses modified Teflon bearings for rotation. This bearing assembly requires no maintenance and remains accurate for at least two years in most environments.

The use of redundant anemometers at a given height is recommended for minimizing the risk of wind speed data loss due to a failed primary sensor. Redundant sensors are situated to not interfere with the wind the primary sensor measures. The redundant sensor can also be used to provide substitution data when the primary sensor is in the wake of the tower (i.e., when the wind direction places the primary sensor directly downwind of the tower, resulting in erroneous data). Generally, it will be less expensive to provide sensor redundancy than to conduct an unscheduled site visit to replace or repair a failed sensor.

At the onset of the measurement program, the measurements from the redundant sensor should be compared with the primary sensor in a side-by-side field comparison of sequential recorded values. This test will determine the difference in readings attributed to the instruments themselves. To ensure that the collected sample size is sufficient and representative of a broad range of wind speeds, the test period should last at least one week. The wind direction should be noted during this period so that values taken when either sensor is downwind of the tower are not included in the comparison. A least-squares regression analysis of the valid data values will provide slope and offset calibration constants for the redundant sensor.

B. Wind Direction

A wind vane is used to measure wind direction. The most familiar type uses a fin connected to a vertical shaft. The vane constantly seeks a position of force equilibrium by aligning itself into the wind. Most wind vanes use a potentiometer type transducer that outputs an electrical signal relative to the position of the vane. This electrical signal is transmitted via wire to a data logger and relates the vane's position to a known reference point (usually true north). Therefore, the alignment (or orientation) of the wind vane to a specified reference point is important.

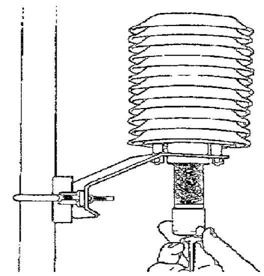
The data logger provides a known voltage across the entire potentiometer element and measures the voltage where the wiper arm contacts a conductive element. The ratio between these two voltages determines the position of the wind vane. This signal is interpreted by the data logger system, which uses the ratio (a known multiplier) and the offset (a known correction for any misalignment to the standard reference point) to calculate the actual wind direction. Electrically the linear potentiometer element does not cover a full 360°. This “open” area is the deadband of the wind vane. When the wiper arm is in this area, the output signal is random. Some manufacturers compensate for the deadband in their data logger software to prevent random signals. Therefore, the deadband area should not be aligned into or near the prevailing wind direction.

When choosing a wind vane, you should use the same selection criteria as for the anemometer. Pay particular attention to the size of the open deadband area of the potentiometer; this should not exceed 8°. The resolution of the wind vane is also important. Some divide a complete 360° rotation into 16, 22.5° segments. This resolution is too coarse for optimizing the layout of a wind turbine array.

A popular wind vane model is the NRG 200P because of its simple design and low maintenance requirements. It is a passive potentiometer constructed of thermoplastic and stainless steel components. Other models offer enhanced performance, such as higher sensitivities, but this comes at a much higher price usually not warranted by the program objectives.

C. Air Temperature

A typical ambient air temperature sensor is composed of three parts: the transducer, an interface device, and a radiation shield. The transducer contains a material element (usually nickel or platinum) with a relationship between its resistance and temperature. Thermistors, resistance thermal detectors (RTDs), and semiconductors are common element types recommended for use. The resistance value is measured by the data logger (or an interface device), which uses a known equation to calculate the actual air temperature. The transducer is housed within a radiation shield to protect it from direct solar radiation. A common radiation shield is the Gill type, multi-layer, passive shield.



5.2 OPTIONAL SENSORS

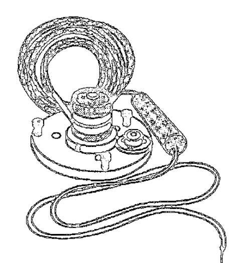
In addition to the required measurements, you may wish to include optional sensors for solar radiation, vertical wind speed, ΔT, and barometric pressure. Table 5.2 lists the nominal specifications for these sensors.

Table 5.2
Specifications for Optional Sensors

Specification	Pyranometer (Solar Radiation)	W Anemometer (Vertical Wind Speed)	ΔT Sensors (Delta Temperature)	Barometer (Atmospheric Pressure)
Measurement Range	0 to 1500 W/m^2	0 to 50 m/s	-40 to 60°C	94 to 106 kPa (sea level equivalent)
Starting Threshold	N/A	≤1.0 m/s	N/A	N/A
Distance Constant	N/A	≤4.0m	N/A	N/A
Operating Temperature Range	-40 to 60°C	-40 to 60°C	-40 to 60°C	-40 to 60°C
Operating Humidity Range	0 to 100%	0 to 100%	0 to 100%	0 to 100%
System Accuracy	≤5%	≤3%	≤0.1°C	≤1 kPa
Recording Resolution	≤1 W/m^2	≤0.1 m/s	≤0.01°	≤0.2 kPa

A. Global Solar Radiation

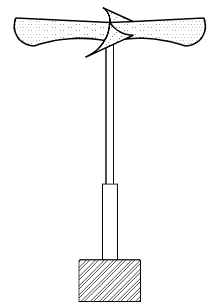
A pyranometer is used to measure global, or total, solar radiation, which combines direct sunlight and diffuse sky radiation. One common type uses a photodiode that generates a small voltage (millivolts) across a fixed resistance proportional to the amount of solar radiation (insolation). The recommended pyranometer, the LI-COR Model LI-200S, is a photodiode sensor. Another common type uses a thermopile, a group of thermal sensors that react to radiant energy and produce a voltage proportional to temperature.



An output current is measured from both types by the data logger (or interface device), which uses a known multiplier and offset to calculate the global solar radiation. The current output is usually very small (microamps or less). Normally, the measuring instrument will have a "dropping" resistor and an amplifier that conditions the signal to obtain adequate output range.

The pyranometer must be horizontally level in its final mounting position to measure accurately. It should be located above any obstructions or with its boom arm extending southward (in the Northern Hemisphere) to prevent or minimize any shading.

B. "W" Anemometer

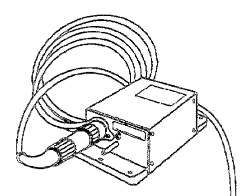


The propeller anemometer is especially suited for measuring the vertical wind component. It consists of a propeller mounted on a fixed vertical arm. The sensor requires a transducer that can electrically relate both the rotational direction (indicative of upward or downward motion) and the speed of the propeller. This signal is usually a polarized DC voltage that is interpreted by the data logging system (or interface device). The polarity indicates rotational direction; the magnitude indicates rotational speed. The data logger then uses a known multiplier and offset to calculate the actual vertical wind speed.

C. Delta Temperature Sensors

The parameter ΔT is used to determine atmospheric stability and is defined as the temperature difference between a matched pair of temperature sensing subsystems located at different heights. The sensor types previously cited are applicable and are usually tested over a specified range and matched by the manufacturer. Identical subsystems are required because of the inherent errors in the method and equipment used. If you want to conform to the rigorous guidelines cited in the *EPA Quality Assurance Handbook (1989),* the maximum allowable ΔT error is 0.003°C/m. Using the monitoring configuration of 10 m and 40 m levels, the allowable error would be approximately 0.1°C, which is quite small. To minimize errors caused by environmental factors such as direct sunlight, both monitoring heights should use identical equipment (e.g., radiation shield, mounting hardware, etc.) so they similarly respond to the ambient conditions. When the difference between the two values is taken, both errors are about the same and cancel each other out in the equation. To reduce radiation errors during all conditions, a radiation shield that uses either forced (mechanical) or natural (passive) aspiration is required. To meet EPA guidelines, forced aspiration is normally required. You should consult with the data logger manufacturer to determine a compatible sensor type and model.

D. Barometric Pressure Sensors



A barometer measures atmospheric (barometric) pressure. Several barometric pressure sensors are commercially available. Most models use a piezoelectric transducer that provides a standard output to a data logger. This may require an external power source to operate properly. Again, consult with the data logger manufacturer to determine a compatible sensor model.

5.3 DATA LOGGERS

Data loggers (or data recorders) come in a variety of types and have evolved from simple strip chart recorders to integrated electronic on-board cards for personal computers. Many manufacturers offer complete data logging systems that include peripheral storage and data transfer devices.

Data loggers can be grouped by their method of data transfer, either in-field or remote. Those that feature remote phone modem or cellular phone data transfer capabilities allow you to obtain and inspect stored data without making frequent site visits. Section 5.5 provides detailed information on data transfer equipment options.

The data logger should be electronic and compatible with the sensor types, number of sensors, measurement parameters, and desired sampling and recording intervals. It should be mounted in a non-corrosive, water-tight, lockable electrical enclosure to protect itself and peripheral equipment from the environment and vandalism. It should also:

- Be capable of storing data values in a serial format with corresponding time and date stamps
- Contribute negligible errors to the signals received from the sensors
- Have an internal data storage capacity of at least 40 days
- Operate in the same environmental extremes as those listed in Table 5.1
- Offer retrievable data storage media
- Operate on battery power.

A number of electronic data loggers that meet these criteria are commercially available. A vendor's list is provided in Appendix A.

5.4 DATA STORAGE DEVICES

Every electronic data logger has some type of operating software that includes a small internal data buffer to temporarily store incremental (e.g., once per second) data. Internal algorithms use this buffer to calculate and record the desired data parameters. The data values are stored in one of two memory formats. Some data loggers have a fixed internal program that cannot be altered; others are user-interactive and can be programmed for a specific task. This program, and the data buffer, are usually stored in volatile memory. Their drawback is that they need a continuous power source to retain data. Data loggers that incorporate the use of internal backup batteries or use non-volatile memory are available. They are preferred because data cannot be lost due to low battery voltage.

A. Data Processing and Storage

Data processing and storage methods depend on the data logger chosen. A basic understanding of how the logger processes data is important with respect to data protection issues (refer to Chapter 8). There are two commonly used formats for recording and storing data, ring memory and fill and stop.

- **Ring Memory:** In this format, data archiving is continuous. However, once the available memory is filled to capacity, the newest data record is written over the oldest. The data set must be retrieved before the memory capacity of the storage device is reached.
- **Fill and Stop Memory:** In this configuration, once the memory is filled to capacity, no additional data are archived. This effectively stops the data logging process until more memory becomes available. The device must be replaced or downloaded and erased before the data logger can archive new data.

B. Storage Devices

Most manufacturers offer several options for data storage devices. The most common are presented in Table 5.3 below.

Table 5.3
Data Storage Devices

Storage Device	Description	Memory/Storage Configuration	Download Method/ Needs
Solid State Module	Integrated electronic device that directly interfaces with the data logger.	Ring or Fill and Stop Volatile	Read and erased onsite or replaced. Reading device and software required.
Data Card	Programmable read write device that plugs into a special data logger socket.	Fill and Stop Volatile/Non-volatile	Read and erased on-site or replaced. Reading device and software required.
EEPROM Data Chip	An integrated circuit chip incorporating an electrically erasable and programmable read-only memory device.	Fill and Stop Non-volatile	EEPROM reading device and software required.
Magnetic Media	Familiar floppy disk or magnetic tape (i.e., cassette).	Fill and Stop Volatile/Non-volatile	Software required to read data from the media.
Portable Computer	Laptop or notebook type computer.	Magnetic Media Type	Special cabling, interface device, and/or software may be required.

5.5 DATA TRANSFER EQUIPMENT

Your selection of a data transfer and handling process and data logger model, will depend on your resources and requirements. As a rule, work with the manufacturer when selecting your equipment. Some vendors may allow you to test their system before you purchase it.

Data are typically retrieved and transferred to a computer either manually or remotely.

A. Manual Data Transfer

This method requires site visits to transfer data. Typically this involves two steps: (1) remove and replace the current storage device (e.g., *data card*) or transfer data directly to a laptop computer; and (2) upload the data to a central computer in an office. The advantage of the manual method is that it promotes a visual on-site inspection of the equipment. Disadvantages include additional data handling steps (thus increasing potential data loss) and frequent site visits.

B. Remote Data Transfer

Remote transfer requires a telecommunication system to link the in-field data logger to the central computer. The communications system may incorporate direct wire cabling, modems, phone lines, cellular phone equipment, or RF telemetry equipment, or some combination thereof. An advantage of this method is that you can retrieve and inspect data more frequently than you can conduct site visits. This allows you to promptly identify and resolve site problems. Disadvantages include the cost and time required to purchase and install the equipment. This may prove worthwhile in the long term if data monitoring problems can be spotted early and quickly remedied.

There are two basic remote data retrieval types: those that require the user to initiate the communications (call out) and others that contact the central computer via the link (phone home), both at prescribed intervals. The first type requires you to oversee the telecommunication operation. You initiate communications to the in-field data logger, download the data, verify data transfer, and erase the logger memory. Some call-out data logger models are compatible with computer-based terminal emulation software packages with batch calling features. Batch calling automates the data transfer process by initiating the modem's dialing sequence at a prescribed interval to sequence through the various monitoring sites. Batch programs can also be written to include data verification routines. You should consult with data logger manufacturers to determine compatibility of their equipment with this beneficial feature.

The phone home type data logger automatically calls the central computer to transfer data. A single personal computer can communicate with a larger number of sites in the call out mode compared to the phone home mode. In the latter case, enough time must be allotted for each call to account for a normal data transfer time and several retries for unsuccessful transfer attempts.

Cellular phone data loggers are gaining popularity today for their ease of use and reasonable cost. You need to determine the minimum signal strength requirements of the data logger and relate that to actual field testing when researching this type of system. A portable phone can be used at the proposed site to determine the signal strength and the cellular company. Locations that experience weak signal strengths may be improved by selecting an antenna with higher gain. Guidelines for establishing a cellular account are usually provided by the data logger supplier. Work closely with your supplier and cellular telephone company to resolve any questions before you begin to monitor. To avoid conflicts with local or regional cellular network use, you should schedule data transfers during off-peak hours. This often has an economic advantage, as many cellular networks offer discounts for volume off-peak usage. In addition, the ability to perform frequent data transfer will maximize your data recovery.

5.6 POWER SUPPLIES

All electronic data logger systems require a main power source that is sized to meet the total power requirements of the system. A backup power supply should be included to minimize chances of data loss caused by power failure. The backup system should be designed with the objective of saving the stored data. This can be accomplished by shutting down peripheral devices (modems, cellular telephones, and other data transfer equipment) at a designated low voltage level, or isolating a particular power source that is dedicated to protecting the data.

Most systems offer a variety of battery options including long-life lithium batteries or lead acid cells with various charging options (AC or solar powered). Nickel cadmium batteries do not hold a charge well in cold temperatures. Examples of power supplies are presented below.

A. AC Power

AC power (through a power transformer) should be used as the direct source of system power only if a battery backup is available. In this case, you should use AC power to trickle charge a storage battery that provides power to the data logger. Be sure to install a surge/spike suppression device to protect the system from electrical transients. In addition, ensure that both systems are properly tied to a common earth ground (see Section 5.9).

