III

Final Detailed Measurement Program Plan

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Detailed Measurement Program Plan

Prepared by TrueWind Solutions, LLC
Albany, New York

for

California Energy Commission

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Task 4: Measurement Program

Objective

The fundamental goal of the measurement program is to improve the understanding of the atmospheric boundary layer to heights of relevance for modern wind turbines (up to 150 m). This collected data will be used to refine wind resource estimates for particular focus areas throughout the state. In addition, the data may be used to improve the modeling of the boundary layer, and hence the accuracy of model estimates elsewhere in the state.

Background

This document is the Final Detailed Measurement Program Plan, hereon referred to as the Final Plan. The Final Plan was developed by TrueWind Solutions, hereon referred to as TrueWind, to guide Task 4 of the Wind Energy Resource Modeling and Measurement Project, contact number 500-03-006, with the California Energy Commission. The California Energy Commission will be referred to as the Commission from this point forward.

Test Plan Approval

The Final Plan is submitted following the submission of the Draft Plan to the Commission. Time was allocated after the submission of the Draft Plan for the Commission to review and comment on the Draft. The Commission requested that the Final Plan further detail the SODAR campaign. In response, the Draft SODAR Deployment Plan was generated and submitted to the Commission. The Final Plan incorporates the Draft SODAR Deployment Plan into the Final Detailed Measurement Program Plan.

Locations of Focus Areas

Task 2 of the Wind Energy Resource Modeling and Measurement Project identified five Focus Areas to be covered by the Measurement Program. These areas are referred to as:

- Antelope Valley Focus Area
- Mojave Desert Focus Area
- San Gorgonio Pass Focus Area
- Shasta Valley Focus Area
- Blue Ridge Focus Area

The centroids of the focus areas are listed in Table 1.

Group	Focus Area Name	Longitude	Latitude
B	Mojave Desert	-116.83155	35.03514
C	San Gorgonio Pass	-116.62582	33.93259
D	Antelope Valley	-118.30435	34.81656
H	Mayacamas Mountains	-122.66575?	38.69379
I	Shasta Valley	-122.44268	41.51182

Table 1

Measurement Locations

Measurements will be made from locations within the boundaries of all of the Focus Areas and from three or four tall towers within or near the Focus Areas. A SODAR unit will be used for Focus Areas that lack a representative tall tower. Each Focus Area will be instrumented with a SODAR unit. Some Focus Areas will be equipped with both an instrumented tall tower and a SODAR unit. This will allow further study of the Focus Area and comparison of the data generated by the two types of equipment.

The centroid of the Antelope Valley Focus Area is 25 km southwest of Mojave, California. In general, the terrain within this Focus Area is flat, sloping upwards on the northern, western, and southern edges. The City of Mojave, located in the northern portion of the Focus Area, has an elevation of 841 m. Lancaster, in the south of the Focus Area, is at 718 m. At the centroid, the prevailing wind direction is from the southwest. Temperatures range from highs of 44^{o}C to lows of –21 ^{o}C.

The centroid of the Mojave Focus Areas is located 26 km northeast of Barstow, California. It is composed of mixed terrain. In the south of the Area is the Mojave Valley. The Calico Mountains form the mid-section of the Focus Area. Flat regions intermixed with mountains extend north, away from the Calico Mountains. The Mojave Valley is roughly 550 m in elevation. The Calico Mountains peak at 1180 m. The floor of the flat northern area is roughly 1060m while the mountains there reach roughly 1300 m. At the centroid, the prevailing wind direction is from the west. Temperatures range from highs of 48 ^{o}C to lows of –13 ^{o}C.

The centroid of the San Gorgonio Pass Focus Area is located 15 km northwest of Palm Springs, California. The San Gorgonio Pass runs roughly east to west, transitioning from roughly 725 m in the west to 225 m in the east. At the centroid, the prevailing wind is from the west-southwest. Seasonal temperatures ranging from highs of 51 ^{o}C to lows of -12 ^{o}C.

The centroid of the Shasta Valley Focus Area is located 11 km northwest of Weed, California. The valley is marked by hills. The typical elevation of the valley floor is 250 m. To the south, mountains border the area. At the centroid, the prevailing wind direction is from the south-southeast. The climate varies, with temperatures ranging from typical highs of 39 ^{o}C to lows of –24 ^{o}C.

The Mayacamas Mountains Focus Area consists of a ridgeline that runs roughly north-west to south-east on the border of Sonoma and Lake Counties. Its centroid is located 28 km north-northeast of Santa Rosa, California. It includes Mount Saint Helena and ranges from a high point of 1435 m to a low of 95 m. At the centroid, the prevailing wind direction is from the northwest. Temperatures range from typical highs of 28 ^{o}C to lows of -6 ^{o}C.

