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Governor

City and County of San Francisco Wind Resource Assessment Project

Task 5: Data Analysis and Reporting Final Report

PIER FINAL PROJECT REPORT

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PREFACE

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

What follows is the final report for the City and County of San Francisco Wind Resource Assessment Project, 500-01-006, conducted by Itron, Inc. The report is entitled City and County of San Francisco Wind Resource Assessment Project – Final Report. This project contributes to the PIER Renewable Energy program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The California Energy Commission's (Commission) Public Interest Energy Research (PIER) Renewables program element undertook an urban wind resource assessment project to help the City and County of San Francisco optimize its future investment in distributed wind energy generation.

Five prospective wind energy generation sites within the City and County were selected. Wind speed data were collected for periods ranging from 5 to 14 months. Sites included in the analysis are Twin Peaks, Treasure Island, Hunters Point, S.F. Zoo, and Pier 39. Wind data over an 11 year period from the S.F. International Airport (SFO) weather station were used in a normalization analysis for each of the monitored sites. For SFO and for each of the monitored sites, an 8,760-hour wind speed dataset was developed to represent typical, or "normal" wind energy resource. For each site annual energy production estimates were calculated for a generic 10 kW horizontal axis wind turbine on a 98-foot tower. Annual energy production estimates ranged from 7,371 kWh/yr for Hunters Point to 15,632 kWh/yr for Twin Peaks. With the exception of Twin Peaks the wind energy resource at the monitored sites appear to be quite modest relative to levels customarily associated with wind energy generation development. Stakeholders responsible for making decisions concerning investment in wind energy generation equipment at the five monitored sites should consider limitations of normalization analyses relying on short-term datasets when incorporating the results of this wind resource assessment into their turbine-specific performance, economic and financial analyses .

The findings of this project will help the City and County of San Francisco make better decisions regarding their future investments in small wind-based renewable energy distributed generation, thereby benefiting California.

Keywords:

- California,
- Urban,
- Wind,
- Data,
- Analysis,
- Energy,
- San Francisco,
- Small turbine,
- Renewable

EXECUTIVE SUMMARY

Introduction

In November 2001, San Francisco voters approved two bond measures earmarking $100 million for installation of wind energy generation, solar energy generation, and energy efficiency technologies on city-owned property. In the case of wind energy generation, optimum allocation of resources will hinge on availability of wind energy resource information. To date little information has been developed concerning wind energy resource variability within the City of San Francisco. The California Energy Commission's (Commission) Public Interest Energy Research's (PIER) Renewable Energy program undertook this urban wind resource assessment project to help the City and County of San Francisco optimize its future investment in distributed wind energy generation capacity.

To determine whether there may be economically feasible wind resources available at several select sites within the City/County geographic boundaries an urban wind resource assessment research project was conducted. Project objectives were to:

- Measure wind speeds at five sites within the City/County of San Francisco,
- Identify relationships between the measured wind speed data at the five monitored sites and wind speed data for the San Francisco International Airport (SFO), a nearby weather station for which a long-term historical record exists,
- Develop 8,760-hour wind speed datasets reflecting typical, or "normal" wind energy resources for each of the five monitored sites, and
- Estimate annual energy production for a generic 10 kW wind turbine installed on a 98-foot tower at each of the five monitored sites.

The information gathered and developed as a result of this project will be used by the City/County of San Francisco staff in ascertaining the feasibility of developing urban wind projects. The scope of this project was limited to quantifying the wind resources at select urban locations within the City/County of San Francisco.

Project Approach

Before visiting any prospective monitoring sites the various factors influencing urban wind energy resource were compiled. During subsequent site selection meetings and site visits these criteria were used to assess the suitability of particular sites. Two parallel paths were pursued to accomplish monitoring system selection and installation. First, a local meteorological consulting firm with many years' experience in wind resource assessment both in California and elsewhere was invited to join the project team. Data for three sites were collected via this path. Data for two additional sites were obtained from secondary sources and incorporated into the analysis.

Analysis of wind speed data included development of typical 8,760-hour wind speed datasets for a "normal" wind energy resource year, and estimation of annual energy production for hypothetical generic 10 kW wind turbines installed on 98-foot towers at each of the 5 monitored sites. The normalization process entailed three fundamental steps.

1. Define a normal 8,760-hour SFO wind speed dataset based on long-term historical wind speed data,
2. Identify relationships between SFO wind speeds and coincident wind speeds at each monitored site, and
3. Estimate 8,760-hour normal wind speed datasets for each of the monitored sites.

Depending on seasonal availability of measured data for both SFO and a monitored site one of two different analytic methodologies was used to identify a relationship between coincident wind speeds at the two locations. In 80% of cases sufficient data were available to enable use of a whole-day substitution approach akin to the method used to define the normal 8,760-hour SFO wind speed dataset. Days of measured data for the monitored sites were selected for inclusion in the normal wind speed datasets based on daily wind energy totals for SFO. A principal advantage of this approach is that it retains all of the site-specific diurnal wind speed characteristics in the measured data.

When less than two months of data were available for a season a single-hour substitution approach was used to avoid estimation of normal wind speed data with unsatisfactory diurnal characteristics. This approach entailed using measured data to determine distributions of monitored-site wind speeds corresponding to particular SFO wind speeds. For individual hours in the normal wind speed dataset a monitored-site wind speed was probabilistically selected from a distribution of wind speeds corresponding to the SFO wind speed for that hour.

Wind speed data used in the analysis were collected at a variety of heights ranging from 24 feet to 60 feet. Initial results of the normalization analysis were adjusted such that final normal wind speed estimates are based on a sensor height of 33 feet. Finally, assumed performance characteristics for a generic wind turbine were combined with normal wind speed datasets in a calculation of annual energy production. For this analysis the 33-foot normal wind speeds were adjusted upward to estimate wind speeds for 98-foot tall towers.

Project Outcomes

Five sites were selected for inclusion in the wind resource assessment project. The characteristics of the monitored sites are summarized in Table 1. Data were obtained from several sources, and the monitoring period extended from July 2002 through November 2003. Data availability varied from site to site. The large quantity of SFO data was required for the normalization analysis.

Table 1 Characteristics of Five Monitored Sites (& SFO)

Monitored Site	Source of Data	Sensor Mount Type	Instrument Height Above Roof/Ground (Feet)	Quantity of Data Compiled/Collected (Months)
Pier 39	Itron team	Roof	24	5
S.F. Zoo	Itron team	Ground	30	9
Treasure Island	WeatherFlow	Roof	12	12
Hunters Point	Tetra Tech EM	Ground	33	14
Twin Peaks	Itron team	Ground	60	8
S.F. Airport	WeatherBank	Ground	33	142

Monthly average wind speeds based on the final 33-foot normal wind speed datasets are depicted graphically in Figure 1, which also includes results for SFO.

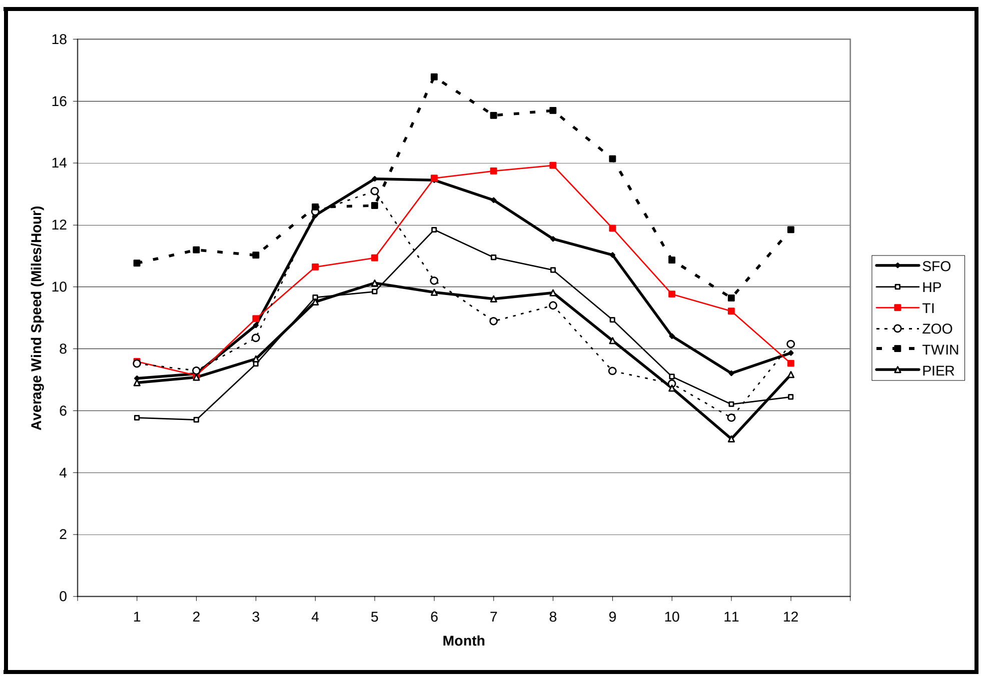

Figure 1 Normalized 33-foot Monthly Average Wind Speeds

Annual average wind speeds corresponding to each of the normal 33-foot 8,760-hour wind speed datasets developed for this project are presented in Table 2 alongside an estimate of the corresponding wind power class and generic turbine annual energy production. Annual energy production was estimated for a generic 10 kW wind machine installed on a 98-foot tower. The annual energy production estimates range from 7,371 kWh/yr to 15,632 kWh/yr.

Table 2 Annual Average Wind Speeds and Wind Power Classes for Monitored Sites (& SFO)

Monitored Site	Normal 33-Foot Annual Average Wind Speed (Miles/Hour)	Wind Power Class	Annual Energy (kWh)
Pier 39	8.2	1	7,574
S.F. Zoo	8.9	1	8,498
Treasure Island	10.4	2	13,299
Hunters Point	8.4	1	7,371
Twin Peaks	12.7	4	15,632
S.F. Airport	10.1	2	11,754

Conclusions and Recommendations

With the exception of Twin Peaks the wind energy resources at the monitored sites appear to be quite modest relative to levels customarily associated with wind energy generation development. From the standpoint of economic feasibility of prospective wind energy generation facilities a wind power class equal to 1 is generally considered 'very poor' or 'poor'. In the case of small turbines, under the right circumstances (e.g., valuation of generated electricity at a high retail rate) a wind power class of 2 may be sufficient to justify development on financial grounds.

City and County of San Francisco staff responsible for making decisions concerning investment in wind energy generation equipment at the five monitored sites should incorporate results of this urban wind resource assessment project into their technical and financial analyses. It is conceivable that now or at some time in the future installation of wind energy generation systems on the roofs of high-rise buildings may be technically feasible. In this eventuality the Commission or others may want to augment the present research with an urban high-rise rooftop wind resource assessment.

This project developed site-specific wind energy resource information for five prospective wind energy generation facility sites within the City of San Francisco. This information will help the City and County of San Francisco make better decisions regarding their future investments in renewable energy distributed generation, thereby benefiting California.

Benefits to California

Economic, political, electric transmission system loading, Renewable Portfolio Standards (RPS), fuel diversity, and other factors have combined to create an atmosphere of increased interest in developing wind energy generation facilities in California and elsewhere throughout the US and Europe. However, economic feasibility of particular, prospective wind energy projects is highly site specific. In the absence of satisfactory information concerning wind energy resource there is an elevated risk of investing in wind energy generation facilities that are located sub-optimally. This project developed site-specific wind energy resource information for five prospective wind energy generation sites within the City of San Francisco. This information will help the City and County of San Francisco to make better decisions regarding their future investments in renewable distributed generation, thereby benefiting California.

1.0 Introduction

1.1. Background and Overview

In November 2001, San Francisco voters approved two bond measures that provided up to $100 million for installation of solar energy generation, wind energy generation and energy efficiency technologies on city-owned property. Proposition B provides financing for approximately 10 to 12 MW of solar power and about 30 MW of wind generation. Approximately $30 million is budgeted for wind energy development projects.

Given the substantial variability exhibited by wind energy resources due to local topographic and other factors these investments in wind energy projects can only be optimized if sufficient information concerning the wind energy resource is made available. To date little information has been developed concerning wind energy resource variability within the City of San Francisco. The California Energy Commission's (Commission) Public Interest Energy Research's (PIER) Renewable Energy program is assisting the City and County of San Francisco to begin quantifying its urban wind energy resource, thereby enabling it to optimize its future investment in renewable distributed generation.

1.2. Project Objectives

To determine whether there may be economically feasible wind resources available at a few selected sites within the City/County geographic boundaries an urban wind resource assessment research project was conducted. Project objectives included to:

- Measure wind speeds at five sites within the City/County of San Francisco,
- Identify relationships between the measured wind speed data at the five monitored sites and wind speed data for the San Francisco International Airport (SFO) a nearby weather station for which a long-term historical record exists,
- Develop 8,760-hour wind speed datasets reflecting typical, or "normal" wind energy resources for each of the five monitored sites, and
- Estimate annual energy production for a generic 10 kW wind turbine installed on a 98-foot tower at each of the five monitored sites.