B. Lead Acid Battery

A deep discharge, gel type lead acid storage battery is the preferred power source. It withstands repeated discharge and recharge cycles without significantly affecting the energy storage capacity of the battery. It also offers a margin of safety over a wet acid battery, because the acid is contained in a gel and cannot be easily spilled. Always use caution when working with batteries to avoid a short circuit between the battery terminals.

C. Solar Power

The solar recharge option is a convenient way to recharge a lead acid battery when AC power is unavailable. The solar panel must supply enough wattage to recharge the battery and maintain system power during extended periods of low solar conditions (i.e., winter months). As a precaution, the battery should be sized to provide at least a week of reserve capacity to power the entire system without recharging. Be sure that the solar panel is reverse bias protected with a diode to prevent power drain from the battery at night. In addition, the solar panel must include a voltage regulator to supply a voltage compatible with the battery and to prevent overcharging.

5.7 TOWERS AND SENSOR SUPPORT HARDWARE

A. Towers

There are two basic tower types for sensor mounting: tubular and lattice. For both, tilt-up, telescoping, and fixed versions are available. In addition, these versions may be either guyed or self-supporting. For new sites, tubular, tilt-up guyed types are recommended for their ease of installation (the tower can be assembled and sensors mounted and serviced at ground level), minimal ground preparation, and relative low cost. Towers should:

- Have an erected height sufficient to attain the highest measurement level
- Be able to withstand wind and ice loading extremes expected for the location
- Be structurally stable to minimize wind-induced vibration
- Have guy wires secured with the proper anchor type, which must match the site's soil conditions (see Section 6.6)
- Be equipped with lightning protection measures including lightning rod, cable, and grounding rod
- Be secured against vandalism and unauthorized tower climbing
- Have all ground-level components clearly marked to avoid collision hazards
- Be protected against corrosion from environmental effects, including those found in marine environments
- Be protected from cattle or other grazing animals.

B. Sensor Support Hardware

The sensor support hardware includes the masts (vertical extensions) and mounting booms (horizontal extensions). Both must position the sensor away from the support tower to minimize any influence on the measured parameter caused by the tower and the mounting hardware itself. Sensor support hardware should:

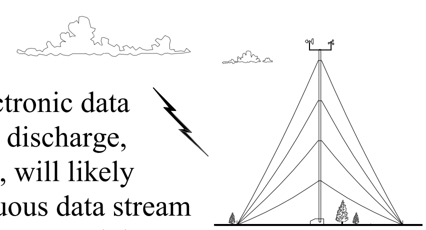
- Be able to withstand wind and ice loading extremes expected for the location
- Be structurally stable to minimize wind-induced vibration
- Be properly oriented into prevailing wind and secured to the tower
- Be protected against corrosion from environmental effects, including those found in marine environments
- Not block the sensor housing drainage hole. Water accumulation and expansion during freezing conditions will likely damage the internal sensor components. Tubular (hollow) sensor masts should be used instead of solid stock material.

5.8 WIRING

Here are some guidelines for selecting the proper electrical wire or cable type:

- Use the proper class wire for the voltage level employed (typically low voltage)
- Use wire with a UV resistant insulating jacket
- Use insulation and conductor types that are flexible over the full temperature range expected at the site
- Use shielded and/or twisted pair cable. Both prevent ambient electrical noise from affecting your measurements. Normal practice is to tie only one end of a shielded cable's drain wire to earth ground.

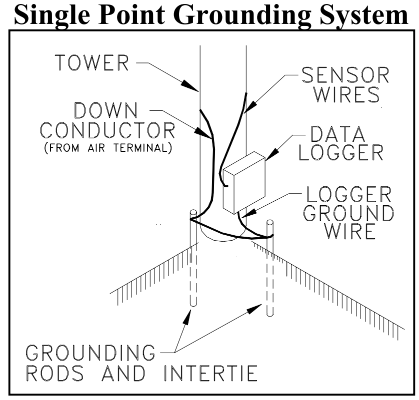
5.9 GROUNDING AND LIGHTNING PROTECTION



Grounding equipment is especially important when using electronic data loggers and sensors. Electrical surge type events, such as electrostatic discharge, lightning induced spikes or surges, or a difference in ground potential, will likely occur over an extended monitoring period. For each event, the continuous data stream is at risk from individual sensor failures or a data logger meltdown. Tower and data logger manufacturers may provide complete grounding kits designed to protect their systems. Keep in mind that different monitoring areas may have different requirements. Sites prone to lightning activity likely require a higher level of protection. Protection against a direct strike cannot be guaranteed. Each type of grounding need is presented below.

The single point grounding system, presented in Figure 5.1, is the recommended configuration. This setup will minimize the potential for developing an offset voltage by a grounding loop. In this system, the down conductor wire (≤10 gauge) is directly connected to earth ground, via a grounding rod, buried ring or plate (or combination). It is not routed through the data logger's grounding stud. The sensor drain or shield wires are electrically tied to the same earth ground via the data logger's common grounding buss (terminal strip). Earth ground is an electrical potential (voltage) level referenced to the earth. Typically the grounding rod, ring and plates are copper-based to provide a low resistivity for charge dissipation.

Figure 5.1
Single Point Grounding System



Their dimensions will determine the contact surface area with the soil, a key element for proper system grounding. A combination of the three can be used to enhance the contact area if they are all electrically connected.

It is helpful to know the resistivity characteristics of the soil to select the proper grounding system. This is the electrical resistance to current flow within a unit volume of soil, usually located near the earth's surface. It can be approximated by measuring the resistance between two conductive rods driven into the soil to a specified depth and distance apart. In general the lower the resistivity of the earth, the better the earth ground it will provide. Soils with low resistivity (e.g., moist dirt) will quickly dissipate any voltage potential that develops between two points and provide a better earth ground. High resistivity soil (e.g., dry sand) builds up a large potential voltage and/or current that may be destructive. The resistance between the grounding system and the earth should be less than 100 ohms. Soil resistivity will likely change seasonally. The value in early spring, following a winter thaw, may not reflect the soil conditions during the lightning season. In addition, towers in arid climates may be prone to electrostatic discharge if system grounding is poorly done. When in doubt, take the conservative approach and provide added protection. It is, in the long run, the least costly route. Section 6.7 presents additional means for improving a system’s earth ground.

A. Data Logger and Sensor Grounding

Lightning protection devices, such as spark gaps, transorbs, and metal oxide varistors (MOVs), should be incorporated into the data logging system electronics to supplement grounding. Anemometers and wind vanes are available with MOVs as part of their circuitry, and if not, can easily be outfitted. Their primary purpose is to limit the peak surge current allowed to reach the protected equipment while diverting the destructive surge current. You should inquire about the protection offered by each data logger manufacturer. Additional protection equipment may be needed in lightning-prone areas.

B. Tower Grounding

Lightning protection equipment must be installed on the tower and connected to the common ground. An example of a lightning protection kit consists of an air terminal, sometimes referred to as a lightning rod, along with a length of heavy gauge (≤10 gauge), non-insulated copper wire referred to as the down conductor tied to the earth ground with a grounding rod or loop. The air terminal should have at least one point, with several points preferred (streamer retardant air terminal).

The protection equipment is designed to equalize any voltage potential that may develop between the soil and the air at the tower top. This is accomplished by allowing a path for electrons to flow from the soil surface up through the down conductor and then be dispersed into the surrounding air by the air terminal. This equipment is not intended as a path for lightning to travel.

5.10 MEASUREMENT SYSTEM ACCURACY AND RELIABILITY

Manufacturers use various definitions and methods to express their product’s accuracy and reliability. With that in mind, how can you know that the system you assemble will meet the specifications cited in Table 5.1? This section provides the basic information needed to select the proper equipment.

A. Accuracy

The accuracy of any system is determined by its weakest link, or least accurate component. It is also influenced by its complexity, the total number of components or links. The measurement of wind speed, for example, requires that several components (sensor, cabling, and data logger), each potentially contributing an error (or inaccuracy) to the measured parameter, be interconnected. The combination of these errors will determine the system error for that parameter. Errors contributed by the physical subsystem (sensors) represent the main concern, because those associated with the electronic subsystem (data logger, signal conditioner, and associated wiring and connectors) are typically negligible (less than 0.1%).

System error is the difference (or inaccuracy) between the measurement reported and the accepted standard (or true value). Using wind speed again as an example, the system inaccuracy in the reported wind speed should be less than or equal to 3% of the true wind speed value at wind speeds of 4.5 m/s (10 mph) and greater. This allows for a 6% error window (±3%) centered about the true wind speed.

Accuracy is typically expressed in three ways:

1. As a difference (as in, for temperature, $\leq 1^{\circ}C$), calculated as

$$\left(\textit{Measured Value} \ - \ \textit{Accepted Standard Value}\right)$$

2. A difference stated as a percentage of the accepted standard value (as in, for wind speed, ≤3%), calculated as

$$\left[\frac{\textit{Measured Value} \ - \ \textit{Accepted Standard Value}}{\textit{Accepted Standard Value}}\right](100)$$

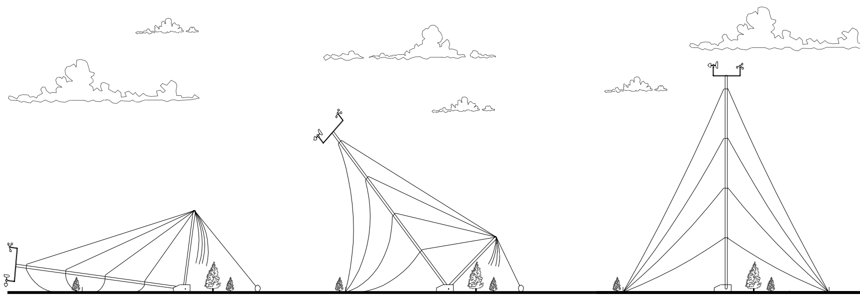
3. An agreement ratio stated as a percentage of the accepted standard value (as in, 95% accuracy), calculated as

$$\left[\frac{\textit{Measured Value}}{\textit{Accepted Standard Value}}\right](100)$$

Accuracy is often confused with precision. System precision (sometimes expressed in terms of standard deviation) is the measure of mutual agreement between repeated values under constant conditions. In other words, it is a comparison of a measured value against the average value.

B. Reliability

System reliability is the measure of a system's ability to constantly provide valid data for a parameter over its measurement range. Vendors usually test the reliability of their equipment to determine the product's life cycle. They will often provide information in terms of a mean time between failures under certain conditions. In general, the best indication of a product's reliability is its performance history. Ask the vendor for a few references. Comprehensive quality assurance procedures and redundant sensors are two of the best ways to improve system reliability.



Chapter 6

INSTALLATION OF MONITORING STATIONS

The installation phase of the monitoring program can proceed once the site selection process has been completed and the necessary equipment acquired. This chapter provides installation guidelines on equipment procurement, inspection and preparation, site layout, tower installation, sensor and equipment installation, site commissioning, and documentation.

6.1 EQUIPMENT PROCUREMENT

Items specific to the wind monitoring program that should be included or addressed in the equipment procurement process are:

- Equipment and sensor specification list
- Sensor types and quantities, including spares
- Tower type and height
- Measurement parameters and heights
- Sampling and recording interval
- Data logger processing requirements: hourly average and standard deviation, plus daily maximum and minimum values
- Sensor calibration documentation
- Environmental tolerance to expected conditions
- Data logger type: manual or telecommunication
- Soil type for proper anchor selection
- Warranty information
- Product support
- Date of delivery.

A list of equipment vendors is provided in Appendix A.

6.2 EQUIPMENT ACCEPTANCE TESTING AND FIELD PREPARATION

You should check the equipment shipment for broken or missing parts when you receive it. To quickly identify and resolve problems, you should ensure that all system components are thoroughly inspected and tested before they are installed. Document your inspection findings, and return components that do not meet specifications to the manufacturer for replacement. To save valuable field installation time, assemble the appropriate components in-house. For example, sensors can be pre-wired and mounted on their booms. It then becomes an easier task to install the pre-assembled sensor hardware to the tower in the field. Installation time can be precious, especially when inclement weather is a factor.

The acceptance testing and field preparation procedures should include:

A. Acceptance Testing

1. Data Logger

- Power up the data logger and check the various system voltages
- If applicable, set up and activate a cellular phone account and test the logger's cellular phone system following the manufacturer's instructions before actual field installation
- Connect all sensors to data logger terminals with the shielded cabling to be used
- Verify that all sensor inputs are operational
- Verify the logger's data collection and data transfer processes. Here is a simple test scenario: Following the manufacturer's instructions, connect a sensor to the data logger and collect a sampling of one minute (or higher) averaging interval data. Manually transfer the recorded data from the storage device (e.g., data card) to a computer using the logger's data management software. View the data and ensure that (a) the data logger is functioning; (b) the data transfer was successful; (c) the storage device is functioning; and (d) the reported values are reasonable. For cellular type loggers, repeat the above steps using their remote transfer capabilities.

2. Anemometers and Wind Vanes

- Inspect each sensor to ensure that it spins freely through a full rotation. You may be able to hear evidence of binding or dragging components.
- Using the shielded cabling and following the manufacturer's instructions, connect each sensor to the correct data logger terminal(s). Verify the reasonableness of each sensor output as displayed by the data logger. For the anemometers, verify both a zero and non-zero value by holding and then spinning the cups or propeller. For the wind vanes, verify the values at the four cardinal points: north, south, east, and west.

3. Temperature Sensor

- Perform a two-point calibration check at room temperature and in an ice-bath. Once stabilized, compare the sensor temperature readings to a known calibrated mercury thermometer. Deviations between sensors should not exceed 1°C.

4. Solar Panel Power Supply

- Place in direct sunlight and confirm the output voltage.

5. Mounting Hardware

- Inspect the sensor mounting booms to ensure they are rugged and durable
- Inspect any welds or joints for soundness.

B. Field Preparation Procedures

- Assign site designation numbers
- Enter all pertinent site and sensor information on a Site Information Log (refer to Section 6.9)
- If required, program the data logger with the site and sensor information (slopes and offsets)
- Install the data logger's data management software on a personal computer and enter the required information
- Enter correct date and time into the data logger
- Insert data logger's data storage card or applicable storage device
- Properly package all equipment for safe transport to the field
- Pack all proper tools needed in the field
- Include at least one spare of each component, when practical.

6.3 INSTALLATION TEAM

The installation team should consist of at least one experienced installer. The quality of the data collected will largely depend on the quality of the installation. The team should consist of at least two people, with one assigned a supervisory role. This will allow for a heightened degree of efficiency and safety.

The personnel responsible for the site's selection may not always be involved in the installation process. If this is the case, it is important that the installation team leader obtain all pertinent site information, including the latitude and longitude (verifiable with a GPS receiver), local magnetic declination, prevailing wind direction, and road maps, as well as topographic maps and site photographs that show the exact tower location.