Equipment Locations

A multi-level meteorological measurement system will be installed on three or four existing tall towers.

Location of the SODAR Units

Mojave Desert (Focus Area B)

One SODAR unit will be sited for three to four weeks, ideally in the northwest of the Focus Area in a relatively flat area with a class 5 wind resource. The majority of the area is controlled by the Bureau of Land Management (BLM).

San Gorgonio Pass (Focus Area C)

One SODAR until will be sited for three to four weeks in a class 5 to 7 wind resource area, out of the influence of active turbines. Currently, two sites are secured; both on the western end of the pass structure and well clear of active turbines. One of the secured sites is controlled by the BLM and the other is privately held.

Antelope Valley (Focus Area D)

Two SODAR units will be sited in or near Focus Area D. The first SODAR will be sited in a representative location within the heart of the Antelope Valley wind resource for three to four weeks. Numerous sites are being considered, all with online meteorological towers owned and operated by Oak Creek Energy Systems.

The other SODAR will be sited within the Oak Creek Energy Systems plant, located northwest of the Focus Area, for one to two weeks. The unit will be placed out of the influence of active turbines. The Oak Creek plant is home to the Oak Creek tall tower

Mayacamas Mountains (Focus Area H)

One SODAR unit will be sited for three to four weeks on the primary ridgeline within the northwest section of Focus Area D. The Geyserville tall tower is located on Geyser Peak, to the west of the planned SODAR site. The ridgeline is controlled by the BLM and private owners.

Shasta Valley (Focus Area I)

One SODAR unit will be sited for up to five weeks within the primary wind resource of the Shasta Valley. The selected location is the Shasta Airport, away from ground and air traffic. The airport is operated by the County of Siskiyou.

Montezuma Hills

One SODAR unit will be sited for one week in a class 3 or better wind resource, preferably as close as possible to the Dozier tall tower. The land is controlled by enXco, FPL, SMUD, and private landowners.

Two SODAR measurement systems (one leased from the supplier and one owned by TrueWind) will be used for the project. They will be set up at each measurement location for a minimum of 3 weeks. SODAR siting will follow standard conventions, including requisite standoff distances from obstructions, water bodies, ambient sounds, aircraft flight paths, and bird habitats. TrueWind employees will conduct setup and breakdown of the SODAR units.

Measurement Period

The tall tower instrumentation will gather equipment for 12 months after the equipment is commissioned.

SODAR deployments of three to four weeks aim to comprehensively characterize the wind resource at a site by collecting measurements over several synoptic weather cycles and tying the measurements to a long-term record. Such a characterization typically requires three weeks but can require additional weeks due to the variability of weather patterns and possible equipment downtime.

SODAR deployments of one to two weeks provide a snapshot of the wind resource. Such short campaigns are more effective when used in conjunction with a nearby meteorological record or additional SODAR deployments.

SODAR Deployment Schedule

The tentative schedule of SODAR operational dates in 2004 is listed below.

Leased Unit

Date Range	Location
4/07 – 5/11	Shasta Valley
5/13 – 6/08	San Gorgonio Pass
6/11– 7/07	Antelope Valley
7/09 – 7/16	Oak Creek Energy Systems

TrueWind Unit

Date Range	Location
6/05 – 6/30	Mayacamas Mountains
7/03 – 7/28	Mojave Desert
7/31-8/07	Montezuma Hills

Preparation and Installation of Equipment

TrueWind Solutions will specify and acquire the tall tower system components. The equipment will be programmed, tested, and packaged for shipment in-house before being sent to the field for installation. A tower climb contractor will complete tasks requiring scaling of the tower. The tower owner's climb contractor will be the preferred installation agent. The selection of a climb contractor will be dependent on rigger experience with similar work. A TrueWind employee will oversee the work of said contractor. TrueWind personnel will perform the tasks not requiring a tower climb contractor.

Vertical and horizontal separation of equipment mounted to tall towers will be consistent with the International Energy Association's specifications for the instrumentation of tall towers. For lattice towers, this means instruments are to be at least 3.75 times the tower face width away from the closest portion of the tower. In the vertical dimension, instruments are to be mounted at least 3 obstruction diameters from non-solid equipment mounted to the tower and 7 obstruction diameters from solid equipment on the tower. In addition, instruments are to be placed on a mast at least 10 times the height of the mounting boom. Finally, the instruments must be mounted at least 5 horizontal instrument-diameters away from any other instruments. Refer to Figure 1 for a pictorial representation of the International Energy Association's specifications. Different specifications apply to obstructions on the tower and non-lattice towers.