The information gathered and developed as a result of this project will be used by the City/County of San Francisco staff in ascertaining the feasibility of developing urban wind projects. These wind characterization results will then allow others to take the additional steps necessary to assess the technical/regulatory/political feasibility of siting wind turbines at these selected urban locations. The scope of this project was limited to quantifying the wind resources within the constraints of the available data collected at the selected urban locations within the City/County of San Francisco.

1.3. Report Organization

The project approach is discussed in Section 2. Key elements of the project approach include development of site selection criteria, selection of sites, collection of data, and data analysis. Project outcomes are presented in Section 3. Important characteristics of monitored sites are summarized, and results of data summaries and analyses are presented. Conclusions yielded by the San Francisco Wind Resource Assessment project are discussed in Section 4. Wind speed data are included as Appendix A. Wind speed data include those measured during the monitoring period, as well as estimated 8,760-hour annual wind speed datasets for a typical, year, or estimated “normal” wind energy conditions at these sites.

In summary the report is organized as follows:

Section 1.0	Introduction
Section 2.0	Project Approach
Section 3.0	Project Outcomes
Section 4.0	Conclusions and Recommendations

Appendix A: Wind Speed Data

Appendix B: Task 2.1 Site Tour and Selection Report and Photographs

Appendix C: Site Installation Worksheets and Photographs

2.0 Project Approach

The procedural and analytic approaches employed for the Energy Commission PIER-funded City and County of San Francisco Wind Resource Assessment project are described below. The key elements discussed within the approach include: 1) site review and selection criteria, 2) monitoring system selection and equipment installation, 3) data collection/quality control processes, and 4) wind data normalization and generic wind turbine energy output analyses process description.

2.1. Site Review and Selection Criteria

Successful wind power development projects hinge on quality wind resource assessments and understanding of the variables affecting the wind resource. Wind power is strongly influenced by the wind resource behavior that fluctuates with a host of variables including topology, altitude, meteorological conditions, and complex weather patterns. Obstructions and complex terrain complicate the measurement process and require careful analysis of quality wind data as well as correlation to historical data from an existing monitoring station. Urban settings can present some of the most complex terrains for wind assessment. Within urban settings long-term wind data monitoring projects are essential to fully characterize wind patterns throughout the year and to account for interaction of wind and weather and building induced effects.

Before visiting any prospective monitoring sites the various factors influencing urban wind energy resource were compiled. The site selection criteria that proved particularly critical in the assessment of possible Host sites are summarized below. During subsequent site selection meetings and site visits these criteria were used to assess the suitability of particular sites.

- Building Top Mounts:
    - Physical characteristics of existing, available instrument mounts
    - Location with respect to prevailing winds
    - Location with respect to edge of roof

      Flow separates at leading roof edge
    - Height

      Instrument placement above separation streamline
- Degree of Exposure to SW/NW Prevailing Winds During Peak Season
- Building or Property Manager Interest and Cooperation
    - Equipment installation support
    - Security/Controlled roof access
    - Opportunities for promotion/education
- Ground-mounted Tower Sites
    - Land use, topography, and soil properties
    - Security, controlled access to towers and data loggers
    - Zoning, aesthetics, obstructions within 300 ft.

- Proximity to Turbulence-causing Obstructions
  - Other buildings/structures
  - Hills/ridgelines Trees

2.2. Monitoring System Selection/Installation

Two parallel paths were pursued to accomplish monitoring system selection and installation. First, a local meteorological consulting firm with many years' experience in monitoring wind resources in both in California and internationally was selected to join the project team to provide local meteorological and wind monitoring system installation expertise. Wind measurement equipment was installed and data collected on a monthly basis for three sites, as described more fully in Section 3 of this report.

2.3. Data Collection/QC Process

This project included installation of wind speed monitoring equipment at three sites. Data from two other existing monitoring systems located at Treasure Island and Hunters Point were also collected, reviewed and incorporated into the analysis. These three sites with installed metering systems were visited monthly to download data, check system operation, and perform routine equipment maintenance as necessary. Data quality control included checking for completeness and reasonableness of the monthly datasets. Review of the results of this activity is discussed in Section 3 of this report.

2.4. Wind Data Analysis Process Description

Wind data received from SF PUC, Windots, and WeatherBank were imported into a single database containing data for all sites. Formats used for date and time fields were transformed so that they would all conform to a single convention. Descriptive statistics were calculated for the monitored data to summarize the seasonal [where data availability allowed] and diurnal wind speed characteristics of each site. The data analysis processes for the wind resource normalization and generic turbine energy production portions of this work effort were necessarily more involved. These processes are each described in detail below.

2.4.1. Wind Resource Normalization

Wind speeds observed during any one year (or less) monitoring period are not likely to be identical to typical or "long-term average" wind speeds observed over multi-year periods of time. To increase its usefulness, measured data collected over the short term of this project were used as the basis for datasets more reflective of long-term average wind energy resource for each site. For this analysis historical wind speed data collected at San Francisco International Airport (SFO) were used to establish a common, regional reference point for the long-term wind resource. This estimation process implemented here is referred to as "normalization".

The normalization process entailed three fundamental steps. First, long-term historical wind speed data were used to estimate a normal 8,760-hour SFO wind speed dataset. Second, measured wind speed data collected for both SFO and the five monitored sites were examined to identify relationships between the SFO wind energy resource and the wind energy resource at each monitored site. Finally, in the third step, these relationships were used in combination with the normal SFO wind speed dataset to estimate 8,760-hour normal wind speed datasets for each of the monitored sites. Each of these steps is described more completely in the following subsections.

2.4.1.1. Normal 8,760-Hour Wind Speed Dataset For SFO

First, hourly SFO wind speed data available for the 11-year period from 1992 to 2002 were compiled and 11-year monthly average wind speeds were calculated. These SFO monthly average wind speed data are summarized in Figure 2. As expected, these data exhibit a substantial degree of variability as driven by differing ocean surface temperature conditions and the resulting weather patterns over this period.

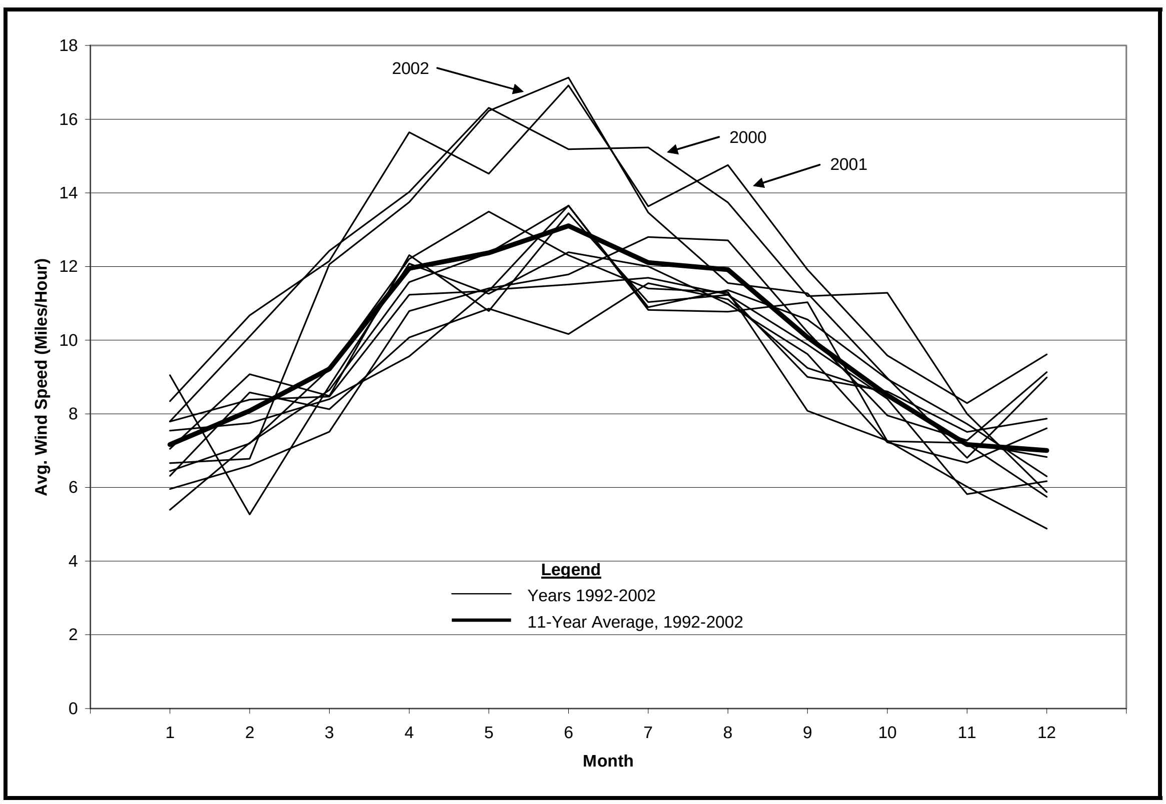

Figure 2 Summary of 11-Year SFO Wind Speed Data Record

Average wind *speeds* were summarized above in Figure 2. However, the parameter of primary interest in this study is wind *energy*, which is not linearly proportional to wind speed. To better focus the analysis on the parameter of principal interest, the raw wind speed data were transformed to represent a measure of wind power. For each hourly average wind speed value in the 11-year historical record for SFO a relative measure of wind power was calculated as:

$$P_{100} = 0.508 \times V^3$$

Where:

P_{100}	=	Wind Power (Watts/100 ft^2 of swept area)
V	=	Hourly Average Wind Speed (Miles/Hour)
0.508	=	Constant based on assumed air density for sea level

Resulting SFO wind power data are summarized in Figure 3, which graphically depicts monthly average wind power for particular years, as well as the average of values for individual years. Because wind power varies with the cube of wind speed, the higher wind speed values observed during 2000-2002 have a larger percentage impact on the 11-year average power result than they did on the 11-year average wind speed result.

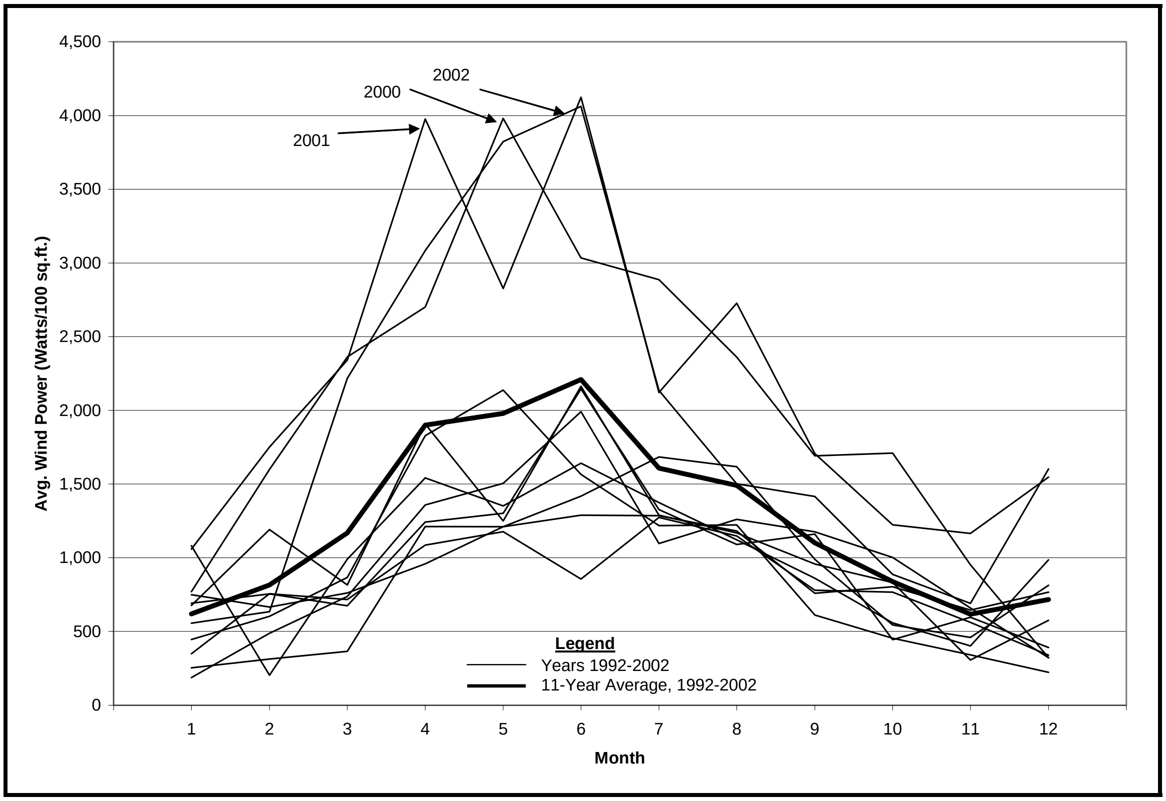

Figure 3 Summary of 11-Year SFO Wind Power Data Record

An 8,760-hour normal dataset was constructed by compiling 1-month subsets from the hourly data available for the period 1992-2002. Selection of year-month combinations for inclusion in the normal dataset was based on monthly average wind power values. For each month, differences were calculated between the 11-year average value and the particular-year average values for 1992-2002. Month-year combinations with the smallest differences were selected for inclusion in the 8,760-hour normal dataset for SFO. Results of this analysis are summarized in Table 3

Table 3 Constituent Year-Months of Normal SFO Wind Speed Dataset

Month	Year	Actual Average Wind Power (W/100 ft^2)	11-Year Avg. Average Wind Power (W/100 ft^2)
January	1997	676	620
February	1999	604	815
March	1995	990	1,168
April	1997	1,908	1,900
May	1999	2,138	1,980
June	1997	2,164	2,208
July	1992	1,684	1,608
August	2002	1,502	1,491
September	1993	1,161	1,101
October	1997	831	839
November	1993	597	616
December	1996	767	717

2.4.1.2. Examine Relationships between Wind Resource at SFO & Monitored Sites

Two different analytic methodologies were used to examine relationships between wind energy at SFO and the monitored sites. For each Site-Month combination selection of one of these methods was based on seasonal availability of measured data for both SFO and the monitored site. First, measured data were classified according to season. The basis of season assignments is summarized in Table 4.

