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Technical Memorandum BNW/EWRA-TM1

KITE ANEMOMETER STUDIES AT THE PROPOSED RAS GHAREB WIND FARM SITE

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1.0 INTRODUCTION

A ridge line located approximately 5 km to the south of the city of Ras Ghareb, Egypt has been selected as a proposed field test site for a small wind farm. This field test is part of the Renewable Energy Field Testing Program for Egypt, sponsored by USAID and the Egyptian Electricity Authority (EEA). Ras Ghareb is an oil-producing community situated on the west shore of the Gulf of Suez approximately 230 km to the south of the town of Suez, and 80 km to the north of the point where the Gulf becomes the Red Sea.

A 20-m wind measuring tower was installed at the crest of the ridge by Battelle-Northwest and EEA personnel to evaluate the wind energy potential of the site at the 10-m and 20-m levels. The tower is located at Latitude $28^{o}21'$N and Longitude $33^{o}06'$E. Measurements at the tower began on 28 March 1985. Data collected from this tower (referred to as the EEA/Battelle tower) confirm earlier expectations that the wind resource at the site is favorable for wind energy use. The measurements also compare favorably with historical data collected approximately 2 km to the east of the site at a height of 6-m above the roof of a 6-m high building near the harbor (this station is known as the "Harbor Station"). Nevertheless, uncertainties in the representativeness of the Harbor Station data to the proposed wind farm site due to terrain and anemometer exposure makes the use of these data for wind energy analyses questionable.

Kite anemometers can be a useful tool for developing a better understanding of the effects of local terrain on flow variability across a given site, and

on the representativeness of a long term nearby station to short term data being collected at the proposed site. Because both of these issues prevail at the Ras Ghareb site, a series of studies have been planned to address the data uncertainties. Personnel from Battelle-Northwest, Meridian Corporation, and EEA are participating in these studies. The objectives are to:

- o develop information to quantify the flow variability across the proposed wind farm site so that the representativeness of the EEA/Battelle measuring station to the topography around the ridge crest can be determined

- o develop information to compare the representativeness of the Harbor Station data to the reference anemometer station at the proposed site.

This report describes the approach and results of the studies conducted on November 12, and provides recommendations for future studies to meet the above objectives.

2.0 APPROACH

A six-month summary of wind statistics from EEA/Battelle tower[(a)] shows that the monthly wind speed ranged from 7.8 to 10.5 m/s at the 20-m level. Both the tower and the Harbor Station measurements show that the prevailing wind direction in the area is from the northwest and north. The tower shows winds from these two directions occurring well over 90% of the time. Since

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(a)B. D. Holst and D. S. Renne: Egyptian Wind Resource Assessment Program, Interim Site Data Report, April - September, 1985. Battelle, Pacific Northwest Laboratories, Richland, Washington.

the ridge-line is oriented perpendicular to this prevailing direction, we can assume as a first approximation that wind characteristics at any point along the ridge crest are similar. As a result, the main source of uncertainty in wind characteristics for wind farm applications is the variability of the wind resource in the along-wind direction from the upwind to the downwind slopes of the ridge.

In the kite anemometer studies conducted on November 12 the kites were flown at a constant height of approximately 30m above the ground. This height was established by using the following equation supplied by the kite anemometer manufacturer, Approach Fish, Inc.[a]:

$$\text{Alt (m)} = .9(.3N - 2.2\times10^{-5}N^2)\sin O \qquad (1)$$

where: N = Reel count for the line attached to the kite

O = visual vertizal azimuth

On that day, visual azimuth readings obtained from an inclinometer were generally around 050°. Thus, from equation (1) we see that a height of 30m would be attained for a line count of 150. The line count for each kite was set at this value for all measurements conducted on this day. Periodically inclinometer measurements were obtained during the course of the experiments to check the line count selection. No deviations from the 050° value were observed.

(a)Approach Fish, Inc., Rte. 1 Box 620B, Ringgold, Virginia 24586

Simultaneous readings were obtained by each observer, as well as an observer at the meteorological tower, every 20 seconds during the course of a particular run. The procedure for obtaining a reading on the plastic tube scale supplied with each kite anemometer is to pinch the spring-loaded line when a reading is to be made to prevent movement of the wind speed indicator, then manually recording the value indicated. At the same time, a digital read-out of the wind speed at the 20-m height on the tower is obtained from the data logger and manually recorded. All measurements were recorded in miles per hour.