6.4 SAFETY

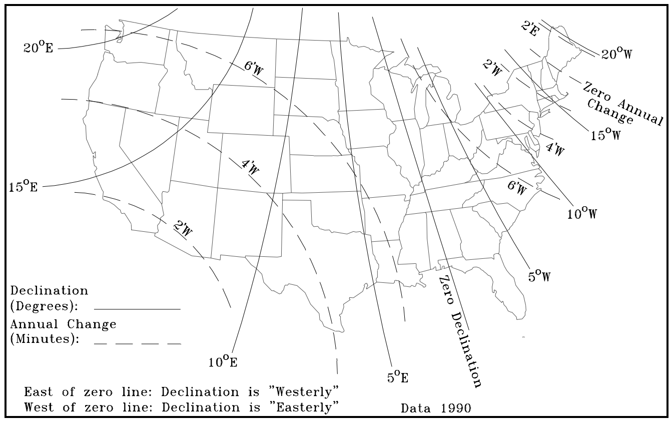
The monitoring station installation process has inherent dangers, some of them life-threatening. There are risks associated with falling towers, falling from towers, falling equipment, and electrocution. Having experienced staff and following manufacturers' recommendations will minimize these risks. The team members should:

- Be trained in and abide by safety procedures, including first aid and CPR, which should be enforced by the team leader
- Remain in constant communication
- Follow all safety guidelines provided by the tower manufacturer
- Use common sense during the installation process. For example, if there is lightning activity, postpone work until the danger has passed.
- Be equipped with the proper safety equipment, including hard hats, protective gloves, a first aid kit, and — if tower climbing is required — certified climbing belts and lanyards as well as proper foot attire
- Locate the base of a tower at least one tower height away from overhead power lines
- Verify the use of all equipment found on towers. Are they energized, etc.?

6.5 DETERMINATION OF TRUE NORTH

The determination of true north (not magnetic north), and thus the site bearings, is essential for proper sensor orientation. It is also useful during the tower layout phase of the installation process. To obtain true north from a compass reading (magnetic north), the local magnetic declination (in degrees) must first be known. This value, or correction factor, can be found on topographic or isogonic maps of the area (Figure 6.1).

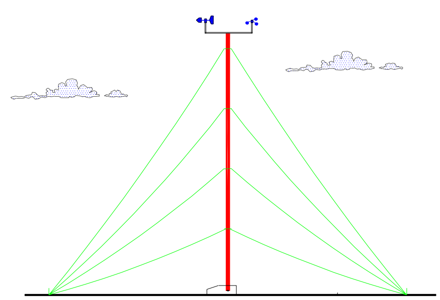
Figure 6.1
Map of Magnetic Declination



How this correction factor is applied depends on the site location with respect to the magnetic north pole. The declination for sites located east of the magnetic north pole will be expressed as the number of degrees that magnetic north is west of true north. For this case the true north bearing is equal to the magnetic north declination. The declination for sites located west of the magnetic north pole will be expressed as the number of degrees that magnetic north is east of true north. For this case the true north bearing is equal to 360° minus the local magnetic declination. For example, if a site is located east of the magnetic north pole and its local magnetic declination is 10° degrees, the bearing for true north is simply 10°. If the site were west of the magnetic north pole, the bearing for true north would be 350° (360° - 10°).

The possibility for error in determining true north from compass techniques can be reduced through the use of a GPS receiver. In fact, a GPS receiver can indicate true north in the absence of a compass or magnetic declination information. A hand-held receiver can be purchased for as little as $200.

6.6 TOWER INSTALLATION



A. New Tilt Tower Installations

The tower should be laid out based on safety considerations and ease of installation. Towers can be erected almost anywhere, but the task is much easier if the terrain is relatively flat and free of trees. If the tower is erected on a slope or uneven ground, the guy wires may need to be adjusted often as the tower is raised. If the tower is erected in a wooded area, enough clearance must exist for the guy wires as the tower is raised. For a 40 m tower, the guy anchor radius is 23 m (75 ft).

The guy anchors should be located at each of the four cardinal directions and the tower raised along one of these directions, preferably as near to the prevailing wind direction as possible. Bearing reference stakes are useful to locate and then mark each direction. The advantages of this are:

- The tilt-up tower will be outfitted in a horizontal position. To orient the sensors properly, you will need to establish which position on the horizontal tower represents north, for example. This will now be a simple task since north will be either straight up, straight down, or directly left or right. If the tower cannot be laid out along a principal direction, the angle of deviation must be determined and documented for the proper orientation of the wind vane.

- Raising the tower into the principal wind direction (and lowering with the principal wind direction) offers a welcomed degree of tower stability by maintaining the lifting guy wires in constant tension.

Tilt-up towers are secured and controlled with an anchoring system and equal controlled tension on the guy wires at all times. Anchors should be carefully selected and installed to ensure stability.

- **Anchor Selection:** Your choice of anchoring system will depend on the sub-surface characteristics at each site. This should have been determined during the initial site investigation. A mismatch between the anchor type and soil conditions could cause the anchor to fail and tower to collapse. Table 6.1 provides guidelines for the selecting and installing an anchor system. Consult with the tower manufacturer if you require additional guidance.

Table 6.1
Soil Type and Recommended Anchoring System

Soil Type	Anchor Type	Installation Method
Loose to firm sand, gravel, or clay	Screw-in	Screw-in with crowbar
Soil with rocks	Arrowhead	Sledge or jack-hammer
Solid Rock	Pin / Rock Anchors	Drill hole and secure with epoxy/ expand with crowbar

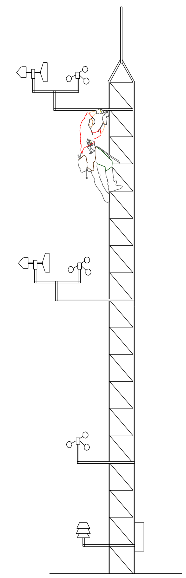
- **Anchor Installation:** The installation of each guy anchor and lifting station anchor should adhere to the manufacturer's instructions. The lifting station anchor warrants special attention. Normally a winch and pulley system is connected to this anchor to service a tower. During tower lifting and lowering, this anchor will carry all of the tower load and is thus under great stress. The greatest loads occur when the tower is just raised above the ground. The carrying capacity of the soil will vary with a change in soil consistency. For example, saturated soil from a winter thaw will exhibit a much reduced carrying capacity. If the holding capacity of this anchoring system is insufficient, the anchor will creep and the tower will fall. For this reason, the lifting anchor station should be secured with at least twice as many anchors as used at the guy anchor stations. As an added precaution, secure these anchors to a vehicle bumper.

- **Guy Wires:** Under proper tension the guy wires keep the tower system in equilibrium and thus vertical. This is essential to properly align the wind speed and direction sensors. As a rule, you should ensure that all guy wire tension adjustments are coordinated and are made smoothly. Refer to the manufacturer's instructions for guy wire tension recommendations. It is advisable to clearly marked with a reflective material at each anchor station to alert pedestrians or vehicle operators. If animals graze at the site, a fence may be necessary to protect the guy stations and tower.

B. Use of Existing Towers

The use of existing fixed or tilt towers offer installation challenges that must be addressed. The following points should be considered:

- **Sensor Mounting and Exposure:** Custom mounting schemes may have to be designed and fabricated for lattice tower installations. The design needs must be determined during the initial site investigation; this is not a "day-of-installation" task. In addition, each design should adhere to the sensor mounting and exposure specifications presented in Section 6.7. For example, to minimize potential tower wake effects associated with wide towers, much longer mounting booms fabricated from heavier stock may be required.



- **Tower Climbing:** Fixed towers will require staff to climb to install equipment and perform operation and maintenance tasks. Before climbing is permitted qualified personnel should evaluate the structural integrity of the tower, especially the climbing pegs, ladder, climbing safety cable, and guy wires (if present). Personnel must be properly trained and equipped. Because work will be performed aloft, the weather must be given special consideration when scheduling tower work. The wind causes complications when raising mounting hardware aloft. When wind chill is a factor, the danger of frostbite is great, and tasks involving manual dexterity become very difficult.

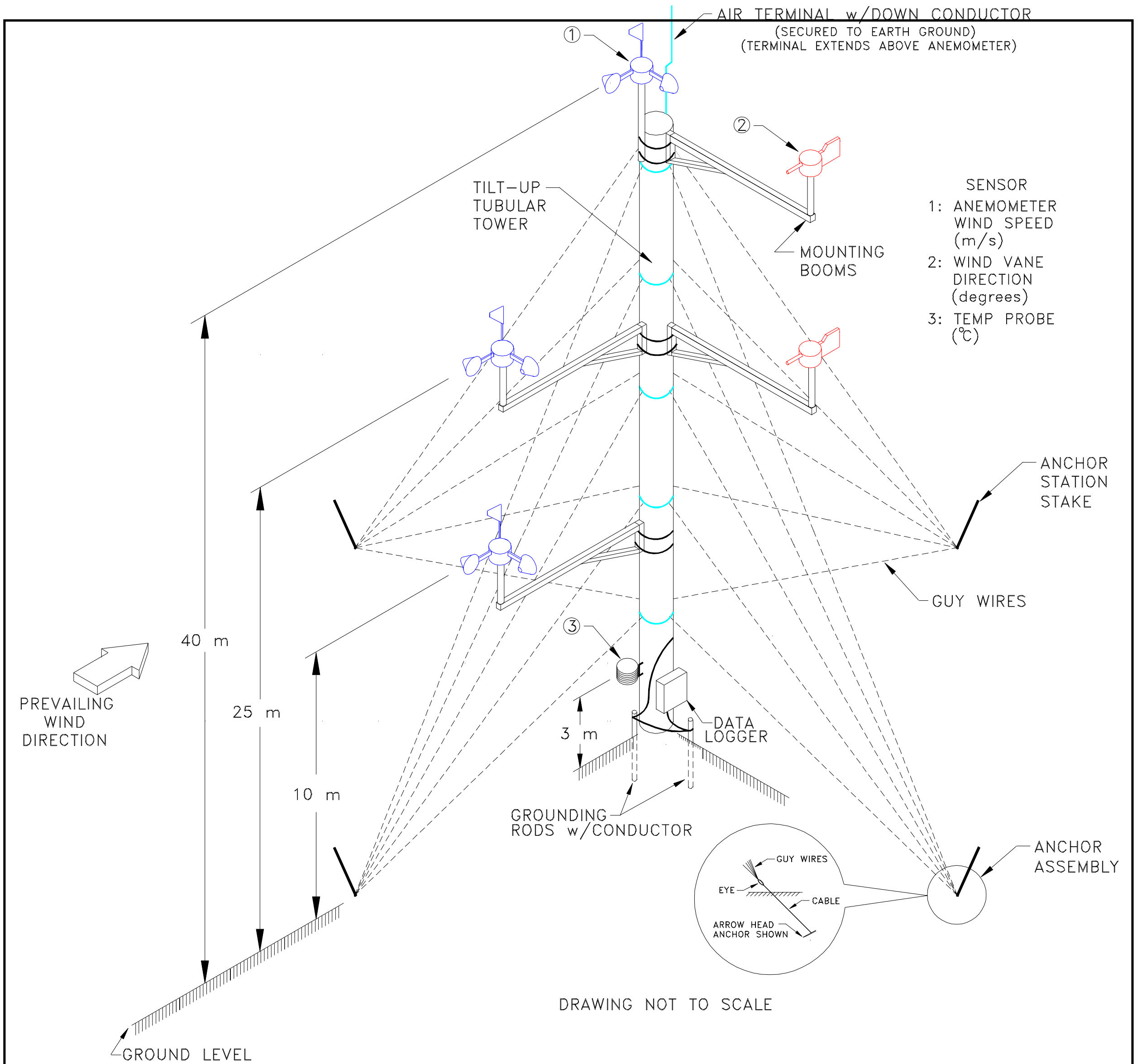
6.7 SENSOR AND EQUIPMENT INSTALLATION

Wind sensors must be mounted onto the tower with support hardware in a manner that minimizes any influence on the measured parameter caused by the tower, mounting hardware, and other equipment and sensors. This can be achieved by adhering to the following guidelines, consulting specific manufacturers' instructions, and referring to the sample installation configuration shown in Figure 6.2.

A. Wind Speed and Direction Sensors

- Mount the upper-level sensors at least 0.3 m (1 ft) above the tower top to minimize potential tower shading effects
- Mount sensors on independent mounting booms. For sensors positioned off the side of the tower, use mounting hardware that is horizontally level and long enough to position the sensor at least three tower widths out from lattice-type towers and six tower diameters out from tubular towers. For triangular lattice towers, the tower width is measured as the length of one face.
- Orient sensors mounted off the tower side into the prevailing wind direction, or, if there is more than one prevailing direction, in a direction that minimizes the probability of tower and sensor shadow effects
- Locate sensors above the horizontal mounting hardware at a height equal to at least eight diameters of the mounting hardware. For square stock hardware, the diameter equals the length of the vertical side.
- Sensor drainage holes must not be blocked by the vertical mounting hardware to prevent internal freezing damage during cold weather. Tubing, not solid stock masts, should be used.

Figure 6.2



Sample Installation

- The wind vane must be oriented so its deadband position is not directed towards the prevailing wind. The deadband should be positioned at least 90° away from the prevailing wind direction, preferably in a principle direction. The deadband orientation must be known and documented for the data logger or analysis software to report the correct wind direction. Consult the data logger manufacturer's requirements for reporting the deadband position.
- Verify the deadband position of the wind vane once the tower is raised. If it has been aligned with the mounting boom arm, verification can be accomplished with a sighting compass to a high degree of accuracy.

B. Temperature Sensor

- Mount the shielded sensor at least one tower diameter away from the tower face to minimize tower heating effects
- Orient the sensor on the tower for maximum exposure to the prevailing wind direction to ensure adequate ventilation.

C. Data Logger and Associated Hardware

- Place the desiccant packs n the data logger enclosure to absorb moisture
- House the data logger, as well as cabling connections, telecommunication equipment, etc., in a weatherproof and secure (locked) enclosure
- Mount the enclosure at a sufficient tower height to allow for above average snow depth and to deter vandalism
- If applicable, position the solar panel above the enclosure to avoid shading, oriented south and near vertical to minimize dirt build-up and maximize power during the winter's low sun angle.
- Ensure that all cabling that enters the equipment enclosure has drip loops
- Seal all openings in the enclosure, such as knock-outs, to prevent damage from precipitation, insects, and rodents
- If applicable, orient the cellular communication antenna at an easily accessible height.

D. Sensor Connections and Cabling

- Refer to the manufacturer's instructions for the proper sensor and data logger wiring configurations
- Seal sensor terminal connections with silicone caulking and protect from direct exposure with rubber boots
- Wrap sensor cabling along the length of the tower and secure it with UV resistant wire ties or electrical tape
- If not installed by the manufacturer, consider installing MOVs across each anemometer's and wind vane's terminals for added transient protection
- Where chafing can occur between the sensor wire(s) and the support structure (e.g., tilt-up tower anchor collars), wrap tape around the sensor wire and leave sufficient slack.