Table 4: Basis of Season Assignments

Season	Months
Spring	March, April, May
Summer	June, July, August
Fall	September, October, November
Winter	December, January, February

In cases where measured data were available for at least two months within a season a whole-day substitution approach was used. When less than two months of data were available for a season a single-hour substitution approach was used.

Whole-Day Substitution

The whole-day substitution approach is akin to the substitution approach used to construct the normal 8,760-hour SFO wind speed dataset. However, rather than substituting entire months of hourly wind speed data based on monthly average wind power, single days of hourly wind speed values were substituted based on daily wind energy. A principal advantage of this approach is that it retains site-specific diurnal wind speed characteristics observed in the measured data.

First, for each hour where measured wind speed data were available for both SFO and the monitored site the same relative measure of wind power as was described above was calculated for SFO. Next, total SFO wind energy for each day was calculated as the sum of hourly values, and resulting matched-pair lists of dates and SFO daily wind energy were sorted according to daily wind energy. Separate lists of sorted matched pairs were developed for each monitored site, and for each season. The general form and content of the lists is summarized in Table 5, which illustrates the range of values observed for summertime Hunters Point data.

Table 5: General Form of Whole-Day Substitution Lists

SFO Daily Wind Energy (Wh/100 sq.ft.)	Date	Hunters Point Hourly Wind Speed (Miles/Hour, Hours 0 to 23)
5,067	6/5/03	13,13,13,14,13,11,10,6,5,8,10,12,14,16,18,18,18,19,18,16,14,13,12,9
10,368	8/22/03	8,9,6,5,5,6,5,4,6,6,6,7,8,10,13,13,13,14,12,11,11,11,8,8
11,284	7/31/03	11,11,9,8,7,5,4,7,8,6,7,7,10,9,8,8,9,9,10,12,11,7,11,13
•	•	•
•	•	•
•	•	•
118,900	8/11/03	13,12,10,9,8,6,8,10,10,8,10,12,15,18,18,16,17,20,24,22,18,15,10,8
132,911	6/19/03	13,11,18,11,10,5,7,7,3,7,10,10,14,15,18,19,22,22,21,20,19,18,17,20
176,547	6/20/03	18,17,18,17,15,16,13,10,9,10,11,14,18,21,23,23,25,25,25,25,22,18,17,18

Review of data from Table 5 is suggestive of general relationships between SFO wind energy resource and Hunters Point wind energy resource. During the three days with the least SFO wind energy Hunters Point wind speeds never reached 20 MPH, whereas during the three days with the most SFO wind energy Hunters Point wind speeds exceeded 20 MPH for an average of 4 hours per day.

The sorted lists were used to select days of monitored site measured wind speed data to include in normal 8,760-hour wind speed datasets for each monitored site. First SFO daily wind energy was calculated for the normal 8,760-hour wind speed dataset. Next, days in the sorted lists with SFO daily wind energy values in closest agreement with the normal values were identified. Finally, hourly wind speed data from these matched days were substituted into the normal wind speed datasets for the monitored sites.

Single-Hour Substitution

There are several Site-Month combinations where less than two months of measured data are available. In these cases use of the whole-day substitution approach would yield estimated normal wind speed data with unsatisfactory diurnal characteristics. To avoid this outcome a single-hour substitution approach was used. First, measured SFO and monitored site data were grouped according to SFO wind speed. Second, the distribution of monitored site wind speeds corresponding to particular SFO wind speeds was determined. Next, these correspondence distributions were used to estimate monitored site wind speed occurrence probabilities for particular SFO wind speed levels. Finally, hourly wind speed values from the normal 8,760-hour SFO wind speed dataset were combined with the correspondence distributions to assign monitored site wind speeds that were substituted into the 8,760-hour monitored site wind speed datasets.

A representative example correspondence distribution is depicted graphically in Figure 4, which summarizes the occurrence frequency of Pier 39 wind speeds corresponding to an SFO wind speed of 10 MPH. When SFO wind speed is equal to 10 MPH, coincident Pier 39 wind speeds were observed to range from 1 to 16 MPH, with a median value equal to 8 MPH.

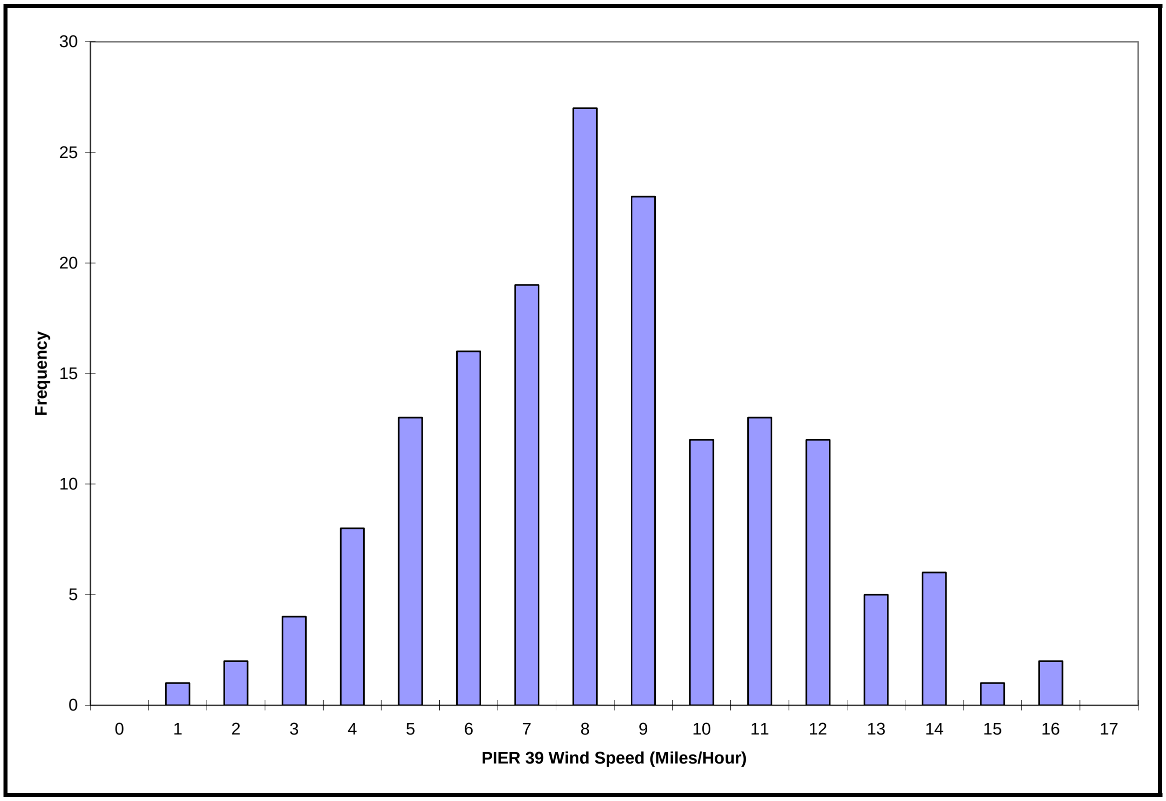

Figure 4 Example of Hourly Wind Speed Correspondence Distribution (Pier 39 Wind Speeds Coincident with 10 MPH SFO Wind Speed)

The distribution illustrated in the histogram of Figure 4 was used to calculate the probability of occurrence of particular coincident Pier 39 wind speeds. For example, when SFO wind speed is equal to 10 MPH, there is a 7% probability (i.e., 12 out of 164) that the Pier 39 wind speed will also be 10 MPH. The frequency distributions were used to calculate occurrence probabilities for all monitored sites and SFO wind speeds.

The normal 8,760-hour SFO wind speed dataset served as the foundation of normal wind speed datasets for each monitored site. For each hour, a monitored site wind speed was probabilistically assigned based on the SFO wind speed and the correspondence distribution for the monitored site and SFO wind speed. For example, for a wind speed of 10 MPH from the SFO normal 8,760-hour dataset there was a 7% probability that a wind speed equal to 10 MPH was assigned to the corresponding hour in the Pier 39 normal 8,760-hour dataset.

2.4.1.3. Calculate normal 8,760-hour wind speed datasets for five sites

Results of the whole-day substitution and single-hour substitution analyses were combined to construct normal 8,760-hour wind speed datasets for the monitored sites. A majority of the resulting hourly wind speed values were based on the whole-day substitution approach, as summarized in Table 6.

Table 6: Summary of Normalization Analytic Methodologies

Analytic Methodology	Monitored Site and Season
Whole-Day Substitution	Hunters Point: Spring/Summer/Fall/Winter Treasure Island: Spring/Summer/Fall/Winter S.F. Zoo: Spring/Summer/Fall Twin Peaks: Spring/Summer/Fall Pier 39: Summer/Fall
Single-Hour Substitution	S.F. Zoo: Winter Twin Peaks: Winter Pier 39: Spring/Winter

The analysis described above produced wind speed datasets for heights at which wind speed sensors were actually installed. These heights are summarized in Table 7.

Table 7: Sensor Heights at Monitored Sites

Monitored Site	Sensor Height, H (feet)
Hunters Point	33
Treasure Island	33
S.F. Zoo	33
Twin Peaks	60
Pier 39	24

The initial results were adjusted such that final estimates are based on a sensor height of 33 feet. Final 33-foot wind speed estimates were calculated as:

$$S_{33} = S_H \times \left(\frac{H_{33}}{H} \right)^{1/7}$$

Where:

S_{33} = Wind speed at 33 feet

S_H = Wind speed at Sensor Height H

H_{33} = Sensor Height equal to 33 feet

H = Monitored Site Sensor Height (Table 7)

1/7= Wind Shear Factor (Assumed Rule of Thumb[1])

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1 Strictly speaking this wind shear value is valid only for smooth, level, grass-covered terrain. However, in the absence of site-specific information it is often used as a general rule-of-thumb. Actual wind shear values for the monitored sites could deviate substantially from this rule-of-thumb value. Determination of actual wind shear values for the monitored sites would require use of additional wind speed sensors.

2.4.2. Generic Turbine Energy Production

Normal 8,760-hour wind speed datasets were used to estimate annual energy production for a generic 10 kW wind turbine installed on a 98-foot tower. A tower height of 98 feet was selected because it is a commercially available height commonly used in applications involving smaller wind turbines. While some of the sites (e.g., The Aquarium of the Bay at Pier 39) may not accommodate a tower as tall as 98 feet, this is a useful height upon which to base initial viability assessment. That is, if viability is doubtful at 98 feet then it would be even less appealing at a lower height.

Wind turbine electric energy production depends not only on the power in the wind, but also on wind turbine performance characteristics. Generic turbine performance characteristics assumed for this analysis are summarized in Figure 5, which depicts the relationship between instantaneous wind speed and wind turbine power output. In this curve wind turbine power output is expressed with respect to nominal, nameplate system size.