Calibration runs were conducted prior to the actual flow variability studies. In the calibration runs, all three kites were flown at an identical height at the same location simultaneously. This established the relative difference of wind speed measurements obtained from each kite, as well as the difference in measurements between the kites and the 20-m level of the EEA/Battelle tower. Two 10-minute calibration runs were made prior to the actual studies, from 1043 to 1110 local time. An additional calibration run was conducted at the conclusion of the experiments, from 1305 to 1315 local time.

Following the initial two calibration runs, two runs were conducted to address the objectives stated above. The first run consisted of the three kite anemometers positioned in the along-wind direction. The upwind kite was flown at a position approximately 400 m due north of the EEA/Battelle tower, near the upwind base of the ridge. A second kite was flown adjacent to the tower at the ridge crest and a third kite was flown approximately 400 m due

south of the tower near the downwind base of the ridge. This run was designed to assess the variability of the wind resource from the upwind to the downwind slopes of the ridge. Readings from each kite and the tower were obtained simultaneously every 20 seconds for a period of 20 minutes, from 1120 to 1140 local time.

The second run consisted of two kite anemometers positioned along the crest of the ridge. One was located at the EEA/Battelle tower, and the other located approximately 400 m to the east. The third was located at the Harbor Station, approximately 2 km to the east. This experiment was designed to evaluate the variability of the wind resource along the crest of the ridge and the representativeness of the Harbor Station data to the EEA/Battelle tower. Readings from each kite and the tower were obtained every 20 seconds for a period of twenty minutes, from 1231 to 1250 local time.

3.0 RESULTS

3.1 CALIBRATION RUNS

Results of the three calibration runs are shown in Table 1. The values in this table represent the average of all 20-second observations over each respective 10-minute calibration run, and the standard deviation of the 20-second values. The averages obtained from the 20-m level of the meteorological tower are included as well, to help identify temporal trends in the wind speeds during the course of the calibration runs. The intent of these calibration runs is to establish a correction factor for the upwind and downwind kite, so that all measurements are normalized to the kite flown at the tower. This

correction factor, also shown in Table 1, is the value by which the measured wind speeds for the upwind and downwind kites must be multiplied in order to be normalized to the kite at the tower.

The standard deviation of the 20-second readings provides an indication of the amount of turbulence in the atmosphere, as well as the relative performance of each kite. For example, a poorly-harnessed kite may indicate a higher standard deviation than a kite in which the harness is tied properly. The reason for this is that a kite is both a lift and drag device; if the harness were tied incorrectly, the motion of the kite to establish an aerodynamic equilibrium would be expected to be greater, possibly causing a higher standard deviation than an adjacent kite with a properly-tied harness.

By normalizing the standard deviation to the mean wind speed over the same time period, we obtain a measure of the "Turbulent Intensity" (T.I.) of the atmosphere. This value is also shown in the table.

Table 1 indicates that the mean wind speed decreased, and the turbulent intensity increased somewhat between the first and the second calibration run. For the third calibration run winds were at their heighest level for the entire study. However the variability throughout the period is quite small. Consequently, the average of all three calibration runs was used to establish the correction factor applied to the other experiments. Use of all three, as opposed to the first two, calibration runs introduces an uncertainty of only 0.1 mph into the corrected results.

3.2 ALONG-WIND (NORTH-SOUTH) PROFILE

Table 2 provides the results of the 20-minute profile obtained from the upwind to the downwind slopes of the ridge. All values are adjusted using the correction factors provided in Table 1. A variability of only 0.3 mph is detected across the ridge for this run. This variability is well within the overall uncertainty of the measurements, indicating that at the 30-m level wind flow across the ridge was reasonably constant on this day. If a statistically significant sampling of these types of experiments were obtained with the same results, it would indicate that long-term measurements at the crest of the ridge are representative of the flow characteristics from the upwind to the downwind slopes of the ridge.

3.3 REPRESENTATIVENESS OF TOWER MEASUREMENTS TO HARBOR STATION

Table 3 provides the results of the 20-minute run comparing winds at the Harbor Station with those at the tower and an additional site along the ridge crest. The table shows that measurements between the tower and the Harbor Station are essentially identical, indicating that if this experiment was repeated with the same results a statistically significant number of times, wind measurements at the 30-m level at the Harbor Station are representative of wind measurements at the 30-m level at the tower. This result increases our confidences in applying the long-term historical data collected at the Harbor Station to the wind characteristics at the proposed site.