E. Grounding System

⇒ **Basic Guidelines**

- Investigate the incidence of lightning activity in the site's locale. For high frequency areas, take the conservative approach and increase the grounding system capabilities.
- For existing tower installations, tie the data logger's ground into the grounding system (if adequate)
- Install an air terminal above the tower top and connected via the down conductor wire to earth ground
- Ensure that single strand bare copper down conductor is ≤10 gauge
- Ensure that the grounding rod(s) is free from non-conducting coatings, such as paint or enamel

- Use at least one 12.5 cm (½-in) diameter, 2.4 m (8 ft) long grounding rod to provide the minimum soil contact surface area
- Wire all grounding rods together to provide electrical continuity
- Drive all grounding rod(s) below surface. Where rock is encountered, drive the rod at a 45° angle, or bury it in a trench at least 0.6 m (2 ft) deep, the deeper the better. The key here is to maximize the soil contact area.
- Protect the above-soil end of the rod and its electrical conductor attachment against damage
- Where the soil can become frozen, drive grounding rods below the frost line
- Use a single point grounding system as described in Section 5.9
- Determine the soil type and classify its resistivity. In general, the lower the resistivity, the better the earth ground provided.
- Ensure that the resistance between the grounding system and the earth is less than 100 ohms
- Apply a de-oxidation agent to all grounding connections.

⇒ **Additional Transient Protection Measures**

- Connect the sensor wires to an additional bank of spark gaps (or surge arrestors) before they are connected to the data logger input terminals
- Use longer grounding rods. Two benefits are: (a) generally, the soil's conducting properties improve with increasing depth, and (b) additional contact surface area is gained. Rods can be purchased that fit together to reach greater soil depths.
- Install additional grounding rods
- Use high compression or copper-clad fittings at all conductor/rod connections
- Use multi-strand down conductor wire to increase the current carrying capacity (e.g., 28 strands of 14 gauge wire)
- Secure the ground conductor to the tower's metal surface with band clamps (use de-oxidizing gel), one per tower section. Install a buried copper ground plate or ground ring at the recommended depths. All grounding rods and/or rings must be electrically connected.
- Install a multi-point air terminal (or streamer retardant air terminal). The more points the better to reduce the accumulation of a static ground charge.
- Install horizontally mounted air terminals at various levels and directions on the tower to provide additional points for charge dissipation. Tie each rod to the down conductor so as to not adversely affect any sensor readings.
- Ensure that any side mounted sensors at the tower top are within the theoretical 45° "cone-of-protection". A longer air terminal rod may be required.

6.8 SITE COMMISSIONING

The equipment must be tested for proper operation on the tower before a tilt-up tower is raised, or while personnel are still aloft on towers. These functional tests should be repeated once the installation is complete. Having spare equipment on hand makes repairs easy if problems are found during these functional tests. Site commissioning tasks should include the following:

- Ensure that all sensors are reporting reasonable values
- Verify that all system power sources are operating

- Verify required data logger programming inputs, including site number, date, time, and sensor slope and offset values
- Verify the data retrieval process. For cellular phone systems, perform a successful data download with the homebase computer, and compare transmitted values to on-site readings.
- Ensure that the data logger is in the proper long-term power mode
- Secure the equipment enclosure with a padlock
- Document the departure time and all pertinent observations.

6.9 DOCUMENTATION

A complete and detailed record of all site characteristics, as well as data logger, sensor, and support hardware information, should be maintained in a Site Information Log; a detailed example is provided on the next page. The following main topics should be included:

- **Site Description:** Include a unique site designation number, a copy of a USGS map showing the location and elevation of the site, the latitude and longitude, the installation date, and the commission time. The coordinates of the site should be determined or confirmed using a GPS receiver during the site selection or installation process. Typically, coordinates should be expressed to an accuracy of less than 0.1 minute (at least 100 m) in latitude and longitude and at least 10 m in elevation. This should eliminate errors caused by inadvertently marking sites in the wrong place on a map and recording incorrect coordinates taken from the map.

- **Site Equipment List:** For all equipment (data logger, sensors, and support hardware), document the manufacturer, model, and serial numbers as well as the mounting height and directional orientation (including direction of deadbands, cellular antenna, and solar panel). Sensor information should include slope and offset values and data logger terminal number connections.

- **Telecommunication Information:** Include all pertinent cellular phone programming information.

- **Contact Information:** Include all pertinent land owner and cellular phone company contact information.

SAMPLE SITE INFORMATION LOG
(Cellular Site)

Form Revision Date:

Site Description	
Site Designation	
Location	
Elevation	
Installation/Commission Date	
Commission Time	
Soil Type	
Surroundings Description	
Prevailing Wind Direction	
Declination	

Site Equipment List						
Equipment Description	Mounting Height	Serial Number	Sensor Slope	Sensor Offset	Logger Terminal Number	Boom Direction (Vane Deadband)

Telecommunication Information	
ESN #	
Carrier	
Phone Number	
SYSID	
LOCAL	
MINMARK	
IPCH	
ACCOLC	
PRESYS	
GROUP	
Activation Date	

Contact Information	
Land Owner Name	
• Address	
• Phone Number	
Cellular Company	
• Phone Number	
• Contact Person	
• Contact's Extension	

Chapter 7

STATION OPERATION AND MAINTENANCE

During the course of a wind resource assessment project, the integrity of all system components must be maintained and documented to ensure smooth and continuous data collection. Meteorological instruments, for example, require periodic calibration, preventive maintenance, and on-site visual inspections if the data are to be accurate and complete. To achieve this, a simple but thorough operation and maintenance plan that incorporates various quality control and quality assurance measures and provides procedural guidelines for all program personnel should be developed. Personnel must be thoroughly trained in all aspects of the operation and maintenance program. This includes a working knowledge of all monitoring system equipment.

The success of any operation and maintenance program depends on the plan and on the field personnel assigned to carry out the prescribed tasks. They should be conscientious and dedicated individuals determined to keep the network in optimum working order. They will be the direct link with all field-related events. In essence, they will be the eyes of the wind resource network and responsible for documenting and explaining any periods of lost data. They must therefore be observant note takers and have good problem-solving abilities.

Key elements of this program should include scheduled and unscheduled site visits, procedures, checklists and logs, calibration checks, and a spare parts inventory. Guidelines to develop such a program are provided in this section.

7.1 SITE INSPECTIONS

A regular schedule of site visits must be developed and conducted over the project duration. Site visit frequency will also depend on the data recovery format. If data are retrieved remotely and received at least weekly, then quarterly scheduled site visits are sufficient. If data retrieval is manual, site visits should be conducted at least bi-weekly. The appropriate frequency is recommended to meet the 90% data recovery objective. The data retrieval process is detailed in Chapter 8.

Situations will likely arise in which additional inspections are warranted. These unscheduled events are important, as they are usually in response to data loss. Examples include suspected sensor malfunctions found during the data validation process or an investigative response from site-threatening weather-related events, such as gale-force winds or severe ice loading. To minimize potential data loss, these functions should be carried out within 72 hours. With this in mind, both types of operation and maintenance needs must be accounted for during your program development from a cost and personnel availability basis. At least one unscheduled operation and maintenance visit should be anticipated for each monitoring site per year.

7.2 OPERATION AND MAINTENANCE PROCEDURES

The operation and maintenance program should be documented in an *Operation and Maintenance Site Manual*. The goal of this document is to provide field personnel with thorough and clear procedures for scheduled and unscheduled operation and maintenance needs. Of the many manual formats available, a step-by-step approach in conjunction with task completion checklists and site visit logs is a proven and preferred choice. Specifically, the manual should provide each component described below:

A. Project Description and Operation and Maintenance Philosophy

This section should describe the project and its overall goals. The importance of the technician's role in the project's success through maintaining data quality and completeness should be highlighted.

B. System Component Descriptions

The technician must understand the fundamentals of all system components to ensure proper installation and to perform system checks and operation and maintenance procedures. A brief description of all instruments (anemometers, wind vanes, temperature probes, data logger, etc.) and how they work should be provided. Detailed component information, such as manufacturer's manuals, should be provided in an appendix.

C. Routine Instrument Care Instructions

All instruments that require routine maintenance should be identified and instructions provided. For example, the optional solar sensor (pyranometer) should be cleaned and leveled as part of each visit. Some anemometer models require periodic bearing replacement. If sensors are replaced, all pertinent information, including serial numbers and calibration values, should be recorded.

D. Site Visit Procedures

The field visit can be divided into three categories: the in-house preparation, the on-site procedures, and the site departure procedures.

1. In-House Preparation

- Establish the reason for the inspection and the specific needs. Is it a scheduled inspection or is it in response to a potential problem? Will a tower be lowered or is climbing required?
- If necessary, notify the landowners of each site you are to visit. This can be a courtesy call, a simple and effective public relations tool.
- Ensure that field personnel have a complete set of tools, supplies, equipment manuals, and spare parts to accomplish all tasks. Develop a site visit checklist that specifies the required tools and supplies. This list should include all equipment

necessary to download the site data, such as laptop computers, tape recorders, and data storage cards.

- Perform an in-house functionality test on each memory card before field installation. This is especially important when swapping memory cards is your primary method of data retrieval. This will require a spare in-house data logger to record dummy data to the memory card.
- Determine the number of people required for the site visit. Sensor servicing will require at least two people.
- Have field personnel inform another staff member of where they plan to be and when they expect to return.

2. On-Site Procedures

- Retrieving the raw data from the data logger upon arrival and before conducting any other work is essential. This will minimize the risk of potential data loss from operator error, static discharges, or electrical surges during handling or checking of system components.
- The basic visit includes a thorough visual inspection (with binoculars) of all system components, and testing when applicable. The results of the visual inspection on a checklist must be recorded (see sample at the end of this chapter). It should include the following:
  - ◊ Data logger
  - ◊ Sensors
  - ◊ Communication system
  - ◊ Grounding system
  - ◊ Wiring and connections
  - ◊ Power supply(s)
  - ◊ Support booms
  - ◊ Tower components (for guyed tower systems this includes anchors, guy wire tension, and tower vertical orientation).
- Scheduled component replacement (e.g., batteries), calibration, and troubleshooting (develop general guidelines before the first site visit).
- To ensure that all operation and maintenance tasks have been completed and the necessary information documented, a Site Visit Checklist should be added to the Operation and Maintenance Site Manual.
- As an added check, instantaneous data should be examined to verify that all measured values are reasonable.

3. Site Departure Procedures

- The data retrieval process should be confirmed before leaving a site. This involves completing a successful data transfer with the homebase computer (for remote systems) or in-field laptop computer (for manual systems). This simple but valuable test will ensure the system is operating properly and the remote communication system (antenna direction and phone connections) was not inadvertently altered.
- Ensure the data logger has been returned to the proper long-term system power mode. Some models have a low-power mode for normal operation to conserve

system power. Neglecting to invoke this mode will significantly reduce battery life and increase potential data loss.
- Protect your investment. Always secure the data logger enclosure with a good quality padlock. The monitoring stations may attract visitors and increase the likelihood of vandalism.
- Record the departure time and all work performed and observations in the Site Visit Checklist.

7.3 DOCUMENTATION

A Site Visit Checklist that sequentially follows the procedures outlined in the *Operation and Maintenance Site Manual* is a helpful tool for the field technician. It ensures that all required operation and maintenance tasks are successfully completed, and serves as an historical record of a site's quality control, quality assurance, and operational activities. These are directly related to your claims of data validity. The value of this document becomes evident when a reconstruction of past events becomes necessary. A precise, detailed information record can help explain any periods of questionable data and may prevent significant data from being discarded.

For these reasons, a standardized Site Visit Checklist should be developed, completed for each site visit, and kept on file. Example information and activities to detail in the checklist include:

- **General Information:** Site name, technicians, date and time of site visit, and work to be performed.

- **In-House Preparation:** List of necessary tools, equipment and supplies (including spares), documentation, maps, and safety items.

- **On-site Activities:** A sequential list of the various site activities, including equipment checks, data retrieval, tower-related work (raising and lowering procedures), and departure activities.

- **Findings and Recommendations:** A detailed account of the work performed, findings, and observations, and if applicable, further required or recommended actions.

A sample Site Visit Checklist is presented at the end of this chapter.

7.4 EQUIPMENT FUNCTIONAL CHECKS

All sensors should be inspected and their functionality tested before being installed and when applicable, as part of the scheduled operation and maintenance requirements. Generally, tower lowering or climbing should not be necessary to perform these tasks. Unless the data validation process (presented in Chapter 9) has detected potential problems, the scheduled anemometer and wind vane checks should be visual with binoculars, with attention directed toward physical damage. Damaged or suspect equipment should be replaced or repaired. The results of all functional checks must be documented. General sensor quality control procedures are described below:

- **Anemometers:** Ensure that the sensors are rotating freely and that the mounting hardware and sensors are intact and oriented correctly. Ensure that the sensor inputs to the data logger are reasonable.

- **Wind Vanes:** Ensure that the sensors are rotating freely and that the mounting hardware and sensors are intact and oriented correctly. Ensure that the sensors inputs to the data logger are reasonable. If there are discrepancies, check the deadband position.

- **Temperature Sensor:** Compare the temperature sensor readings to a calibrated thermometer at the same location annually. The test duration should be at least one-half hour with readings taken at 5-minute intervals. Deviations between sensors should not exceed 1°C.

- **Support Tower:** For tilt-up towers, ensure that the tower is vertical. Make any necessary adjustments to guy wire tensions.

7.5 SPARE PARTS INVENTORY

Projected operation and maintenance functions must anticipate potential equipment malfunction and breakage. To minimize downtime, an adequate spare parts inventory must be maintained and included with all site visits. The basic inventory should consist of all items necessary to outfit one monitoring station. Additions to specific inventory items may be appropriate. You should consider the following points when determining your specific inventory needs:

- **Size of the Monitoring Network:** As the size of your monitoring network increases, a corresponding increase in your spare parts inventory may be warranted. As a guide, networks consisting of six or more monitoring stations should have a parts inventory sufficient to outfit two stations. For networks of this size it is also advisable to have a spare data logger on hand.

- **Environmental Conditions:** Weather-related events, such as severe thunderstorms and icing, pose a significant risk to a site's operation. Networks in geographical areas prone to either type of event should be equipped appropriately. Mechanical failures from ice loading or extreme wind gusts, as well as electrical failures from nearby or direct lightning discharges, can occur. Recommended additions to specific inventory items include spare anemometers, wind vanes, and sensor mounting booms. The need to maintain an additional data logger in your inventory, at significant expense, can be reduced by selecting high reliability models that include transient protection and internal shielding.

- **Equipment Availability:** The availability of inventory items from each supplier should be considered, and their in-stock inventory determined in advance. Items that require an extended lead time for delivery should be identified and inventory numbers adjusted accordingly. The turn-around time for critical items, such as data loggers and sensors, is particularly important.

- **Operation and Maintenance History:** The servicing needs of a site should be closely monitored. If warranted, specific item inventories should be adjusted based on experience at each site to maintain a high level of service preparedness.

SAMPLE SITE VISIT CHECKLIST
(Tilt-Tower / Cellular System)

A. GENERAL INFORMATION

Site Designation		
Site Location		
Crew members		
Date(s)		
Time (LST)	Arrival:	Departure:
Visit Type (Check)	Scheduled ☐	Unscheduled ☐
Work Scheduled		

B. IN-HOUSE PREPARATION

Check each box to denote the items have been acquired.