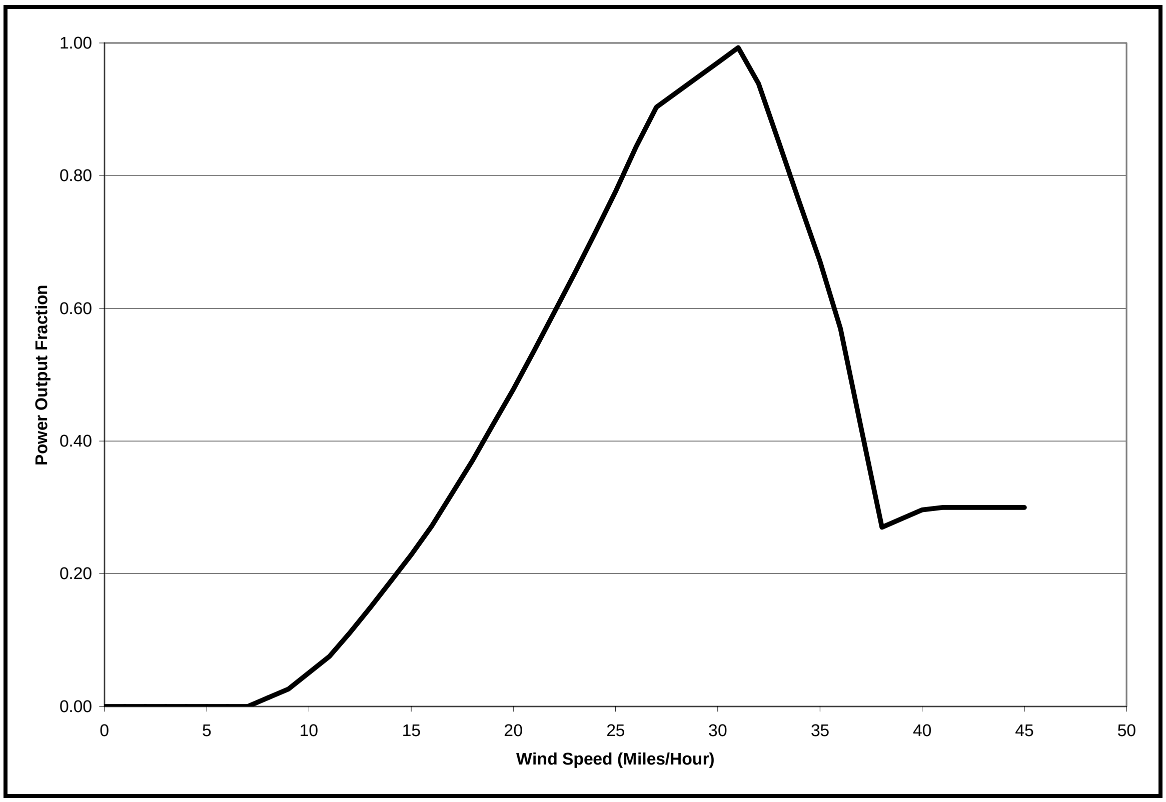

Figure 5 Generic Wind Turbine Power Versus Wind Speed Curve

With the exception of Treasure Island, wind speed data compiled for this project were recorded at 60-minute intervals. Each of the recorded hourly values represents the average of many measurements taken throughout the hour. The hourly averages provide a good indication of the wind resource during the hour, however again due to the cubic relationship between wind speed and available wind power direct use of hourly average wind speed values in wind energy calculations may introduce unwanted error into electric energy production estimates.

During any given hour, instantaneous wind speeds exhibit a significant degree of variability. During some instants the wind speed exceeds the hourly average, while during others it is less than the hourly average. One measure of this variability over time is the standard deviation of wind speed. The standard deviation of wind speed was measured at three monitored sites: San Francisco Zoo, Pier 39, and Twin Peaks.

While the standard deviation provides an indication of the relative scatter around the mean value, it does not provide information on the shape of the distribution of instantaneous values about the mean. In the absence of direct information regarding this shape the normal distribution is commonly assumed. For instance, at the S.F. Zoo when the hourly average wind speed is 20 MPH, corresponding standard deviation values range from 2.0 to 5.2 MPH; the median standard deviation is 2.4 MPH. Combining these three standard deviation values with the assumption of a normal distribution yields three different distributions of wind speeds around the hourly average value of 20 MPH. Each of these three distributions is depicted graphically in Figure 6. While each of these distributions shares a common average wind speed value, they do not correspond to a common wind energy value due to the cubic relationship of wind speed versus wind power.

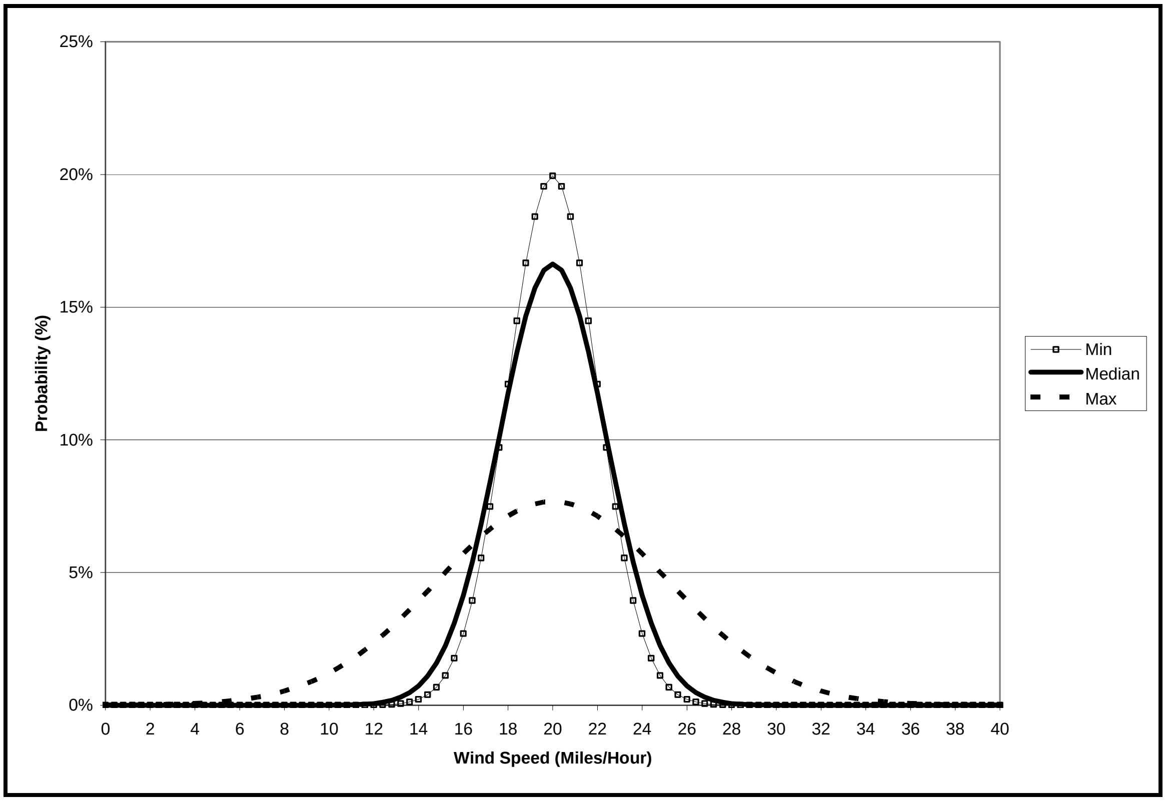

Figure 6 Distribution of Instantaneous Wind Speeds around 20 MPH Average – Minimum, Median, and Maximum Observed Wind Speed Standard Deviation

To assess the influence of intra-hour wind speed variability on hourly average wind power, the measured wind speed data were combined with the representative, typical wind turbine performance curve illustrated above in Figure 5. For each hour, the measured wind speed and standard deviation values were used to construct a distribution of intra-hour wind speeds for which hypothetical wind machine power output was estimated. Each intra-hour wind speed distribution comprised 120 thirty-second intervals. For each of these 30-second intervals power output was calculated in terms of nominal, rated power output. The distribution of 30-second power output results was integrated to arrive at hourly wind turbine energy production estimates. Finally, an energy production factor was calculated as the ratio of this integrated energy production estimate and an energy production estimate based solely on the hourly average measured wind speed.

Results of this analysis are summarized in Figure 7. For each of the three sites for which wind speed standard deviation data were available, at low wind speeds the energy output fraction exceeds the power output fraction by a small amount. However, at higher wind speeds (>22 MPH) the reverse was true. While the power output reaches a maximum at 31 MPH, the energy output reaches a lower maximum value because there are no hours when the wind speed remains at exactly 31 MPH for the entire hour.

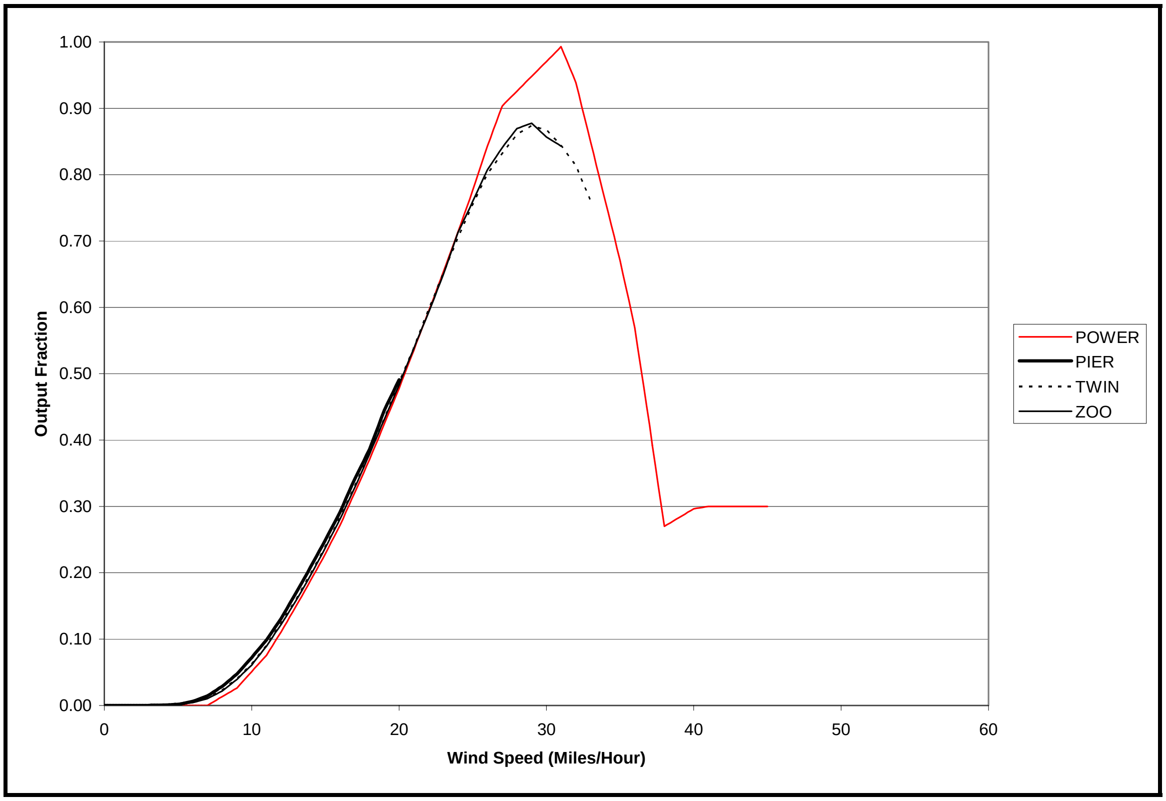

Figure 7 Calculated Energy Factors Based on Measured Data

Standard deviation data were available only for these three sites, and only for the observed wind speeds during the monitoring period of this project. To develop a more general relationship between hourly average wind speed and hourly generic wind machine energy production, energy output fractions were calculated for the assumed case where wind speed standard deviation was equal to 10% of hourly average wind speed. In Figure 8 results of this calculation are compared against the median of energy production factors based on actual, observed standard deviation data. The agreement between these two methods is so close that the differences are indistinguishable in the plot. In cases where metered wind speed standard deviation data were not available to calculate energy production factors, estimated factors were calculated based on assumption of wind speed standard deviation equal to 10% of hourly average wind speed.