The third kite measurement, obtained at the crest of the ridge about 400 m to the east of the tower, shows wind speeds 0.8 mph lower than the Harbor Station or tower. This kite (Kite "U") indicated lower wind speeds than the

other kites throughout the entire study. Consequently, part of this lower reading can be attributed to an inaccurate correction factor established during the calibration runs. It is felt for this study that the difference in measurements among all three kites is within the uncertainty limits inherent with kite anemometers applied in this manner.

4.0 CONCLUSIONS

The experiments conducted at the proposed Ras Ghareb wind farm site on November 12 can be concluded as follows:

- The wind energy resource at the 30-m height across the ridge in the alongwind direction was essentially constant (or certainly within the limits of precision afforded by the kite anemometers) for that day.

- Measurements obtained at the 30m level at the Harbor Station were representative of measurements taken at the same level at the tower site.

Of course, this one study does not necessarily represent a statistically significant sampling of flow variability in the Ras Ghareb region. However, there is general agreement among the participants of this study that wind characteristics on that day were typical of what is observed in Ras Ghareb throughout much of a given day, and throughout much of the year.

5.0 RECOMMENDATIONS

- Studies such as these should be conducted periodically throughout the year and at different times during the day to improve the statistical basis for our conclusions.

- As data are collected from the wind measuring system installed on the Harbor Station mast on November 12 by Battelle-Northwest (a system identical to the one installed on the EEA/Battelle tower), a comparison of the two sites should continue to further establish the representativeness of the long-term Harbor Station data to the proposed site.

- Data collected from the new system installed on the Harbor Station mast on November 12 should be compared directly with the historical strip chart system still in operation at the Harbor Station to establish a comparison of performance of these two different systems to further document data representativeness.

TABLE 1: SUMMARY OF KITE ANEMOMETER CALIBRATION RUNS. ALL KITES FLOWN AT 30 m.

		KITE "T"	KITE "U"	KITE "D"	TOWER (20 m)
CALIBRATION #1 (1043-1053)	U =	24.3	23.5	23.9	20.4
	S.D. =	1.94	1.88	1.65	1.43
	T.I. =	0.080	0.080	0.069	0.070
CALIBRATION #2 (1100-1110)	U =	23.6	22.8	23.7	19.5
	S.D. =	2.56	2.02	2.13	1.77
	T.I. =	0.108	0.089	0.090	0.091
CALIBRATION #3 (1305-1315)	U =	24.6	23.7	24.1	---
	S.D. =	1.59	1.6	2.21	---
	T.I. =	0.065	0.068	0.092	---
AVERAGE SPEED (MPH)	U =	24.2	23.3	23.9	20.0
CORRECTION FACTOR		1.000	1.036	1.011	

NOTE: KITE "T" = TOWER KITE
KITE "U" = UPWIND KITE
KITE "D" = DOWNWIND KITE
U = MEAN WIND SPEED (MPH)
S.D. = STANDARD DEVIATION
T.I. = TURBULENT INTENSITY

TABLE 2: SUMMARY OF KITE ANEMOMETER OBSERVATIONS FOR NORTH-SOUTH PROFILE (1130 - 1140 LOCAL TIME). ALL KITES FLOWN AT 30 m.

	KITE "T"	KITE "U"	KITE "D"	TOWER (20 m)
CORRECTED U =	23.2	22.9	23.2	19.3
S.D. =	2 12	1.57	2.04	1.98
T.I. =	0.091	0.071	0.089	0.103

NOTE: KITE "T" = TOWER KITE
KITE "U" = UPWIND KITE
KITE "D" = DOWNWIND KITE
U = MEAN WIND SPEED (MPH)
S.D. = STANDARD DEVIATION
T.I. = TURBULENT INTENSITY

TABLE 3: SUMMARY OF KITE ANEMOMETER OBSERVATIONS FOR RIDGE CREST TO HARBOR STATION PROFILE (1230 - 1240 LOCAL TIME). ALL KITES FLOWN AT 30 m.

	KITE "T"	KITE "U"	KITE "D"	TOWER (20 m)
CORRECTED U =	23.9	23.2	24.0	20.1
S.D. =	2.06	2.93	1.90	1.80
T.I. =	0.086	0.126	0.079	0.090

NOTE: KITE "T" = TOWER KITE
KITE "U" = OTHER RIDGE CREST KITE
KITE "D" = HARBOR STATION KITE
U = MEAN WIND SPEED (MPH)
S.D. = STANDARD DEVIATION
T.I. = TURBULENT INTENSITY