- ☐ In-house support person:_______________________________
- ☐ Copy of Site Information Log.
- ☐ Acquire necessary tools, equipment, and supplies.
  - ☐ Electrical supplies: voltmeter, fuses, tape, connectors, cable ties, batteries, crimpers, etc.
  - ☐ Wrenches, pliers, screwdrivers, nut drivers, hex set, sledgehammer, wirecutters, etc.
  - ☐ Misc. equipment: silicon, magnetic level, binoculars, camera, GSP, etc.
  - ☐ Spare equipment: cabling, anchors, booms and mounting hardware, etc.
    - Sensors:
      (1) Sensor:__________ Serial #_________ Slope/Offset:______/______
      (2) Sensor:__________ Serial #_________ Slope/Offset:______/______
      (3) Sensor:__________ Serial #_________ Slope/Offset:______/______
    - Data logger: Serial Number_________
  - ☐ Road and topographic site maps.
  - ☐ Rental equipment: jackhammer w/compressor, truck/trailer, etc.
  - ☐ Winch with 12V battery and battery charger.
  - ☐ Gin pole and associated hardware.
  - ☐ Safety equipment: Hard hats, gloves, appropriate clothes, first aid kit, etc.
  - ☐ Manufacturer's manuals for installation and troubleshooting (sensors, datalogger, etc.)

Additional Information/Comments:____

Site Designation:______________ ***Page 2***

C. GENERAL ON-SITE ACTIVITIES

Check the appropriate box. If No, provide an explanation below.

- **General Visual Inspection**
  Yes ☐ No ☐ Area free of vandalism?
  Yes ☐ No ☐ Tower straight?
  Yes ☐ No ☐ Guy wires taut and properly secured?
  Yes ☐ No ☐ Solar panel clean and properly oriented?
  Yes ☐ No ☐ Wind sensors intact, oriented correctly, and operating?
  Yes ☐ No ☐ Ice or snow on sensors, solar panel, antenna?
  Yes ☐ No ☐ Grounding system intact?
  Yes ☐ No ☐ Cellular antenna correctly orientated?

Findings/Actions:____

- **Data Retrieval**
  Manual ☐ Remote ☐ Download method
  Yes ☐ No ☐ Successful download? If No, provide explanation belos.

Findings/Actions:____

- **Datalogger Inspection** (Check when completed)
  Yes ☐ No ☐ Data logger operational? If No, provide explanation below.
  ☐ Record system voltages:______________________________________
  ☐ Date displayed:_ _______ Actual:_________ Corrected? (Circle) Yes / No
  ☐ Time displayed:_________ Actual:_________ Corrected? (Circle) Yes / No
  Yes ☐ No ☐ Check sensor values, are they reasonable? If No, provide explanation below.

Findings/Actions:____

- **Tower Lowering Activities**
  Yes ☐ No ☐ Check all anchors, signs of movement?
  Yes ☐ No ☐ Winch secured to anchor and safety line connected to vehicle bumper?
  Yes ☐ No ☐ Gin pole assembled with safety cable and snaplinks taped?
  Yes ☐ No ☐ Tower base bolt tight?
  Yes ☐ No ☐ Gin pole safety rope attached and tensioned properly (gin pole straight)?
  Yes ☐ No ☐ Weather conditions safe?
  Yes ☐ No ☐ Note start time of tower lowering. ______________(CST)
  Yes ☐ No ☐ Winch battery connected and terminals covered?
  Yes ☐ No ☐ Lifting guy wire attachments to gin pole checked?

Findings/Actions:____

- **On-Ground General Activities**
  Yes ☐ No ☐ Sensor and ground wires securely attached?
  Yes ☐ No ☐ Grounding system intact and secure?
  Yes ☐ No ☐ Sensor boom clamps secure?

Site Designation:______________ ***Page 3***

C. GENERAL ON-SITE ACTIVITIES (Continued)

- **On-Ground General Activities** (Continued)

Yes ☐ No ☐ Boom orientation OK?
Yes ☐ No ☐ Boom welds OK?
Yes ☐ No ☐ Vane deadband orientation as reported on Site Information Log?
Yes ☐ No ☐ Sensors level and oriented correctly?
Yes ☐ No ☐ Sensor wire connections secure and sealed with silicon?
Yes ☐ No ☐ Signs of sensor damage?
Yes ☐ No ☐ Sensor outputs checked and functioning properly?
Yes ☐ No ☐ Sensor serial numbers as reported on Site Information Log?
Yes ☐ No ☐ Sensor and/or data looger replacement? If Yes:

- Sensors:
  (1) Sensor:______ Serial #:______ Slope/Offset:______/______ Height:______
  (2) Sensor:______ Serial #:______ Slope/Offset:______/______ Height:______
  (3) Data Logger:______ Serial #:______

Findings/Actions:____

____

- **Tower Raising Activities**

Yes ☐ No ☐ Guy wire collars positioned correctly?
Yes ☐ No ☐ Lifting lines and anchor lines properly attached?
Yes ☐ No ☐ Gin pole secure, lines tensioned, gin pole straight, snap links taped?
Yes ☐ No ☐ Weather conditions safe?
Yes ☐ No ☐ Guys properly tensioned?
Yes ☐ No ☐ Tower straight?

- Note on-line time:__________(LST)

- **Site Departure Activities**

Yes ☐ No ☐ Successful data transfer with office computer?
Yes ☐ No ☐ Check antenna and phone connections?
Yes ☐ No ☐ Is datalogger date/time correct?
Yes ☐ No ☐ Secure datalogger enclosure with lock?
Yes ☐ No ☐ Clean area?
Yes ☐ No ☐ Guy wires clearly marked?

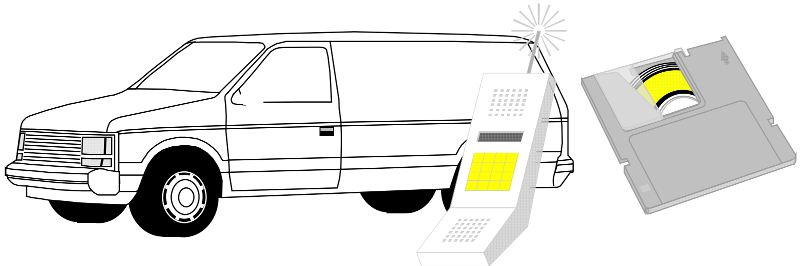
Findings/Actions:____

____

E. FINDINGS AND RECOMMENDATIONS

Yes ☐ No ☐ Further actions required? If Yes, describe below:

____
____
____
____
____



Chapter 8

DATA COLLECTION AND HANDLING

The data collection and handling elements of the monitoring system must incorporate procedures that offer a high level of data protection. In general, the procedures should comply with those specified by the data logger manufacturer and reflect good common sense. This chapter highlights the key aspects of this task, including in-field data storage (raw data), data retrieval and frequency, data protection, and documentation.

8.1 RAW DATA STORAGE

Data that have not been subjected to a validation or verification process are commonly referred to as raw data which are typically stored by the data logger in binary format. The storage device should be non-volatile, whereby the ability to store data is not affected by a loss of system power.

A. Data Storage Types

Each available data storage type and corresponding data transfer method has specific requirements with different advantages and disadvantages.

- **Solid State Devices:** The data may be read at the central computer using software provided by the manufacturer
- **Data Card:** Special software and a data card reading device may be required to transfer data
- **Magnetic Media:** Special software and equipment are required to read and transfer the data from the tape to the central computer
- **EEPROM Data Chip**: Manufacturer's software and an EEPROM reading device are required for data transfer
- **Portable Computer:** Special cabling, interface device, external power supply, and/or software may be required.

B. Data Storage Capacity

Table 8.1
256 kB Card Storage Capacity in Days

Averaging Interval (min)	Number of Active Channels			
	6	7	8	9
10	65	58	53	49
60	337	308	284	264

The storage capacity required depends on the averaging interval, the number of active data logger channels, and any additional logger processing such as the supplemental parameters presented in Section 4.4. Manufacturers usually provide tables or methods to calculate the approximate available storage capacity in days for various memory configurations. Table 8.1 presents examples of storage capacity information for a 256 KB data card for recording intervals of either ten-minutes or hourly. According to the table, a monitoring station configuration of seven active channels (three for wind speed, three for wind direction, and one for temperature) processed at a ten-minute averaging interval has an approximate storage capacity of 58 days. If an optional pyranometer and one redundant anemometer are included, the storage capacity decreases to 49 days. Remember these are approximate storage capacities; do not arrive on day 48 to download data. To be safe, consult with the data logger manufacturer as to your capacity needs and assume a reduction in the expected storage capacity of at least one week.

The minimum storage capacity requirements depend on the maximum time span between data transfers. Capacity estimates should also provide for delays in retrieving a site's raw data. The minimum data logger storage capacity should be 40 days. This reflects a one-month data transfer interval (31 days) with an additional nine day cushion to respond to and correct problems. Plan accordingly and wisely.

8.2 DATA RETRIEVAL

The selection of a data transfer and handling process (manual or remote), and thus the data logger model, will depend on your requirements. The following points should be considered during the selection process:

- Personnel availability
- Travel time to site
- Year-round site accessibility
- Availability of cellular phone service
- Equipment cost
- On-site power needs
- Ease of use
- Support systems required (computers, modems, analysis and presentation software, etc.).

8.3 DATA RETRIEVAL FREQUENCY

A key factor in achieving a high level of data completeness is the ability to identify potential problems and to quickly initiate a response. Data transfer and review are the first-order means of achieving this end. A schedule of regular site data transfers, or downloads, should be developed and maintained. The maximum recommended manual download interval is bi-weekly. For remote data transfer systems, a weekly retrieval rate may suffice but a shorter interval, such as two-day, may be required to successfully transfer the large datasets associated with ten-minute data averaging.

Situations may arise that warrant additional data transfers. For example, sensor data irregularities may become apparent during the review of site data. Weather patterns, such as icing or severe thunderstorms, which pose a risk to a site, merit a follow-up data transfer and review. To better assess each situation a field crew could be dispatched to conduct a visual inspection or, if using cellular phone systems, a current data set could be remotely downloaded for inspection to determine whether a problem has arisen.

8.4 DATA PROTECTION AND STORAGE

There is a risk of data loss or alteration during the measurement program. The following components and procedures are highlighted to offer guidance on minimizing the risk.

A. Electronic Data Collection Subsystem

Aside from the data logger programming requirements, the actual data collection process requires minimal technician input. Data are protected by following installation procedures, including grounding all equipment and the use of spark gaps.

B. Computer Hardware

Field data will eventually be transferred to a personal computer for analysis. This will be the primary location of the working database, but should not be the storage area for the archived database. Electrical surges and static discharges may damage hard drives and floppy disks. Follow the manufacturer's instructions and recommendations for all electrical connections.

C. Data Handling Procedures

Improper data handling procedures may represent the highest risk for data loss. The technical staff will be the handling medium and in constant contact with significant numbers of raw and processed databases. Ensure that all personnel are fully trained and understand the following:

- Data retrieval software and computer operating system (be aware of all instances in which data can be accidentally over-written or erased)
- Good handling practices of all data storage media including RAM cards, tapes, EEPROMs, and floppy disks (protect from static charge, magnetic fields and temperature extremes)
- Computer operations and safety practices, including grounding requirements.

To reduce the risk of data loss, maintain multiple copies of the database, or backups, and store each copy in a separate location (not in the same building). Back up the data on a schedule equal to the data retrieval interval. The three common data backup media available are floppy disk, tape, and CD ROM. The manufacturers provide guidelines for backup strategies that will best suit specific needs. Based on ease of use and price, the tape backup system is the method of choice.

8.5 DOCUMENTATION

Additional paperwork is not a welcome task, but detailed database related records must be maintained. A Site Data File Log should be developed to serve as the master raw data file log for each site. With the selection of pertinent information, the log's function can be expanded to allow personnel to track the success of data transfers, especially those that use telecommunication technology, and document the data protection plan (file backups) as presented in the preceding section. The basic information to include in the Site Data File Log, an example of which is presented at the end of this chapter, follows:

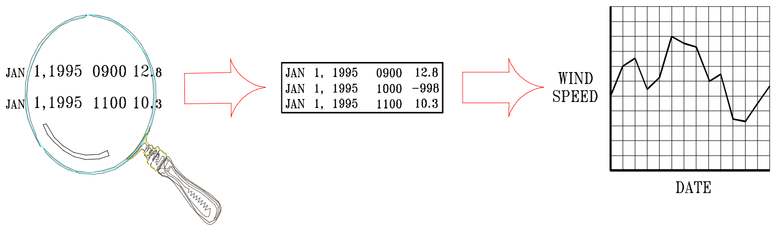
- Site designation
- File names of binary and ASCII data sets
- Start and end dates and times of the data set
- Date and time of data transfer
- Data transfer method: manual or remote
- Confirmation of a valid data transfer: are data present?
- Confirmation that data file was appended to archived database
- Date of database backup
- Comments: problems, actions taken, etc.

In addition to the obvious organizational benefits, this documentation will provide valuable and almost immediate quality control feedback on equipment performance and data completeness. For example, suppose a Site Data File Log entry indicates that the next data set should start on June 1 at 1300 hours. After downloading the data, the time and date stamp of the first data record indicates 1000 hours on June 6. The discrepancy shows an obvious problem. Or, suppose recent entries show that, although data have been successfully retrieved, establishing and maintaining site communication are becoming increasingly difficult. This may be the first indication of an impending failure of the system's telecommunication or power supply. It is time to visit the site and investigate before data are lost.

SAMPLE SITE DATA FILE LOG

Site Designation:___________

Binary File Name	ASCII File Name	Data Start Date	Data End Date	Data Start Time	Data End Time	Transfer Date/ Mode	Valid Transfer (Yes/No)	Data Archived (Yes/No)	File Backup Date	Comments (Problems, Actions Taken)



Chapter 9

DATA VALIDATION, PROCESSING, AND REPORTING

After the field data are collected and transferred to your office computing environment, the next steps are to validate and process data, and generate reports. The flow chart presented in Figure 9.1 illustrates the sequence and roles of these steps.

Figure 9.1
Data Validation Flowchart

Raw Data Files

↓

Develop Data Validation Routines

General System and Measured Parameter Checks

- Range tests
- Relational tests
- Trend tests

Fine-tune Routines with Experience

↓

Validate Data

- Subject all data to validation
- Print validation report of suspect values
- Manually reconcile suspect values
- Insert validation codes
- Alert site operator to suspected measurement problems

↓

Create Valid Data Files

↓

Process Data and Generate Reports

Data validation is defined as the inspection of all the collected data for completeness and reasonableness, and the elimination of erroneous values. This step transforms raw data into validated data. The validated data are then processed to produce the summary reports you require for analysis. This step is also crucial to maintaining high rates of data completeness during the course of the monitoring program. Therefore data must be validated as soon as possible, within one - two days, after they are transferred. The sooner the site operator is notified of a potential measurement problem, the lower the risk of data loss.