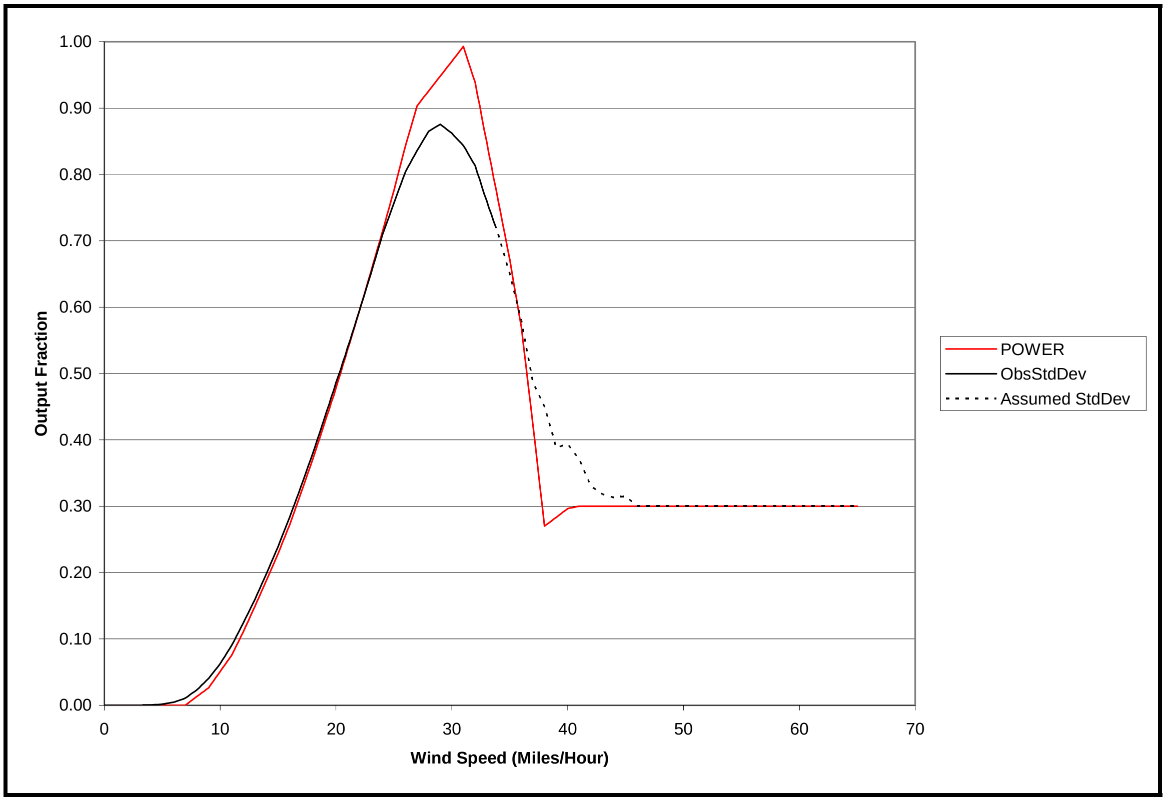

Figure 8 Energy Output Fractions Based on Observed and Assumed Hourly Wind Speed Standard Deviations

Prior to calculating hourly energy production the 33-foot normal wind speed datasets for the monitored sites were adjusted to yield estimates of wind speed at a height of 98 feet. This adjustment was accomplished using the sensor height adjustment approach described previously, which is based on open level terrain. For each hourly average wind speed the corresponding energy output fraction was determined, and hourly electric energy production was calculated as the product of nominal rated wind machine size (i.e., 10 kW) and the energy output fraction. Hourly energy production values were summed to yield estimates of annual energy production for a generic 10 kW wind machine on a 98-foot tower.

Lastly, the energy production result for Twin Peaks was adjusted to account for the slightly reduced air density at its higher elevations. The elevation at Twin Peaks is approximately 900 feet above sea level. To account for this elevation impact on air density, the final electric energy production estimates for Twin Peaks were derated by 3%.

3.0 Project Outcomes

Outcomes of the City and County of San Francisco Wind Resource Assessment project are presented below. The outcome elements discussed within this section include: 1) site review and selection results, 2) data collection/quality control processes, 3) wind speed characteristics of each site, 4) wind data normalization results, and 5) generic turbine estimated average annual energy production.

3.1. Site Review and Selection

Five sites were selected by the project management team for inclusion in the San Francisco Wind Resource Assessment project. The characteristics of the monitored sites are summarized in Table 1. The abbreviations included in parentheses (e.g., PIER) are used later in this section to identify sites in charts summarizing wind speed data. Characteristics of the weather station at San Francisco International Airport (SFO) are also summarized. While this station was not included in the site review process, it was selected for inclusion in the project due to its long-term record of wind speed data that was found to be most suitable for incorporation into the normalization and annualization analyses.

Table 8: Characteristics of Five Monitored Sites (& SFO)

Monitored Site	Coordinates (Approximate)	Mount Type	Instrument Height Above Roof/Ground (Feet)
Pier 39 (PIER)	37° 48′ North 122° 24′ West	Roof	24
S.F. Zoo (ZOO)	37° 44′ North 122° 30′ West	Ground	30
Treasure Island (TI)	37° 49′ North 122° 22′ West	Roof	12
Hunters Point (HP)	37° 43′ North 122° 22′ West	Ground	33
Twin Peaks (TWIN)	37° 45′ North 122° 27′ West	Ground	60
S.F. Airport (SFO)	37° 37′ North 122° 23′ West	Ground	33

A detailed review of the site review and selection process is included in the interim report titled '*Site Tour and Selection Report*', which is included with this report as Appendix B. Pictures of the wind monitoring systems installed by the project team are included as Appendix C. Brief descriptions of each of the monitored sites and its monitoring approach are presented below.

3.1.1. Aquarium of the Bay

The aquarium is located near Pier 39 in the Fisherman's Wharf area on the north side of San Francisco, where it is exposed to prevailing W and NW breezes. The aquarium is located on Pier 39 port property. Its split-level roof is at least 50 feet above the bay and unobstructed from the prevailing westerly winds during the spring and summer months. Wind measurement instruments provided by the Itron team were mounted on a new 24-foot pole affixed at the SW corner of the existing steelwork that supports HVAC/ventilation equipment. The aquarium's engineering staff fabricated the necessary mounting brackets and installed the new steel pole by securing it to the existing steelwork located on the roof.

3.1.2. San Francisco Zoo

The San Francisco Zoo is located in the southwest corner of the city, where it is exposed to prevailing ocean breezes from the SW, west, and NW. Wind speed monitoring was undertaken with a small tower on the embankment located adjacent to the old Fleischaker Pool Building (on the north side) immediately west of the Zoo's main parking lot. This site is immediately adjacent to the Great Highway. The embankment is about 60 to 80 feet in width and rises approximately 20 to 30 feet above the surrounding area and might possibly be a suitable location for installation of small-scale vertical axis wind turbines in the future. The Itron team installed a 30-foot meteorological tower on the ridgeline of the embankment located at the western edge of the main parking lot. The tower is approximately 80 feet north-northeast of the northeast corner of the pumping station. There are scattered trees north, east and south of the tower, but their influence should be minimal.

3.1.3. Treasure Island

Treasure Island, which is located to the northeast of San Francisco in the San Francisco Bay, has recently been turned over to the City by the US DOD and is in the very early stages of the redevelopment process by the City of San Francisco. The island is exposed to W-NW bay breezes and the northwest quadrant has the best exposure to these prevailing westerly winds. According to one redevelopment plan drawing provided by city staff, much of the existing residential housing on the far north end of the island are slated for removal. This area may in the future become undeveloped wetlands. A 2-story apartment building at 1205-F Bayside is equipped with an existing roof-mounted pole (approximately 12 feet above the roofline) where an existing anemometer is mounted. Data from this weather monitoring station were purchased from WeatherFlow, Inc., and used in this wind resource assessment project.

3.1.4. Hunters Point Naval Shipyard

The Hunters Point Naval Shipyard is in the early stages of being turned over to the City. The area is just south of the city, on the San Francisco Bay where it is exposed to winds from the northwest. It is already vacated, and no concrete plans for its redevelopment yet exist. While redevelopment plans have not yet been finalized, they may include some or all of the following: cultural or educational facilities, open space, residential units, and a "Green" business park. The U.S. Navy is collecting meteorological data in the area of the shipyard's landfill (i.e., Parcel E, in the far southwest corner of the Hunters Point area that remains under U.S. Navy control). Tetra Tech EM, Inc., operates the meteorological monitoring station for the Navy. Wind speed is measured every second; averages of these measured values are calculated each hour and recorded in a datalogger. Data from this standard 10-meter weather monitoring station were obtained from the Navy and used in this wind resource assessment project.

3.1.5. Twin Peaks

There are two existing City-controlled communication towers located at the park/lookout area on Twin Peaks. The height of these towers is estimated to be greater than 100 feet. The NW tower is the best candidate for wind speed monitoring because it holds less equipment and it is located upwind from the prevailing W/NW peak season winds. If wind turbines (e.g., vertical axis) were installed in this area in the future, they would likely be installed on another hill in close proximity to Twin Peaks. The Twin Peaks data would provide a good indication of the quality of the wind resource in this higher exposed area, however. And this information may prove useful for determining whether there are potentially other good (economic) wind resource locations within the most exposed areas of the City. There are a few trees in the immediate area of the communications tower but their height is estimated at only approximately 20 feet. A City of San Francisco employee climbed the 200 foot tall NW tower and installed a 6-foot long wind speed monitoring equipment boom. The boom was installed facing north at a height of 60 feet above the ground. The wind speed and wind direction monitoring instruments and datalogger were supplied by the Itron team.

3.2. Data Collection/QC Process

Wind speed data were collected/compiled for six sites around the city. The source and quantity of data for each site is identified in Table 9. The large quantity of SFO airport data was required for the normalization analysis, outcomes of which are summarized below in Section 3.3. These data are included as part of this final report. The format and content of the data file containing observed wind measurements are documented in Appendix A.

Table 9: Source and Quantity of Wind Speed Data

Monitored Site	Source of Data	Quantity of Data Compiled/Collected (Months)
Aquarium of the Bay	Itron team	5
San Francisco Zoo	Itron team	9
Treasure Island – NW	WeatherFlow	12
Hunters Point (Parcel E)	Tetra Tech EM	14
Twin Peaks	Itron team	8
S.F. Airport	Nat'l Weather Service	142

3.3. Wind Speed Characteristics of Each Site

Wind speed characteristics directly observed for the five monitored sites and the SFO Airport during the monitoring period are summarized in Figure 9 and Figure 10. Monthly average observed wind speeds are depicted graphically in Figure 9, which shows that the monitoring period extended from July 2002 through November 2003. Data availability varied from site to site. At least twelve months of acquired data were available for Treasure Island, Hunters Point, and the San Francisco Airport. Data availability for the remaining three sites ranged from five to nine months.

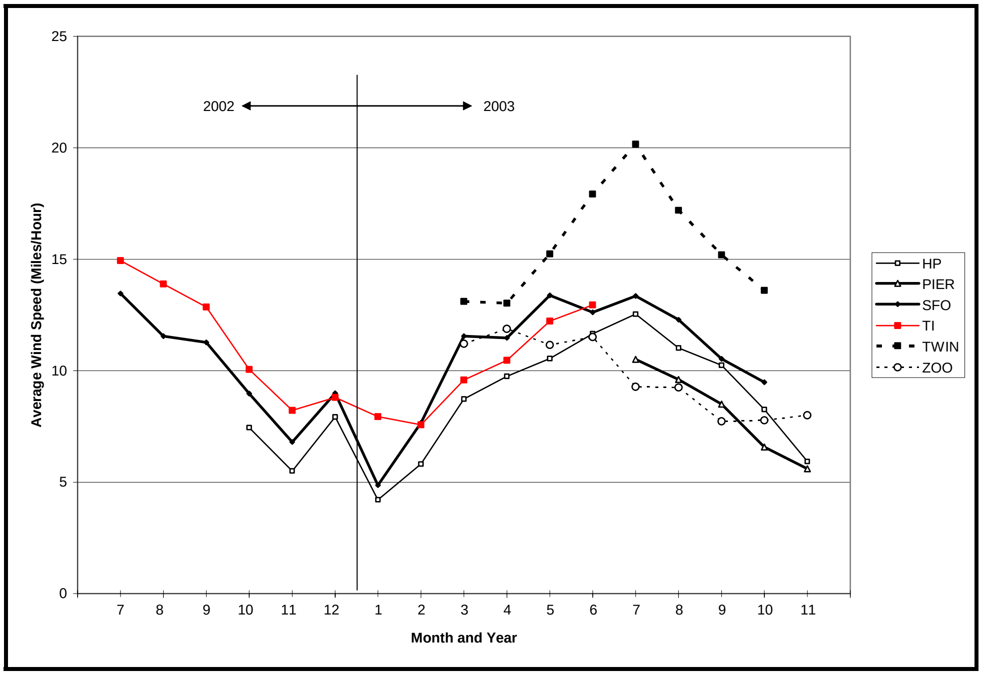

Figure 9 Observed Monthly Average Wind Speeds

Some of the site-to-site variability in wind speeds suggested in Figure 9 is due to the different heights at which wind speed sensors were installed; the remaining variability is due to the influences of local topographic, prevailing wind exposure and/or obstruction features, and the weather patterns experienced during the monitoring period.

The variability of monthly average wind speeds for particular seasons and hours of the day is illustrated in Figure 10 to Figure 13.[2] The diurnal wind speed patterns in each season for SFO are shown in Figure 10. Average summertime wind speeds during the monitoring period (i.e., July 2002 through October 2003) were seen to reach peak values in the evening during the hour from 4 to 5 PM PST.[3] Diurnal wind speed patterns during spring and fall exhibited shapes that were very similar to the summertime shape, however the magnitudes were somewhat less. The average wind speeds during winter were not observed to vary nearly as much throughout the day as during the other seasons.

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2 For reporting purposes the following conventions were used to assign months to seasons: spring (March, April, May), summer (June, July, August), fall (September, October, November), winter (December, January, February).

3 Dates and times corresponding to wind speed values are based on Pacific Standard Time. During the summertime local times would be one hour ahead of standard times.