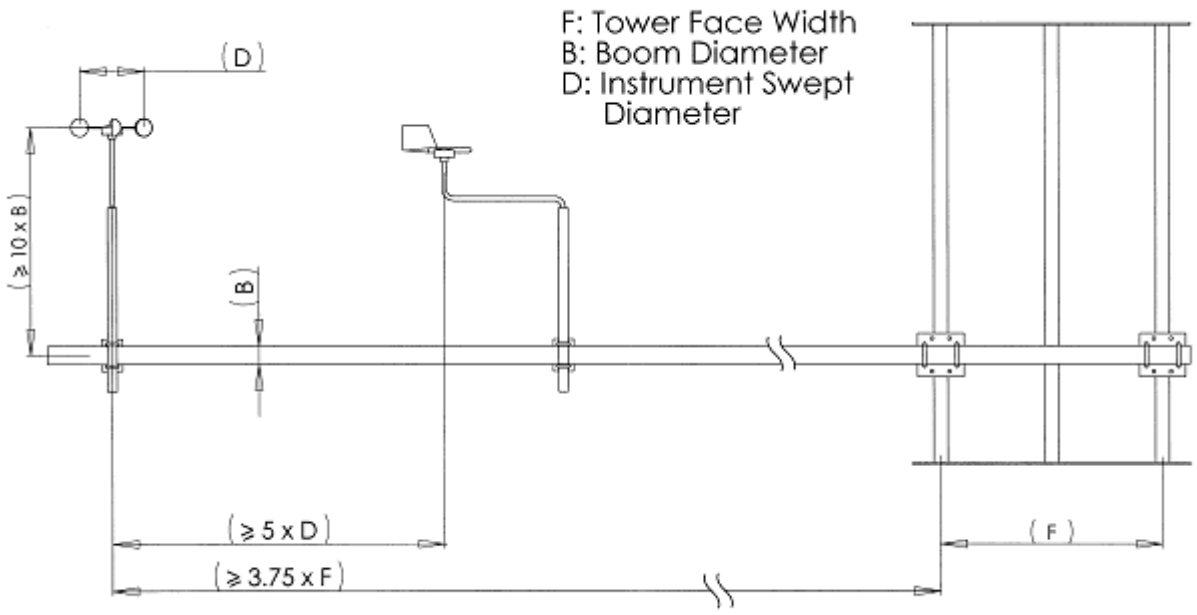

Figure 1

TrueWind owns one SODAR unit and will lease one unit for the measurement program. TrueWind will ensure that the SODAR units are properly specified, acquired, and configured for the measurement program. They will then be transported to the sites in California. The setup, testing, and breakdown of SODAR equipment will be carried-out by qualified TrueWind personnel.

Wind Speed Measurement

Wind speed will be measured at three heights on each tall tower. These heights will depend on the height and space availability of each tower but typical heights will be 50, 75, and 100 m. At each level there will be two anemometers in order to minimize instrument error, maximize reliability, and provide for data validation. Data validation will ensure that data from instrumentation in the wake of the tower will be discarded and replaced by data outside the wake of the tower. TrueWind plans to use the NRG Systems Max 40 Calibrated Cup Anemometer. Anemometers will be oriented into the direction of prevailing winds. If this is not possible or there is more than one prevailing direction, sensors will be mounted to minimize tower and instrumentation wake effects.

For the SODAR units, wind speed will be measured from 30 m to roughly 150 m at 10 m intervals. The maximum measurement height depends on site conditions such as humidity, ambient noise, and atmospheric stability.

Mounting Boom Design

Mounting booms will be used to hold the anemometers and wind vanes away from the tall towers. The use of appropriate booms minimizes the disturbance of airflow by the tower's presence in the flow stream.

Wind Direction

Wind direction will be measured at three heights on each tall tower. These heights will depend on the height and space availability of each tower but typical heights will be 50, 75, and 100 m. There will be one NRG Systems 200P wind vane mounted on each level. Wind direction sensor orientation will be verified in the field to properly reference true north.

For the SODAR units, wind direction will be measured for points starting at 30 m and extending to roughly 150 m, at 10 m intervals. The maximum measurement height depends on site conditions such as humidity, ambient noise, and atmospheric stability.

Air Temperature

Air temperature will be measured on each tall tower by two RM Young 41342 Temperature Sensors, each mounted in a six-plate radiation shield. The lower temperature sensor will be mounted at 10m. The height of the upper temperature sensor will depend on the height of the tower but the typical height will be 100 m. above the ground. The actual measurement height will be documented.

For the SODAR units, air temperature will not be recorded.

Irradiance

Solar radiation will be measured at each tall tower and SODAR by a LiCor Li-200SA pyranometer. Measurement will be made at a height of 1-3 m. The actual measurement height will be documented.

Precipitation

For the instrumented tall towers, precipitation will not be measured.

For the SODAR units, a rain gauge and/or precipitation sensor will be used to determine the existence of precipitation in order to assist in data validation.