9.1 DATA VALIDATION METHODS

Data can be validated either manually or automatically (computer-based). The latter is preferred to take advantage of the power and speed of computers, although some manual review will always be required. Validation software may be purchased from some data logger vendors, created in-house using popular spreadsheet programs (e.g., Microsoft Excel, Quatro Pro, Lotus 123), or adapted from other utility environmental monitoring projects. An advantage of using spreadsheet programs is that they can also be used to process data and generate reports. These programs require an ASCII file format for imported data; the data logger's data management software will make this conversion if binary data transfer is used.

There are essentially two parts to data validation, data screening and data verification.

- **Data Screening:** The first part uses a series of validation routines or algorithms to screen all the data for suspect (questionable and erroneous) values. A suspect value deserves scrutiny but is not necessarily erroneous. For example, an unusually high hourly wind speed caused by a locally severe thunderstorm may appear on an otherwise average windy day. The result of this part is a data validation report (a printout) that lists the suspect values and which validation routine each value failed.

- **Data Verification:** The second part requires a case-by-case decision on what to do with the suspect values — retain them as valid, reject them as invalid, or replace them with redundant, valid values (if available). This part is where judgment by a qualified person familiar with the monitoring equipment and local meteorology is needed.

Before proceeding to the following sections, you should first understand the limitations of data validation. There are many possible causes of erroneous data: faulty or damaged sensors, loose wire connections, broken wires, damaged mounting hardware, data logger malfunctions, static discharges, sensor calibration drift, and icing conditions, among others. The goal of data validation is to detect as many significant errors from as many causes as possible. Catching all the subtle ones is impossible. For example, a disconnected wire can be easily detected by a long string of zero (or random) values, but a loose wire that becomes disconnected intermittently may only partly reduce the recorded value yet keep it within reasonable limits. Therefore, slight deviations in the data can escape detection (although the use of redundant sensors can reduce this possibility). Properly exercising the other quality assurance components of the monitoring program will also reduce the chances of data problems.

To preserve the original raw data, make a copy of the original raw data set and apply the validation steps to the copy.

The next two subsections describe two types of validation routines, recommend specific validation criteria for each measurement parameter, and discuss the treatment of suspect and missing data.

A. Validation Routines

Validation routines are designed to screen each measured parameter for suspect values before they are incorporated into the archived database and used for site analysis. They can be grouped into two main categories, general system checks and measured parameter checks.

1. General System Checks

Two simple tests evaluate the completeness of the collected data:

- **Data Records:** The number of data fields must equal the expected number of measured parameters for each record.

- **Time Sequence:** Are there any missing sequential data values? This test should focus on the time and date stamp of each data record.

2. Measured Parameter Checks:

These tests represent the heart of the data validation process and normally consist of range tests, relational tests, and trend tests.

- **Range Tests:** These are the simplest and most commonly used validation tests. The measured data are compared to allowable upper and lower limiting values. Table 9.1 presents examples of range test criteria. A reasonable range for most expected average wind speeds is 0 to 25 m/s. However, the calibration offset supplied with many calibrated anemometers will prevent zero values. Negative values clearly indicate a problem; speeds above 25 m/s are possible and should be verified with other information. The limits of each range test must be set so they include nearly (but not absolutely) all of the expected values for the site. Technicians can fine-tune these limits as they gain experience. In addition, the limits should be adjusted seasonally where applicable. For instance, the limits for air temperature and solar radiation should be lower in winter than in summer.

Table 9.1
Sample Range Test Criteria

*Sample Parameter	Validation Criteria
Wind Speed: Horizontal	
• Average	offset < Avg. < 25 m/s
• Standard Deviation	0 < Std. Dev. < 3 m/s
• Maximum Gust	offset < Max. < 30 m/s
Wind Direction	
• Average	0° < Avg. ≤ 360°
• Standard Deviation	3° < Std. Dev. < 75°
• Maximum Gust	0° < Max. ≤ 360°
Temperature	(Summer shown)
• Seasonal Variability	5°C < Avg. < 40°C
Solar Radiation	(Optional: Summer shown)
• Average	offset ≤ Avg. < 1100 W/m²
Wind Speed: Vertical	(Optional)
• Average **(F/C)	offset < Avg. <± (2/4) m/s
• Standard Deviation	offset < Std. Dev.<± (1/2) m/s
• Maximum Gust	offset < Max. < ± (3/6) m/s
Barometric Pressure	(Optional: sea level)
• Average	94 kPa < Avg. < 106 kPa
ΔT	(Optional)
• Average Difference	> 1.0° C (1000 hrs to 1700 hrs)
• Average Difference	< -1.0° C (1800 hrs to 0500 hrs)

* All monitoring levels except where noted.
** (F/C): Flat/Complex Terrain

If a value meets a criterion, that check considers the value valid. However, most parameter values should have several criteria checks, because a single criterion is unlikely to detect all problems. For example, if a frozen wind vane reports an average direction of exactly 180° for six consecutive ten-minute intervals, the values would pass the 0°-360° range test, but the stationary vane would report a standard deviation of zero and be flagged as suspect.

- **Relational Tests:** This comparison is based on expected physical relationships between various parameters. Table 9.2 gives examples of relational test criteria. Relational checks should ensure that physically improbable situations are not reported in the data without verification; for example, significantly higher wind speeds at the 25 m level versus the 40 m level.

Table 9.2
Sample Relational Test Criteria

*Sample Parameter	Validation Criteria
Wind Speed: Horizontal	
• Max Gust vs. Average	Max Gust ≤ 2.5 * Avg.
• 40 m/25 m Average Δ**	≤ 2.0 m/s
• 40 m/25 m Daily Max Δ	≤ 5 m/s
• 40 m/10 m Average Δ	≤ 4 m/s
• 40 m/10 m Daily Max Δ	≤ 7.5 m/s
Wind Speed: Redundant	(Optional)
• Average Δ	≤ 0.5 m/s
• Maximum Δ	≤ 2.0 m/s
Wind Direction	
• 40m/25 m Average Δ	≤ 20°

* All monitoring levels except where noted.
** Δ: Difference

- **Trend Tests:** These checks are based on the rate of change in a value over time. Table 9.3 lists sample trend test criteria. An example of a trend that indicates an unusual circumstance and a potential problem is a change in air temperature greater than 5°C in one hour.

The examples of validation criteria in Tables 9.1, 9.2, and 9.3 are not exhaustive, nor do they necessarily apply to all sites. With use, technicians will learn which criteria are most often triggered and under which conditions. For example, some criteria may almost always be triggered under light wind conditions, yet the data are valid. This occurrence may argue for one set of criteria under light wind conditions (below 4 m/s) and another set for stronger winds. Therefore the technician(s) should modify criteria or create new ones as needed.

Table 9.3
Sample Trend Test Criteria

*Sample Parameter	Validation Criteria
Wind Speed Average	(All sensor types)
• 1 Hour Change	< 5.0 m/s
Temperature Average	
• 1 Hour Change	≤ 5°C
Barometric Pressure Average	(Optional)
• 3 Hour Change	≤ 1 kPa
Δ Temperature	(Optional)
• 3 Hour Change	Changes sign twice

* All monitoring levels except where noted.

A secondary benefit of the data validation process is that the person(s) directly involved in the validation process will become very familiar with the local wind climatology. The behavior of the wind under various weather conditions will become apparent, as will the relationship between various parameters. This is an invaluable experience that cannot be appreciated solely by poring over monthly summary tables, and may be important for evaluating the impact of the local meteorology on wind turbine operation and maintenance.

Special Note: *Some data loggers and their data retrieval software record the system battery voltage for each averaging interval. Range and relational tests can be incorporated into your wind data validation routines to check for a reduction in battery voltage that may indicate a system problem.*

B. Treatment of Suspect and Missing Data

After the raw data are subjected to all the validation checks, what should be done with suspect data? Some suspect values may be real, unusual occurrences while others may be truly bad. Here are some guidelines for handling suspect data:

1. Generate a validation report (printout or computer-based visual display) that lists all suspect data. For each data value, the report should give the reported value, the date and time of occurrence, and the validation criteria that it failed.

2. A qualified person should examine the suspect data to determine their acceptability. Invalid data should be assigned and replaced with a validation code. Table 9.4 gives some examples. A common designation for data rejection is assigning a -900 series validation code, with numbers that represent various rejection explanations. Operation and maintenance logs or site temperature data should be reviewed to determine the code.

Table 9.4
Sample Validation Codes

Code	Rejection Criteria
-990	Unknown event
-991	Icing or wet snow event
-992	Static voltage discharge
-993	Wind shading from tower
-995	Wind vane deadband
-996	Operator error
-997	Equipment malfunction
-998	Equipment service
-999	Missing data (no value possible)

3. If redundant sensors are used, replace a rejected value from the primary sensor with a substitute one from the redundant sensor as long as the redundant sensor's data passed all the validation criteria.

4. Maintain a complete record of all data validation actions for each monitoring site in a Site Data Validation Log, an example of which is provided at the end of this chapter. This document should contain the following information for each rejected and substituted value:

   - File name
   - Parameter type and monitoring height
   - Date and time of flagged data
   - Validation code assigned and explanation given for each rejected datum
   - The source of the substituted values.

Important: Maintain raw and validated data files separately. Differentiate the files by assigning different extensions to the file names. For example, the file extension for the raw data file could be designated as ".raw" and the verified data file as ".ver." Valid data can then be compiled into a master data file for further data reporting and archiving.

C. Data Recovery

The data recovery rate is defined as the number of valid data records collected versus that possible over the reporting period and should be determined for each primary wind sensor (for all levels at each site). The method of calculation is as follows:

$$Data\ Recovery\ Rate = \frac{Data\ Records\ Collected}{Data\ Records\ Possible}(100)$$

where

$$Data\ Records\ Collected = Data\ Records\ Possible - Number\ of\ Invalid\ Records$$

For example, the total possible number of ten-minute records in December is 4,464. If 264 records were deemed invalid, the number of valid data records collected would be 4200 (4,464 - 264). The data recovery rate for this example would be:

$$Data\ Recovery\ Rate\ = \left(\frac{4{,}200}{4{,}464}\right)(100) = 94.1\%$$

9.2 DATA PROCESSING AND REPORTING

When the data validation step is complete, the data set must be subjected to various data processing procedures to evaluate the wind resource. This typically involves performing calculations on the data set, as well as binning (sorting) the data values into useful subsets based on your choice of averaging interval. From this, informative reports can be produced, such as summary tables and performance graphs. Data processing and reporting software are available from several sources, including certain data logger manufacturers and vendors of spreadsheet, database, and statistical software.

Hourly averages are normally used for reporting purposes. Compiling validated ten-minute data subsets into an hourly average data base can be performed using available data processing and reporting software. Whatever method is used, care must be taken to not include a flagged data point or -900 series flag code when computing the hourly average.

The basic parameter set allows for the determination and presentation of many valuable wind characterization tools. Table 9.5 presents the recommended monthly data reports. Examples of selected reports are provided at the end of this chapter.

Table 9.5
Sample Monthly Data Reporting

Report Products	Presentation	Reporting Heights
Mean hourly diurnal wind speed	Graph/Table	All
Joint wind speed and direction frequency distribution (16 sectors)	Table	All
Wind speed frequency distribution: 0.5 m/s (1 mph) bins	Graph/Table	All
Mean hourly diurnal temperature	Graph/Table	3 m
Mean hourly wind shear	Graph/Table	Between all heights
Mean turbulence intensity	Graph/Table	All
Wind rose	Graph	All
Mean hourly wind power density	Graph/Table	All

Except for fully programmable data loggers, the wind shear exponent, turbulence intensity, and wind power density are typically not internal processing functions of most data loggers. These parameters can be easily calculated using a spreadsheet software application to obtain hourly and monthly averages. A description of each parameter and calculation method is presented in detail below.

1. Vertical wind shear exponent: Wind shear is defined as the change in horizontal wind speed with a change in height. The wind shear exponent (α) should be determined for each site, because its magnitude is influenced by site-specific characteristics. The 1/7th power law (as used in the initial site screening) may not be applied for this purpose, as actual shear values may vary significantly from this value. Solving the power law equation for α gives

$$\alpha = \frac{Log_{10}\left[\frac{v_2}{v_1}\right]}{Log_{10}\left[\frac{z_2}{z_1}\right]}$$

where

v_2 = the wind speed at height z_2; and
v_1 = the wind speed at height z_1.

2. Turbulence intensity: Wind turbulence is the rapid disturbances or irregularities in the wind speed, direction, and vertical component. It is an important site characteristic, because high turbulence levels may decrease power output and cause extreme loading on wind turbine components. The most common indicator of turbulence for siting purposes is the standard deviation (σ) of wind speed. Normalizing this value with the mean wind speed gives the turbulence intensity (TI). This value allows for an overall assessment of a site's turbulence. TI is a relative indicator of turbulence with low levels indicated by values less than or equal to 0.10, moderate levels to 0.25, and high levels greater than 0.25. TI is defined as

$$TI = \frac{\sigma}{V}$$

where

σ = the standard deviation of wind speed; and
V = the mean wind speed.

3. Wind power density: Wind power density (WPD) is a truer indication of a site's wind energy potential than wind speed alone. Its value combines the effect of a site's wind speed distribution and its dependence on air density and wind speed. WPD is defined as the wind power available per unit area swept by the turbine blades and is given by the following equation:

$$WPD = \frac{1}{2n} \sum_{i=1}^{n} (\rho)\left(v_i^{\,3}\right) \text{ (W/m}^2\text{)}$$

where

n = the number of records in the averaging interval;
ρ = the air density (kg/m^3); and
v_i^3 = the cube of the ith wind speed (m/s) value.

As is evident by the summation sign (Σ), this equation should only be used for all wind speed values (n>1) during an averaging period and not for a single long term average (e.g., monthly, yearly). The reason is based on the normal variability of the wind and the cubic wind speed relationship. The following example is provided to illustrate this point.

> Assume that over a two hour period the average wind speed at a site is 6.7 m/s (15 mph); 4.5 m/s (10 mph) the first hour and 8.9 m/s (20 mph) the next. Calculate the WPD using the combined two hour average (n=1) and then with the two distinct hourly average values (n=2). Applying standard temperature and pressure (101,325 Pa and 288 °K) to the above equation, the calculated WPD using the overall average value is 184 W/m^2 while that using the two average values is 246 W/m^2. The latter value represents the average of that calculated for 4.5 m/s (55 W/m^2) and 8.9 m/s (438 W/m^2). There is actually 34% more power available at the site than would have been realized if the equation was used incorrectly.

The air density term in the WPD must be calculated. It depends on temperature and pressure (thus altitude) and can vary 10% to 15% seasonally. If the site pressure is known (e.g., measured as an optional parameter), the hourly air density values with respect to air temperature can be calculated from the following equation:

$$\rho = \frac{P}{RT} \text{ (kg/m}^3\text{)}$$

where

P = the air pressure (Pa or N/m^2);
R = the specific gas constant for air (287 J/kg·K); and
T = the air temperature in degrees Kelvin (°C+273).