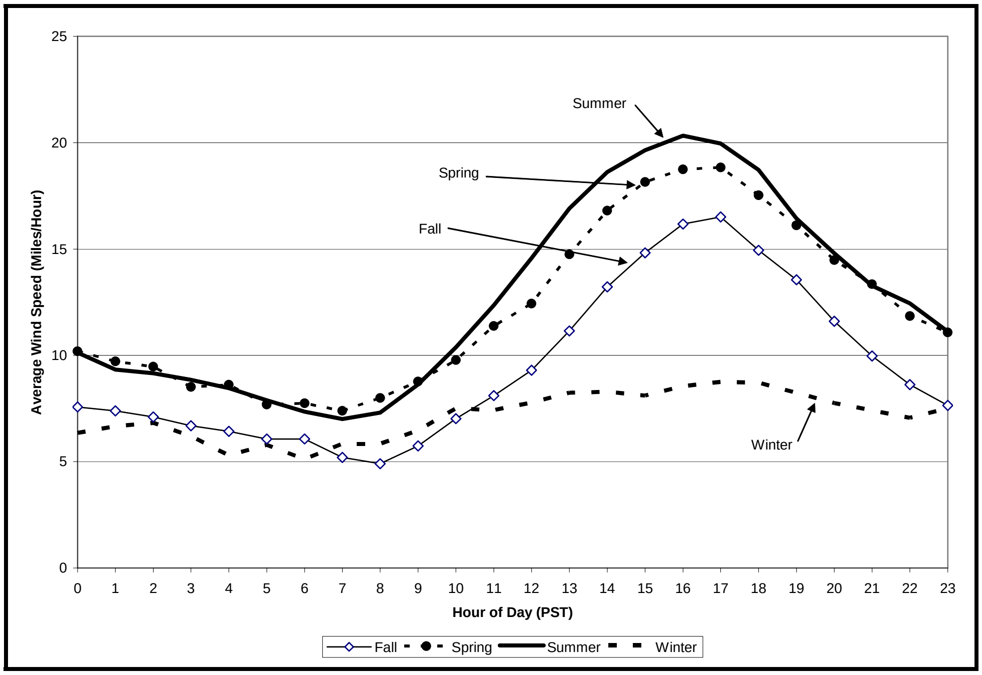

Figure 10 Observed Diurnal Wind Speed Patterns – SFO

The diurnal wind speed patterns for Hunters Point across all seasons are shown in Figure 11. The general trends and relationships exhibited by these data are similar as those observed for the SFO data. Some of the differences in magnitudes may be due to different monitoring periods; the Hunters Point data in Figure 11 are based on observed wind speeds recorded from October 2002 through November 2003.

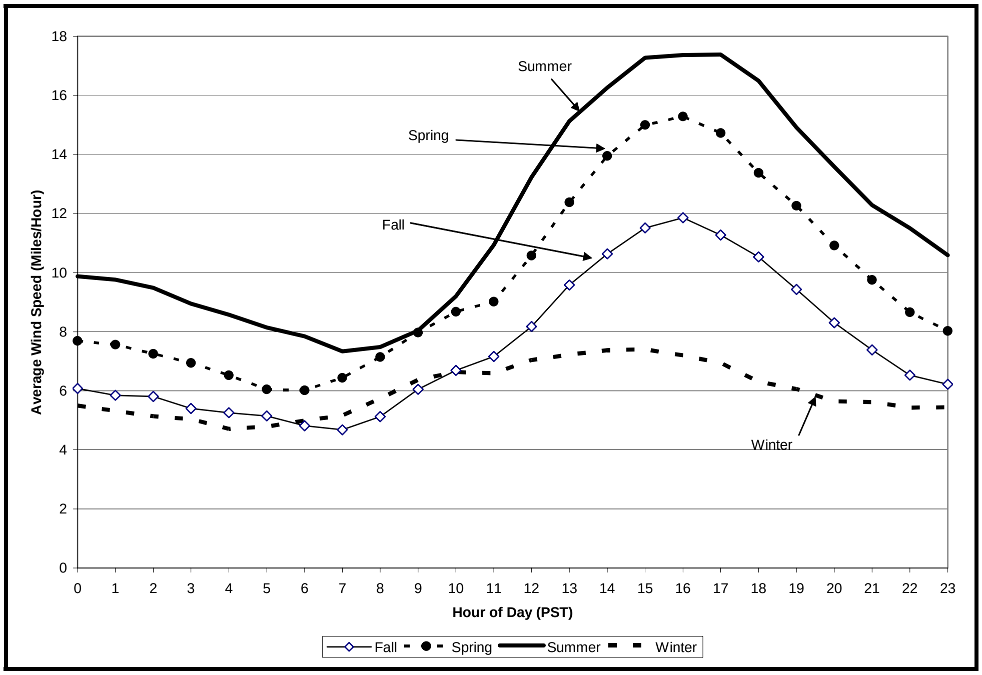

Figure 11 Observed Diurnal Wind Speed Patterns – Hunters Point

The diurnal wind speed patterns for the S.F. Zoo in the Spring, Summer and Fall seasons are shown in Figure 12.

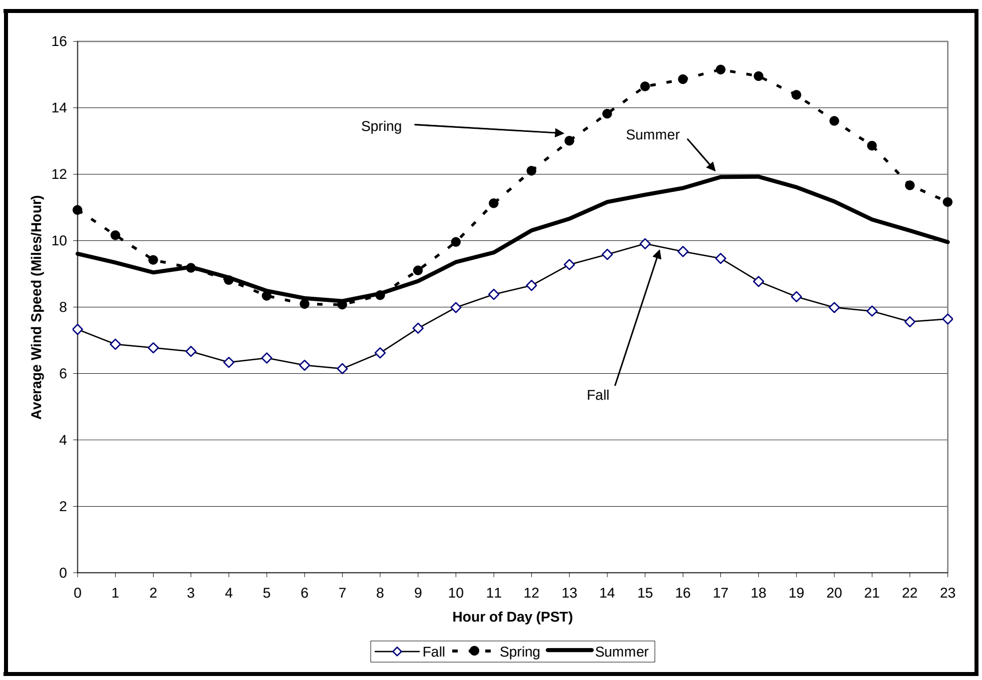

Figure 12 Observed Seasonal Diurnal Wind Speed Patterns – S.F. Zoo

The trends here are substantially different from those observed for the other five wind monitoring stations because the highest average wind speeds were observed in spring rather than in summer. No winter data were collected for the San Francisco Zoo site.

The diurnal wind speed patterns for Twin Peaks in the Spring, Summer and Fall seasons are shown in Figure 13. The maximum of hourly average wind speeds approached 25 MPH at Twin Peaks, which is substantially higher than the maximum values observed for other sites. This difference is due at least in part by the fact that the wind speed sensor at Twin Peaks was installed at the 60-foot level, whereas none of the other sensors was installed higher than 33 feet. No winter data were collected for the Twin Peaks site.

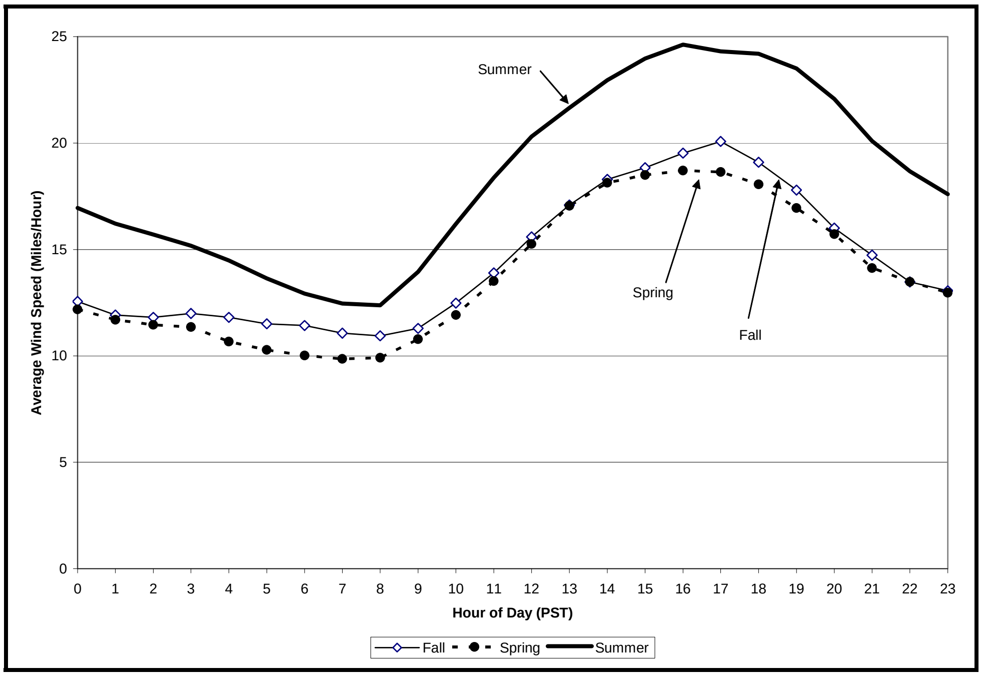

Figure 13 Observed Seasonal Diurnal Wind Speed Patterns – Twin Peaks

The diurnal wind speed patterns for Treasure Island are shown in Figure 14. Again, the shapes and magnitudes of the seasonal curves are reminiscent of those observed for the other sites discussed above.

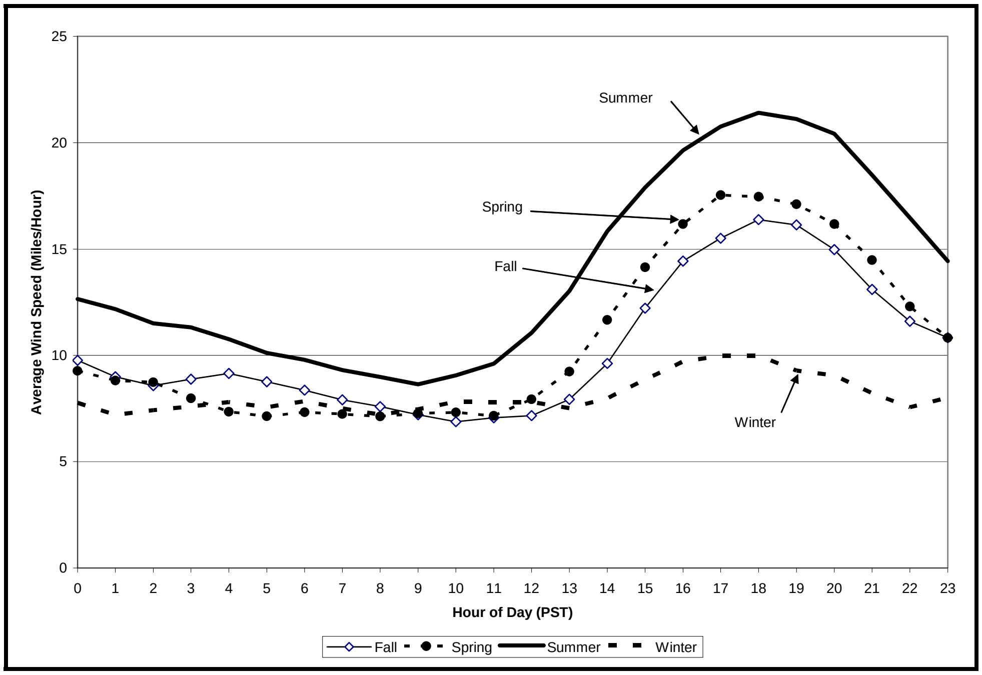

Figure 14 Observed Seasonal Diurnal Wind Speed Patterns – Treasure Island

The diurnal wind speed patterns for The Aquarium of the Bay at Pier 39 are shown in Figure 15. The general shape of the curves for Pier 39 is similar as was observed for SFO and Hunters Point, and summertime wind speeds exceed fall wind speeds. No spring or winter data were collected from this monitored site.