Data Collection

Wind speed, wind direction, air temperature, and irradiance will be measured at a sampling rate of 0.5 Hz at each tall tower. A number of datalogger status parameters will also be recorded. The following parameters are archived into the logger every ten minutes:

- Average
- Standard deviation
- Minimum
- Maximum

For the SODAR units, wind speed and wind direction are measured at a sampling rate of 0.3 Hz**.** Irradiance and precipitation are measured at 1 Hz. Data quality and system status parameters are also recorded. The following parameters are archived into the logger every ten minutes:

- Average wind vector
- Average wind direction
- Mean of each of the three wind speed components
- Standard deviation of each of the three wind speed components
- Data quality parameters
- Average irradiance
- Various system status parameters

Data Acquisition System

For the instrumented tall towers, data will be stored on the datalogger.

For the SODAR units, data will be recorded on the unit's laptop computer.

Instrumentation Checkout and Field Calibration

The following tasks will be performed in the TrueWind office prior to the installation of the dataloggers used on instrumented tall towers:

- Datalogger programming and testing
- Communication system programming and testing
- Meteorological instrumentation testing

Once the equipment is installed at the site, a functionality check will be conducted for each sensor reading. All input data channels will be inspected to verify proper operation upon completion of the installation. Listed in Table 2 are the channel number, parameter name, sensor type, sensor location (assuming a typical upper instrumentation height of 100 m), sensor manufacturer, and sensor model for all sensors used per instrumented tall tower.

Ch.	Sensor Location	Parameter Name	Sensor Type	Sensor Mfg.	Sensor Model
1	100 m	100 m primary wind speed	cup anemometer	NRG	#40C
2	100 m	100 m redundant wind speed	cup anemometer	NRG	#40C
3	75 m	75 m primary wind speed	cup anemometer	NRG	#40C
4	75 m	75 m redundant wind speed	cup anemometer	NRG	#40C
5	50 m	50 m primary wind speed	cup anemometer	NRG	#40C
6	50 m	50 m redundant wind speed	cup anemometer	NRG	#40C
7	100 m	100 m wind direction	wind vane	NRG	#200P
8	75 m	75 m wind direction	wind vane	NRG	#200P
9	50 m	50 m wind direction	wind vane	NRG	#200P
10	1-3 m above ground	irradiance	pyranometer	Li-Cor	200SA
11	100 m	ambient temperature	temperature sensor mounted in radiation shield	RM Young	#41342
12	10 m	ambient temperature	temperature sensor mounted in radiation shield	RM Young	#41342

Table 2

The instrumentation checkout and field calibration procedures listed below are to be performed every six to eight weeks on each SODAR unit:

- Testing each speaker for proper transmission
- Testing the output of the speaker array every
- Occasional testing the response of the speaker array to incoming signals

Data Collection Procedure

TrueWind will remotely retrieve and validate the tall tower data on a weekly basis to ensure that the data acquisition system is functioning properly. In areas where sufficient cellular service exists, data will be transmitted using an NRG Systems Symphonie® iPack. In locations where cellular service is not suitable for data transfer, the data will report via a landline telephone service. If both options listed above are unavailable, regular site visits will be made to the datalogger to recover the data.

For the SODAR units, recorded data will be transmitted to TrueWind via a cellular phone on a daily basis. If cellular service is not available at the SODAR's location, a local representative will travel to the SODAR and retrieve the data on a weekly basis.

Data from the tall towers and SODAR units will be subject to rigorous quality control by TrueWind to identify any problems so that necessary repairs can be made quickly with minimal data loss.

Test Log Book

TrueWind will prepare a site log to record the relevant information about the meteorological equipment. It will note the following information for each site visit:

- Date and time of the site visit
- Meteorological conditions during the site visit
- Reason for the site visit
- Evidence of site tampering
- Information about the structural state of the tall tower or SODAR unit
- Record of instantaneous measurement values during the site visit
- State of the system during the site visit
- Contents of the error log during the site visit
- List of tasks performed at the site visit

Data Processing and Analysis

Raw data will be archived onto CD for backup once a week. Raw files will be imported into MS-Excel or MS-Access to develop a site database for each location.

The accuracy of measurements from the tall towers deteriorates during periods of icing. TrueWind plans to use ambient temperature and the standard deviation of wind direction as the primary method to detect icing events.

For the SODAR units, the accuracy of measurements deteriorates during periods of precipitation. TrueWind plans to use a rain gauge to detect precipitation. Also periods with a signal-to-noise ratio less than a threshold amount will be considered invalid. Finally, signal amplitude profiles will be examined to determine if fixed-echo effects may be compromising measurements.

Troubleshooting

TrueWind maintains a staff of engineers and specialists to diagnose and correct problems with the measurement equipment in a timely fashion. Problems will be detected during the setup process and via data processing and analysis.