If site pressure is not available, air density can be estimated as a function of site elevation (z) and temperature (T) as follows:

$$\rho = \left(\frac{P_o}{\mathrm{RT}}\right) \exp^{\left(\frac{-g \cdot z}{\mathrm{RT}}\right)} \quad (\mathrm{kg/m^3})$$

where

P_o = the standard sea level atmospheric pressure (101,325 Pa), or the actual sea level-adjusted pressure reading from a local airport;
g = the gravitational constant (9.8 m/s^2); and
z = the site elevation above sea level (m).

Substituting in the numerical values for P_o, R, and g, we get:

$$\rho = \left(\frac{353.05}{T}\right) exp^{-0.034\left(\frac{z}{T}\right)} \quad (\mathrm{kg/m^3}).$$

This air density equation can be substituted into the WPD equation for the determination of each hourly average value.

9.3 QUALITY ASSURANCE REPORTING

A component of your monitoring program documentation should be a periodic report on the program's adherence to the quality assurance plan (described in Section 2.4). The field and/or data analysis staff should prepare the report and submit it to the project manager (or quality assurance coordinator) monthly or quarterly. The report should address the following topics:

- Dates of operation and maintenance site visits: activities and findings
- Description of monitoring problems and corrective actions taken
- Record of equipment calibration activities (if applicable)
- Data validation findings and actions taken
- Data recovery rate.

A sample Quality Assurance Report Form is provided at the end of this chapter.

SAMPLE SITE DATA VALIDATION LOG

Site Designation: _____________ **Page:____ of ____**

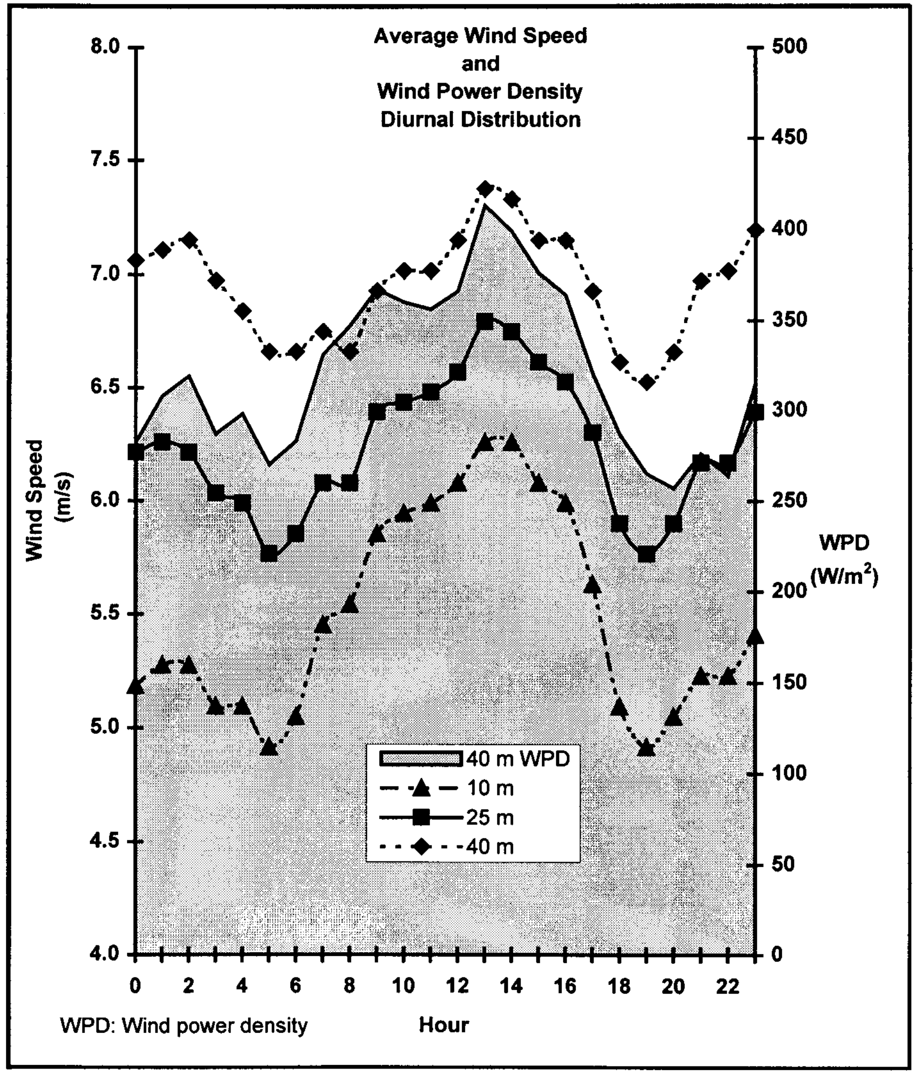
File Name	Parameter Type	Sensor Height	Date & Time Stamp	Flag Code	Explanation of Flag	Source of Substituted Value

SAMPLE MONTHLY DATA REPORTS

Diurnal Wind Speed Analysis Summary

Site:__________ Month:__________ Year:__________

Hour	40 m Wind Speed (m/s)	25 m Wind Speed (m/s)	10 m Wind Speed (m/s)	Wind Shear (40 m/25 m)	40m Wind Power Density (W/m^2)	40 m Turbulence Intensity	3 m Temp (°C)
0	7.1	6.2	5.2	0.31	282	0.11	-0.1
1	7.1	6.3	5.3	0.30	308	0.11	-0.6
2	7.2	6.2	5.3	0.35	319	0.11	-0.9
3	7.0	6.0	5.1	0.35	287	0.12	-1.1
4	6.8	6.0	5.1	0.34	298	0.12	-1.5
5	6.7	5.8	4.9	0.37	270	0.13	-1.9
6	6.7	5.9	5.1	0.29	283	0.14	-2.1
7	6.8	6.1	5.5	0.22	331	0.15	-1.3
8	6.7	6.1	5.5	0.17	347	0.16	-0.3
9	6.9	6.4	5.9	0.13	367	0.18	0.9
10	7.0	6.4	5.9	0.13	360	0.19	2.2
11	7.0	6.5	6.0	0.13	356	0.19	3.2
12	7.2	6.6	6.1	0.14	366	0.2	4.2
13	7.4	6.8	6.3	0.15	413	0.19	4.7
14	7.3	6.8	6.3	0.13	399	0.17	5.2
15	7.2	6.6	6.1	0.14	376	0.21	5.6
16	7.2	6.5	6.0	0.15	364	0.19	5.3
17	6.9	6.3	5.6	0.19	321	0.17	4.4
18	6.6	5.9	5.1	0.27	287	0.14	3.2
19	6.5	5.8	4.9	0.29	265	0.13	2.6
20	6.7	5.9	5.1	0.32	257	0.13	2.1
21	7.0	6.2	5.2	0.29	276	0.12	1.6
22	7.0	6.2	5.2	0.29	264	0.12	1.2
23	7.2	6.4	5.4	0.28	315	0.11	0.7
Avg.	7.0	6.2	5.5	0.24	321	0.15	1.6



SAMPLE MONTHLY DATA REPORTS

Joint Wind Speed/Direction Frequency Distribution Table

Site:_______ Month:______ Year:______

Bins	Wind Direction																%
(m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Calm																	0.4
0.5 - 3.5	0.5	0.7	0.7	0.5	0.7	0.7	0.1	0.4	0.3	0.3	0.1	0.0	0.1	0.1	0.4	0.5	9.8
4	0.4	0.4	0.3	0.3	0.3	0.5	0.0	0.3	0.7	0.0	0.0	0.1	0.0	0.0	0.1	0.3	5.0
4.5	0.1	0.5	0.1	0.7	0.7	0.4	0.3	0.4	0.1	0.1	0.0	0.1	0.1	0.5	0.3	0.4	7.1
5	0.4	0.7	0.1	0.8	0.1	0.7	0.1	0.9	0.4	0.1	0.3	0.3	0.1	0.5	0.9	0.5	6.3
5.5	0.3	1.1	0.3	0.5	0.8	0.1	0.3	0.4	0.5	0.1	0.1	0.1	0.3	0.3	0.5	0.5	8.5
6	0.1	0.4	0.5	0.8	0.8	1.1	0.4	0.8	0.5	0.1	0.1	0.1	0.5	0.5	0.3	1.2	9.3
6.5	0.1	0.5	0.7	0.3	0.8	1.6	1.1	1.3	1.3	0.3	0.1	0.0	0.0	0.8	0.3	0.0	6.7
7	0.3	0.1	0.0	0.0	0.1	0.9	1.3	0.7	0.9	0.0	0.0	0.0	0.3	0.7	1.1	0.3	5.6
7.5	0.1	0.1	0.1	0.0	0.0	0.3	1.1	0.3	1.6	0.1	0.0	0.0	0.1	0.4	1.2	0.1	6.5
8	0.3	0.4	0.1	0.1	0.0	0.5	0.9	1.3	0.1	0.4	0.0	0.0	0.1	1.1	0.5	0.4	5.1
8.5	0.1	0.4	0.1	0.0	0.1	0.1	1.2	1.2	0.7	0.0	0.1	0.0	0.0	0.7	0.3	0.0	3.8
9	0.3	0.0	0.1	0.0	0.0	0.1	0.9	0.8	0.7	0.0	0.0	0.1	0.0	0.3	0.4	0.0	5.9
9.5	0.4	0.0	0.7	0.0	0.0	0.3	1.2	0.8	1.1	0.0	0.0	0.1	0.0	0.3	0.4	0.7	5.2
10	0.5	0.0	0.3	0.1	0.1	0.1	0.5	0.5	0.9	0.1	0.1	0.0	0.0	0.4	0.4	0.9	3.9
10.5	0.3	0.0	0.0	0.0	0.0	0.1	0.5	0.8	0.9	0.0	0.1	0.3	0.0	0.0	0.7	0.1	3.0
11	0.3	0.0	0.0	0.0	0.0	0.1	0.8	0.3	0.3	0.0	0.1	0.1	0.1	0.3	0.4	0.1	1.6
11.5	0.1	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.7	0.1	1.1
12	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.3	1.5
12.5	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.4	0.3	0.3	0.7
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.4
13.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.3
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.4
14.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.4
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.3
15.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.3
16.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.3
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
17.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1
18.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
Total	4.7	5.4	4.2	4.2	4.6	8.3	11.6	12.1	11.3	1.7	1.3	2.6	3.1	8.1	9.7	6.9	100.0

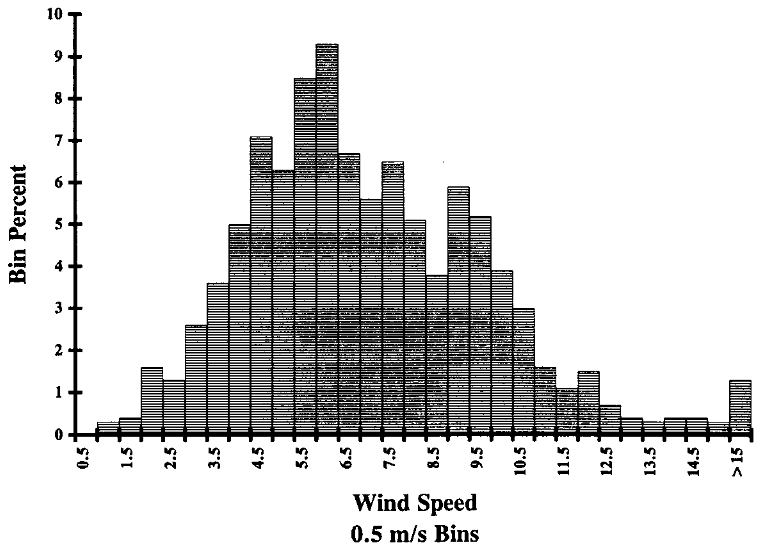
Note: Bin number represents mid-point of speed bin.

SAMPLE MONTHLY DATA REPORTS

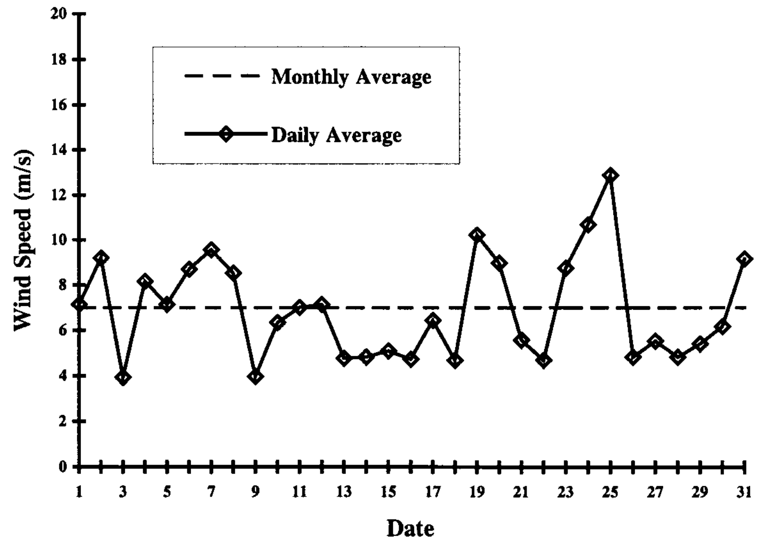
Wind Monitoring Statistics

Site Information	40 m Monthly Statistics	
Project: UWRAP Wind Monitoring Program	Mean Wind Speed (m/s):	7.0
Site Designation: USER - 2	Maximum 1-Sec Gust (m/s):	32.5
Location: East County, Town of West Wind	Std. Dev. of Speed (m/s):	0.8
Elevation: 305 m	Mean Turbulence Intensity:	0.15
Wind Monitoring Heights: 40 m, 25 m and 10 m	Mean Wind Shear:	0.24
Data Averaging Interval: 10 Minute	Prevailing Wind Direction:	SSE
Latitude / Longitude: 42° 30' N / 73° 10' W	Mean Power Density (W/m^2):	321
Month / Year: July 1996	Data Recovery (%):	100.0