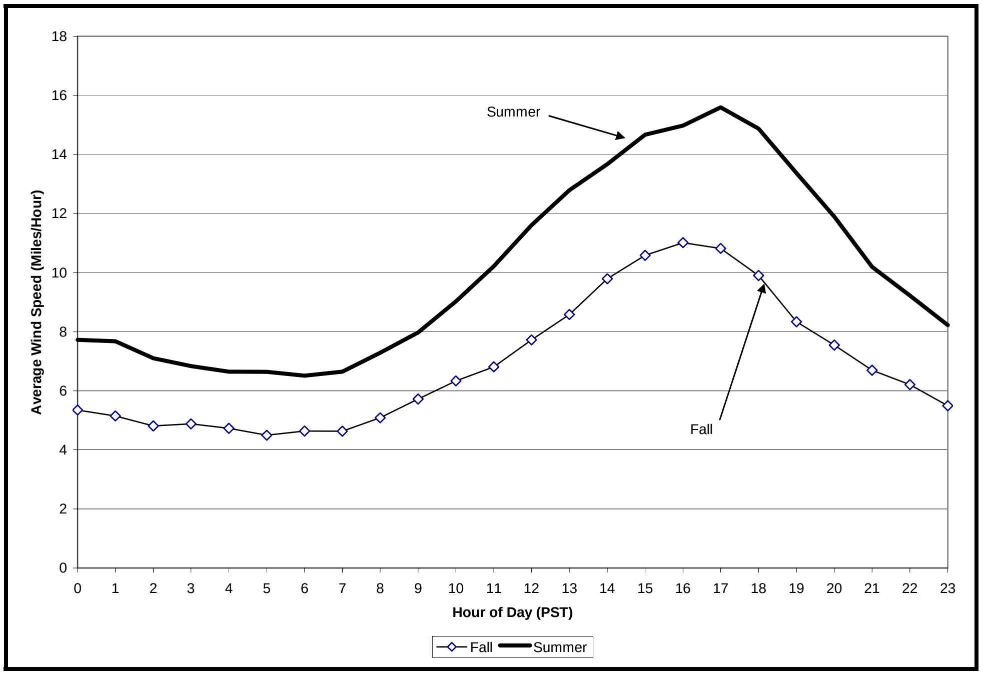

Figure 15 Observed Seasonal Diurnal Wind Speed Patterns – Pier 39

3.4. Normalization Results

Normal 8,760-hour wind speed datasets were developed using the methods previously described in Section 2.4. The normal wind speed dataset for SFO was developed first because it served as the area reference point for the normal data developed for the other five monitored sites. Seasonal and diurnal wind speed characteristics of the normalized SFO wind speed dataset are summarized in Figure 16. Referring back to the observed data in Figure 3 reveals that the patterns and trends in the normal dataset are in close agreement with those observed during the period in which measured data were collected from the five monitored sites.

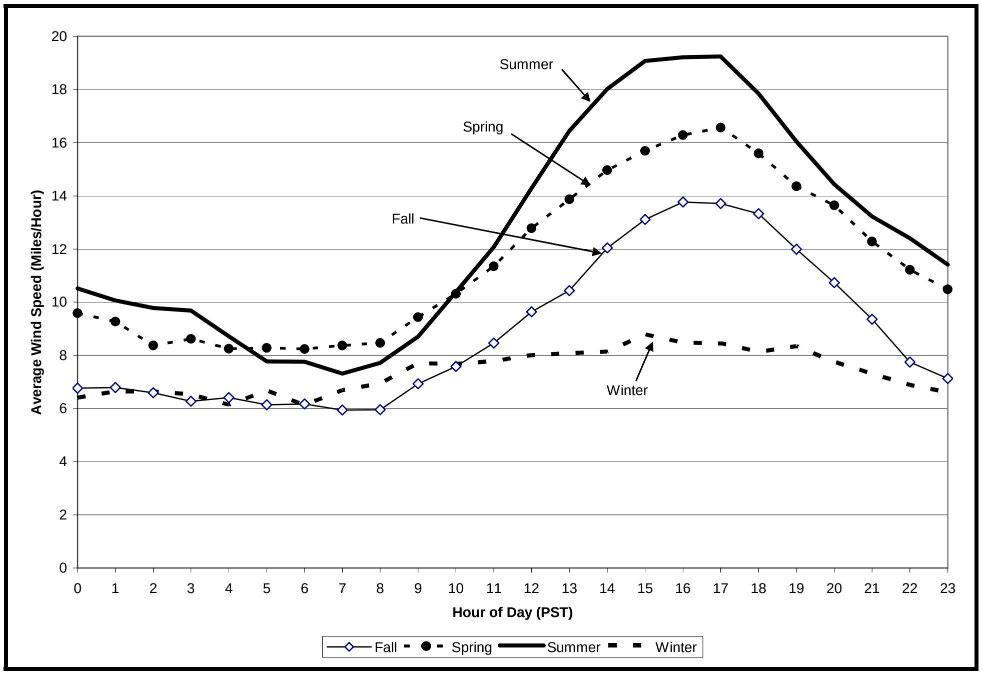

Figure 16 Normalized 33-foot Diurnal Wind Speed Patterns – SFO

Monthly average wind speeds based on the normal wind speed datasets are depicted graphically in Figure 17, which includes results for both SFO and the five monitored sites. All of the normal datasets are based on a sensor height of 33 feet, which in part explains the tighter grouping observed in Figure 17 as compared to the observed data in Figure 2, which was based on actual sensor heights ranging from 24 to 60 feet.

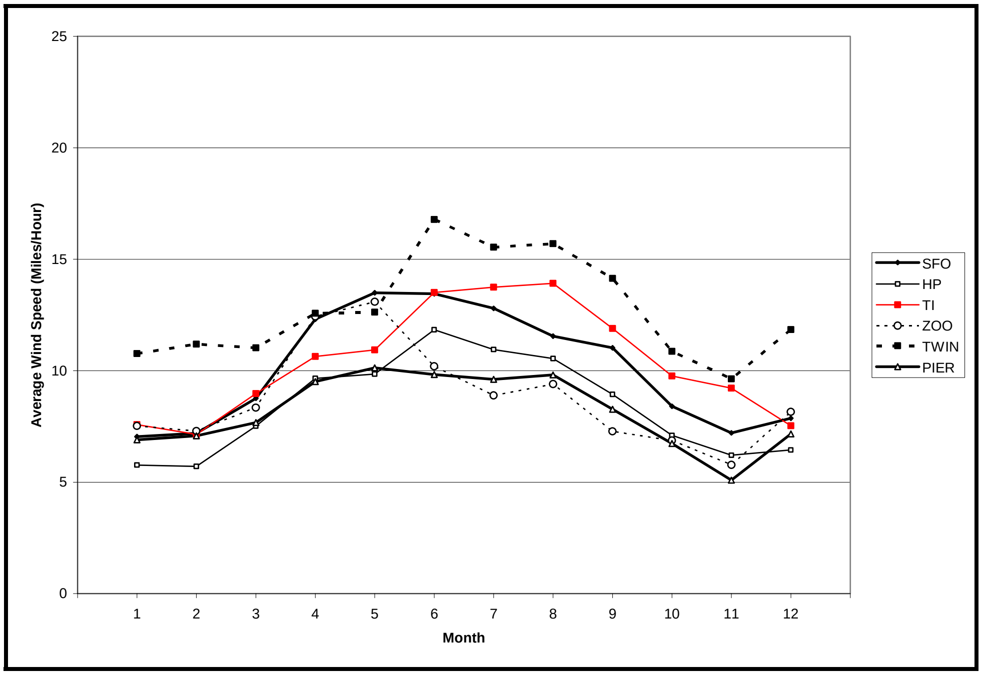

Figure 17 Normalized 33-foot Monthly Average Wind Speeds

Annual average wind speeds for the normal wind speed datasets are presented in Table 10. The result for SFO was 10.1 MPH. Average normal wind speeds at three of the monitored sites are lower. Only at Treasure Island and Twin Peaks have annual average normal wind speeds exceed that exceed the estimate for the SFO Airport.

Table 10: Normal 33-Foot Wind Speed – Annual Averages

Monitored Site	Annual Average Wind Speed (Miles/Hour)
Pier 39	8.2
S.F. Zoo	8.9
Treasure Island	10.4
Hunters Point	8.4
Twin Peaks	12.7
S.F. Airport	10.1

The normal diurnal wind speed patterns for the five monitored sites are presented in Figure 18 to Figure 22. The diurnal patterns for the Hunters Point normal wind speed dataset are shown in Figure 18. As with the observed data, the seasonal trends exhibited by these data are similar to those for SFO. However, the wind resource is lower at Hunters Point than at SFO, where the annual average wind speed exceeds that at Hunters Point by 20.5%.

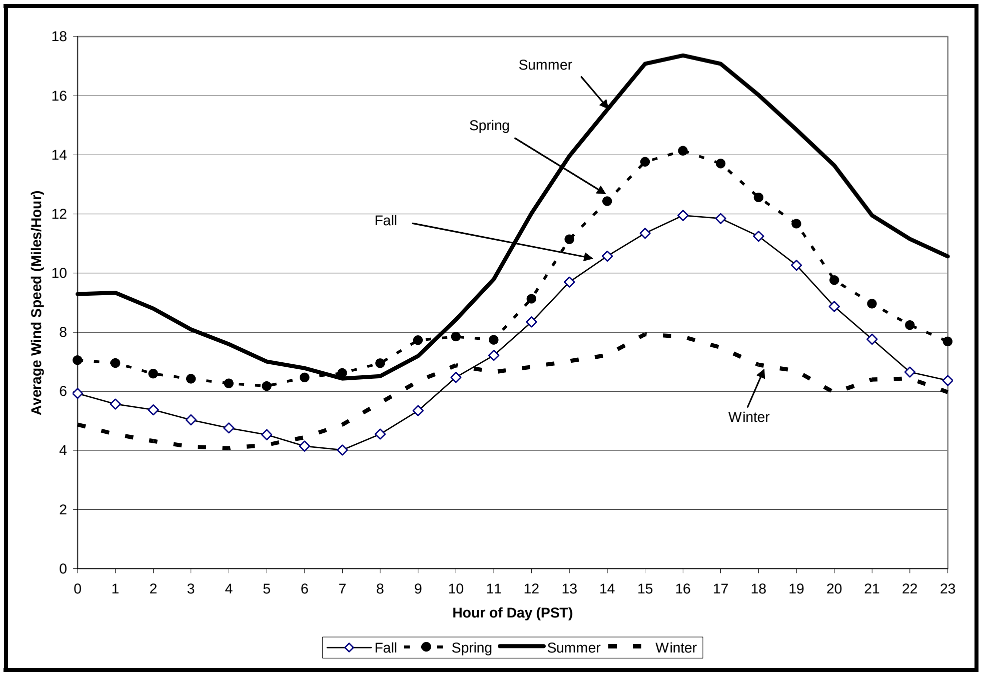

Figure 18 Normalized 33-foot Diurnal Wind Speed Patterns – Hunters Point

The diurnal patterns for the S.F. Zoo normal wind speed dataset are shown in Figure 19. This is the only monitored site where average afternoon and evening wind speeds are higher in spring than in both summer and fall. This is also the site where fall and winter diurnal profiles are in closest agreement.

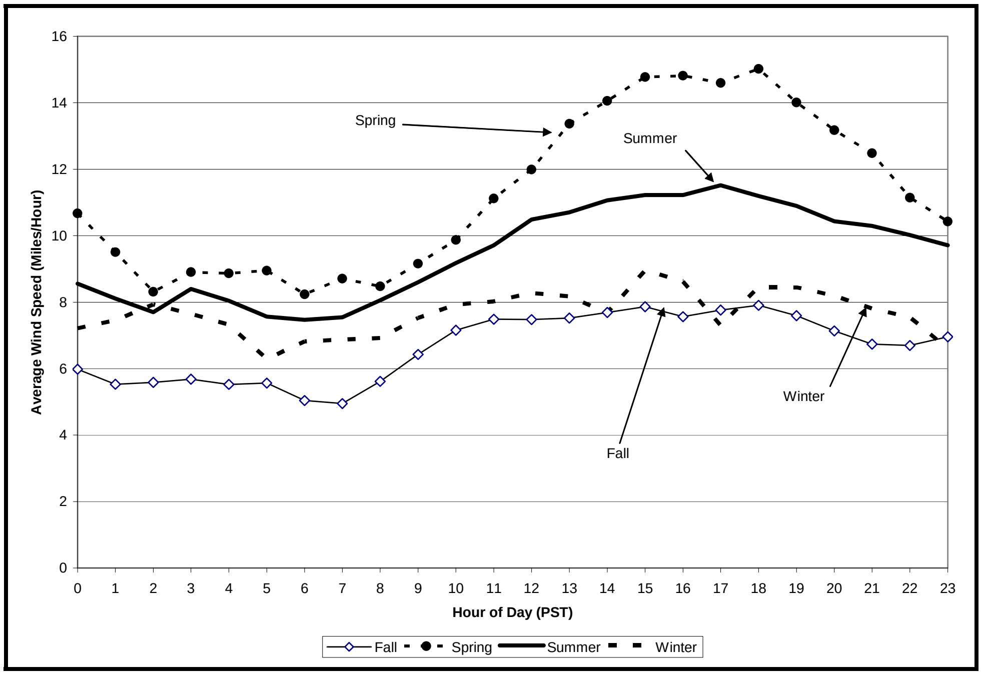

Figure 19 Normalized 33-foot Diurnal Wind Speed Patterns – S.F. Zoo

The diurnal patterns for the Twin Peaks normal wind speed dataset are shown in Figure 20. This is the only site where the normalization analysis' height adjustment was in the downward direction. The shapes of spring and fall diurnal profiles are similar; during summer the afternoon and evening wind speeds exceed night and morning wind speeds by a larger proportion than is the case during spring and fall.