40 m Wind Speed Frequency

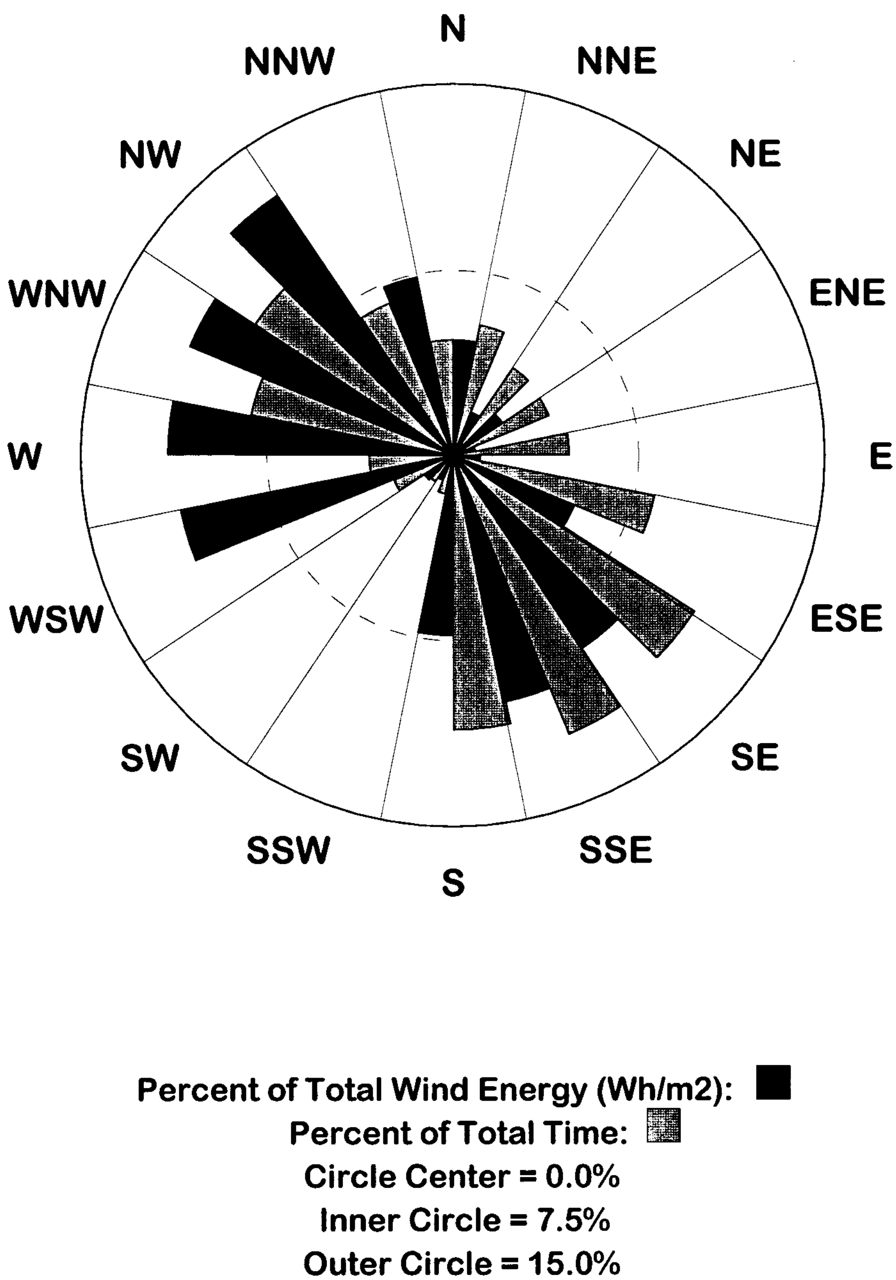


Daily Average 40 m Wind Speed



SAMPLE MONTHLY DATA REPORTS

Wind Direction Frequency: Wind Rose



SAMPLE QUALITY ASSURANCE REPORT FORM

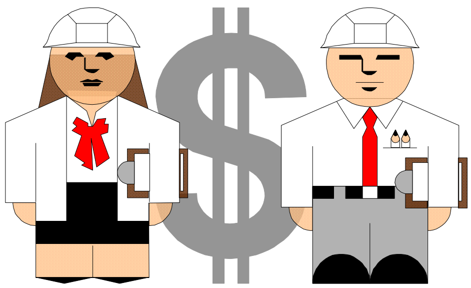
Reporting Period		****Page ____ of ____***	
Prepared By		***Date Prepared***	

****If more than four sites, copy and attach additional forms.***

For each monitoring site, please provide the following:

Site QA Information	Site: ____	Site: ____	Site: ____	Site: ____
1. Were O&M Site Visits Performed? (Circle)	YES NO	YES NO	YES NO	YES NO
• *If YES, attach copy(s) of O&M documentation for each site visit describing the activities, findings, monitoring problems and corrective actions taken. Documentation is attached: Check here ___(✓).*				
• *If NO, provide a detailed explanation (e.g., harsh weather conditions) in the Comments & Information section provided below.*				
2. Were instruments in compliance? (Circle)	YES NO	YES NO	YES NO	YES NO
• *If NO, provide a detailed explanation in the Comments & Information section provided below.*				
3. New/replacement equipment installed? (Circle)	YES NO	YES NO	YES NO	YES NO
• *If YES, attach revised Site Information Log. Documentation is attached: Check here ___(✓).*				
4. Raw data appended to site raw database? (Circle)	YES NO	YES NO	YES NO	YES NO
• *If NO, provide a detailed explanation in the Comments & Information section provided below.*				
5. Data validated and appended to validated database? (Circle)	YES NO	YES NO	YES NO	YES NO
If YES, attach Site Data Validation Log. Documentation is attached: Check here ___(✓). If NO, provide a detailed explanation below.				
6. Data backup performed and properly stored? (Circle)	YES NO	YES NO	YES NO	YES NO
• *If NO, provide a detailed explanation in the Comments & Information section provided below.*				
7. Was data recovery ≥ 90%? (Circle)	YES NO	YES NO	YES NO	YES NO
• *If NO, provide a detailed explanation (e.g., icing conditions) in the Comments & Information section provided below.*				

Comments and Information:
(Continue on back if necessary)



Chapter 10

COSTS AND LABOR REQUIREMENTS FOR A WIND MONITORING PROGRAM

What are the cost and labor implications of conducting a wind resource assessment program? This chapter identifies the major cost elements and outlines the main labor tasks to be considered. Also presented is a discussion on the roles of a nominal staff to carry out a measurement program.

10.1 COST AND LABOR ESTIMATES

Program costs can be divided into three main categories: labor, equipment, and expenses.

- **Labor:** Table 10.1 lists a series of tasks to be accounted for when budgeting for labor. The work will be performed by different levels of staffing. Some tasks, especially those that deal with equipment installation and maintenance, will at times require a team of two or three.

- **Equipment:** Equipment costs can be easily obtained from vendors once the measurement specifications are determined. Other items to include in the budget are shipping charges, taxes, insurance, spare parts, and the tools needed to install and service the tower. The estimated total equipment cost for a single site that uses a 40 m tilt-up tubular guyed tower equipped with three levels of sensors is $7,500 to $9,000.

- **Expenses:** Related expenses include travel, land lease fees, cellular phone fee (if applicable), and sensor calibration. Travel costs should account for the anticipated number of field trips required to select, install, maintain, and decommission a site. Some field trips may require overnight lodging and meals. The land lease fee is the reimbursement to the landowner for the use of his or her land for the monitoring tower. This fee is negotiable and may run $300 to $500 per year. Remote data transfer using a cellular or telemetered phone link can add costs, typically $30 to $50 per month, depending on the number of calls and the distance.

Table 10.1
Labor Tasks to Account for When Budgeting

A. Administration
• Program oversight
• Measurement plan development
• Quality assurance plan development
B. Site Selection
• In-house remote screening
• Field survey & landowner contacts
• Obtain land use agreement & permit
C. Equipment
• Specify and procure
• Test and prepare for field
• Installation (two to three people)
D. Operation & Maintenance
• Routine site visits (one person)
• Unscheduled site visits (two people)
• Calibration at end of period
• Site decommissioning (two people)
E. Data Handling & Reporting
• Validation, processing & report generation
• Data and quality assurance reporting

The re-calibration of anemometers, assuming they are done by the original vendor, is estimated to cost $150 per anemometer.

The estimated total cost for a single 40 m monitoring station operated for two years will likely be $25,000 to $40,000. Your actual costs will of course depend on the specific tower type and equipment selected, the site's proximity to operation and maintenance staff, and the number of site visits.

Economies of scale can be achieved with multiple sites. Most savings are realized in the labor category, where staff time and travel can be used more efficiently. In general, labor expenses for each additional site should be 50% to 70% that of a single site, depending on the number of sites and their mutual proximity. Travel expenses can be economized if more than one site is visited when making most field trips. Equipment cost savings can be realized via quantity discounts (typically 5% to 10%) offered by vendors and by sharing installation equipment (e.g., gin pole, winch kit) among sites. Overall, the total cost to operate a second site is estimated to be 10% to 15% less than the cost for the first site. The average site cost for a five-station monitoring network will be about 25% less than for a single site, or $19,000 to $30,000 per site.

10.2 STAFFING RECOMMENDATIONS

A resource assessment program should have a project manager, a field manager, and a data manager, plus additional support staff such as field technicians. These roles are preferably performed by separate individuals but this need not be the case.

A. Project Manager

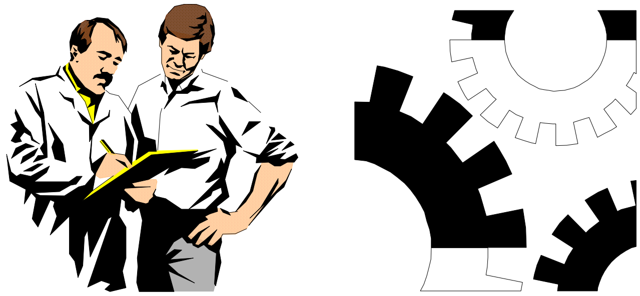
The project manager manages the overall project and ensures that human and material resources are available in a timely manner to meet the program's objectives. The project manager should also oversee the design of and adherence to the measurement and quality assurance plans.

B. Field Manager

The field manager installs and maintains the monitoring equipment and transfers the data to the home office. This person, and/or an assistant, should be available to promptly service a site whenever a problem arises. Installing and decommissioning sites, as well as service visits that require the tower to be lowered or climbed, demand at least two people.

C. Data Manager

The data manager is responsible for all data-related activities, including data validation and report generation. Familiarity with meteorology and the monitoring site and equipment, and a close working dialogue with the field manager, are essential to properly validate the data.



APPENDIX A

WIND RESOURCE ASSESSMENT EQUIPMENT VENDORS

Belfort Instrument
727 S. Wolfe St.
Baltimore, MD 21231
(410) 342-2626

Campbell Scientific, Inc.
815 W. 1800 N.
Logan, UT 84321-1784
(801) 753-2342

Climatronics Corporation
140 Wilbur Pl.
Bohemia, NY 11716
(516) 567-7300

Coastal Environmental Systems
316 Second Ave. S.
Seattle, WA 98104
(206) 682-6048

Kipp & Zonen
390 Central Ave.
Bohemia, NY 11716
(516) 589-2885

Licor, Inc.
P. O. Box 4426
Lincoln, NE 68504
(402) 467-3576

Met One Instruments
1600 Washington Blvd.
Grants Pass, OR 97526
(503) 471-7111

NovaLynx Corporation
P.O. Box 240
Grass Valley, CA 95945
(916) 477-5226

NRG Systems, Inc.
110 Commerce St.
Hinesburg, VT 05461
(802) 482-2255

Qualimetrics, Inc.
1165 National Dr.
Sacramento, CA 95834
(916) 928-1000

R. M. Young
2801 Aero Park Dr.
Traverse City, MI 49684
(616) 946-3980

Unarco Rohn
P.O. Box 2000
Peoria, IL 61656
(309) 697-4400

Scientific Sales
P.O. Box 6725
Lawrenceville, NJ 08648
(609) 844-0055
(609) 844-0466

Second Wind Inc.
366 Summer St.
Somerville, MA 02144
(617) 776-8520

Teledyne Geotech
3401 Shiloh Rd.
Garland, TX 75046-9007
(214) 271-2561

Tower Systems
P.O. Box 1474
Watertown, SD 57201
(605) 886-0930

Vaisala Inc.
100 Commerce Way
Woburn, MA 01801-1068
(617) 933-4500

Yankee Environmental Systems, Inc.
101 Industrial Rd.
P.O. Box 746
Turners Falls, MA 01376
(413) 863-0200

Zond Systems, Inc.
13000 Jameson Rd.
P.O. Box 1910
Tehachapi, CA 93581
(805) 822-6835

APPENDIX B

BIBLIOGRAPHY

Landowner's Guide to Wind Energy in the Upper Midwest
(N. Lange and W. Grant, Izaak, 1995 Walton League of America; available from Midwest Office, Izaak Walton League of America, 5701 Normandale Rd., Suite 317, Minneapolis, MN 55424)

The Meteorological Aspects of Siting Large Wind Turbines
(T. Hiester and W. Pennell, Report No. PNL-2522, 1981; available from National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22151)

Quality Assurance Handbook for Air Pollution Measurement Systems
(U.S. Environmental Protection Agency, revised 1989, Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC 27711)

Recommended Practice for the Siting of Wind Energy Conversion Systems
(American Wind Energy Association, AWEA Standard 8.2-1993: available from AWEA, 122 C Street N.W., Washington, DC 20001)

A Siting Handbook for Small Wind Energy Conversion Systems
(H. Wegley, J. Ramsdell, M. Orgill and R. Drake, Report No. PNL-2521 Rev.1, 1980; available from National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22151)

Siting Guidelines for Utility Application of Wind Turbines
(W. Pennell, Report No. EPRI AP-2795, 1983; available from Electric Power Research Institute, Research Reports Center, Box 50490, Palo Alto, CA 94303)

Standard Procedures for Meteorological Measurements at a Potential Wind Turbine Site
(American Wind Energy Association, AWEA Standard 8.1-1986: available from AWEA, 122 C Street N.W., Washington, DC 20001)

Wind Characteristics: An Analysis for the Generation of Wind Power
(J.S. Rohatgi and V. Nelson, 1994, West Texas A&M University, Box 248, Canyon, TX 79016)

Wind Energy Comes of Age
(P. Gipe, John Wiley & Sons, Inc., New York, 1995.)

Wind Energy Resource Atlas of the United States
(D. Elliott et al., 1987, Pacific Northwest Laboratory: available from the American Wind Energy Association, 122 C Street N.W., Washington, DC 20001)

Wind Turbine Technology: Fundamental Concepts of Wind Turbine Engineering
(D.A. Spera, Editor; ASME Press, New York, 1994: available from The American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017)

REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
April 1997

3. REPORT TYPE AND DATES COVERED
Subcontractor Report

4. TITLE AND SUBTITLE
Wind Resource Assessment Handbook

5. FUNDING NUMBERS
C: TAT-5-15283-01
TA: WE717020

6. AUTHOR(S)
AWS Scientific, Inc.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
AWS Scientific, Inc.
3 Washington Square
Albany, NY 12205

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
SR-440-22223
DE97000250

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

12b. DISTRIBUTION CODE
UC-1212

13. ABSTRACT *(Maximum 200 words)*
This handbook gives industry-accepted guidelines for planning and conducting a wind resource measurement program in support of the user's wind energy feasibility initiative. These guidelines, which are detailed and highly technical, emphasize the tasks of selecting, installing, and operating wind measurement equipment, as well as collecting and analyzing the associated data, once one or more measurement sites are located. The handbook's scope encompasses state-of-the-art measurement and analysis techniques at multiple heights on tall towers (e.g., 40 m) for a measurement duration of at least one year. While these guidelines do not represent every possible method of conducting a quality wind measurement program, they do address the most important elements based upon field-proven experience. The intended audience for this handbook is any organization or individual desiring the planning framework and detailed procedures for conducting a formally structured wind measurement program. Personnel from the management level to field technicians will find this material applicable.

14. SUBJECT TERMS
renewable energy; wind energy; wind resource assessment; wind resource measurement

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT
UL