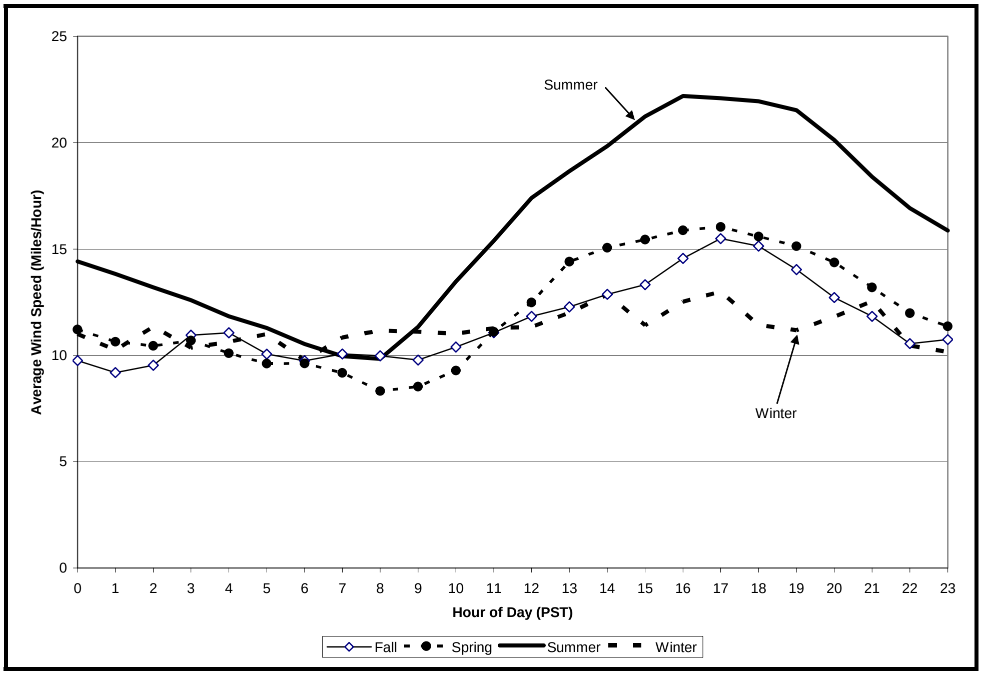

Figure 20 Normalized 33-foot Diurnal Wind Speed Patterns – Twin Peaks

The Treasure Island wind speed instruments are installed on a 12-foot pole affixed to the roof of a 2-story apartment building; the wind speed instruments are approximately 33 feet above the ground. For purposes of the normalization analysis it is necessary to make an assumption concerning the relationship between measured wind speeds and wind speeds that a wind turbine installed in that location would be exposed to after the apartment building is removed. There are at least two options.

First, wind speed measurements could be assumed to represent wind speeds that would be measured 33 feet above the ground after the apartment is removed. Second, wind speed measurements could be assumed to represent wind speeds that would be measured 12 feet above the ground after the apartment building is removed. This latter assumption would reflect the belief that the building obstructs the wind to a very great degree but in such a manner that the sensor is located in a region that is relatively free of turbulence.

Due to the relatively small size of the apartment building and to the relatively good exposure of the wind speed instruments the former assumption was made in this analysis. That is, the building is assumed to have a negligible impact on wind speed measurements, no sensor height adjustments were made in the normalization analysis, and the normal 8,760-hour wind speed dataset developed for this project represents estimated wind speeds 33 feet above the ground. This assumption has implications for the uncertainty of analysis results. The actual influence of the apartment building on wind speed measurements likely lies somewhere between the two assumptions described above. To the extent that actual conditions deviate from the simplifying assumption the normal wind speed dataset yielded by this analysis may underestimate actual normal wind resource at the Treasure Island monitoring site.

The diurnal patterns for the Treasure Island normal wind speed dataset are summarized in Figure 21.

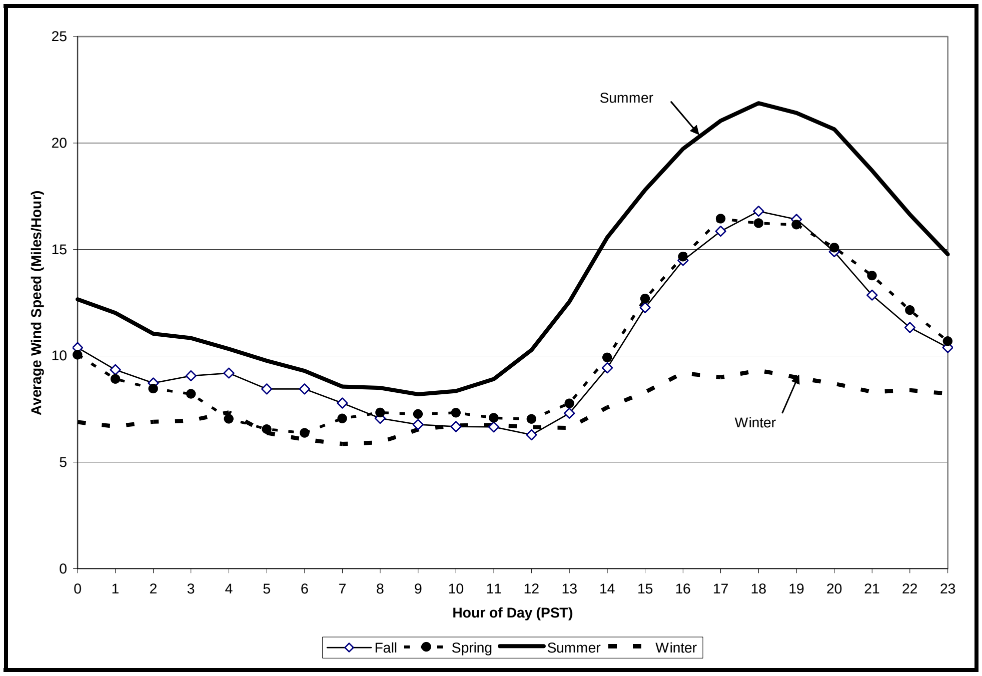

Figure 21 Normalized 33-foot Diurnal Wind Speed Patterns – Treasure Island

The wind speed sensor at Pier 39 was installed on the roof of the Aquarium of the Bay. This situation differs from that at Treasure Island because whereas the apartment building at Treasure Island was relatively small and slated for removal, the Aquarium of the Bay is rather large and is not slated for removal; rather, it is possible that at some time in the future wind turbines might actually be installed on the roof.

For the Pier 39 Aquarium of the Bay analysis the building is assumed to have a substantial influence on wind speeds. That is, the normal 8,760-hour wind speed dataset developed for this project represents estimated wind speeds 33 feet above the roof, <u>not 33 feet above the ground</u>. As was the case with Treasure Island this assumption has a significant impact on uncertainty of results of the normalization analysis. Principal assumptions embedded in selection of this approach include: First, that wind speed measurements made 30 feet above the roof (perhaps 60-70 feet above the ground) are representative of wind speeds that would be measured 30 feet above the ground *if the Aquarium building were not there*. Second, that given the building's most height the wind speed sensor is located high enough above the roof that turbulence and eddy current effects have a negligible impact on wind resource in proximity to the sensor. These results are valid for the particular set of circumstances observed at the Pier 39 Aquarium of the Bay monitored site. Normal wind speeds 33 feet above the ground, or 33 feet above some other building in the area, could be substantially different.

The diurnal patterns for the Pier 39 normal wind speed dataset are shown in Figure 22. Measured data were available for summer and fall only, so spring and winter values in Figure 22 are based on the single-hour substitution normalization method. One consequence of this approach is that there is relatively greater uncertainty in the *shape* of the spring diurnal profile than those for other monitored sites.

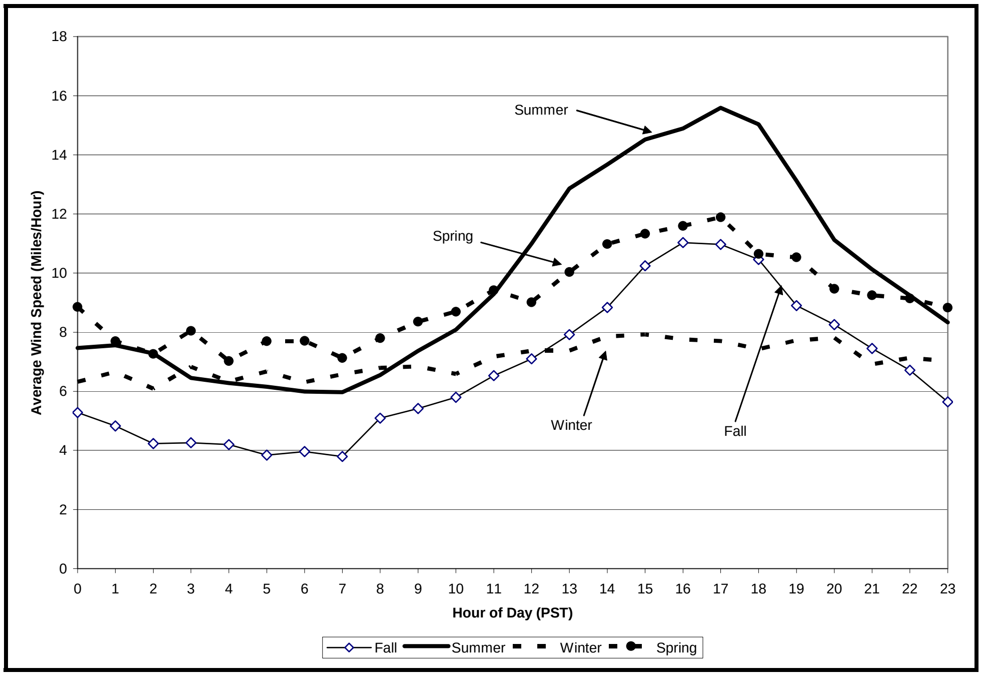

Figure 22 Normalized 33-foot Diurnal Wind Speed Patterns – Pier 39

3.5. Generic Turbine Estimated Average Annual Energy Production

Annual energy production was estimated for a generic 10 kW horizontal axis wind machine installed on a 98-foot tower. These estimates are based on normal wind speed datasets, and are intended to represent longer-term averages that would be observed over wind turbine lives exceeding 10 years. The generic turbine annual energy production estimates are presented in Table 11. The estimates range from 7,371 kWh/yr to 15,632 kWh/yr which imply generic turbine annual capacity factors based on gross generating capacity ranging from 8% to 18%. With the lone exception of the S.F. Zoo, summer is the season with the most generic turbine energy production. In all cases winter is the season with the least energy production.

Table 11: Annual Energy Production for Generic Turbines on 98-foot Towers

Site	Annual Energy (kWh)	Distribution of Annual Energy Across Seasons Spring (%)	Summer (%)	Fall (%)	Winter (%)
Pier 39	7,574[4]	26%	41%	20%	13%
Twin Peaks	15,632	22%	48%	17%	13%
SF Zoo	8,498	51%	27%	12%	9%
Hunters Point	7,371	28%	42%	18%	12%
Treasure Island	13,299	24%	42%	23%	11%
SFO	11,754	33%	37%	18%	13%

4 This annual energy production estimate is based on a hub height of 98 feet above the roof. Due to structural, architectural, and other constraints this tower height is likely not practical with today's technology. The result presented in the table therefore represents a generous estimate of the annual energy production for a wind turbine located on a shorter tower at this site.

4.0 Conclusions and Recommendations

Conclusions and recommendations yielded by the City and County of San Francisco Wind Resource Assessment project are presented below.

4.1. Conclusions

A long-term record of wind speeds measured at S.F. International Airport (SFO) is readily available. This long-term record was combined with short-term wind speed datasets collected and compiled for this project to yield estimates of 8,760-hour normal wind speed datasets for five other sites within the City of San Francisco. The annual wind resource at SFO exceeded the wind energy resource at three of these five other sites. Wind energy resources at Twin Peaks and Treasure Island appear to be better than at the SFO airport. With the exception of Twin Peaks the wind energy resources at the monitored sites appear to be quite modest relative to levels customarily associated with commercial wind energy generation development.

The wind energy resources for the five monitored sites can be put in additional perspective by comparing average wind speeds calculated from the normal 8,760-hour wind speed datasets with wind power classes developed by Pacific Northwest Laboratory. These wind power classes are summarized in Table 12.

Table 12: Wind Power Class Definitions (33-Foot Sensor Height)

Wind Power Class	Wind Speed (Miles/Hour)
1	0.0 to 9.8
2	9.9 to 11.5
3	11.6 to 12.5
4	12.6 to 13.4
5	13.5 to 14.3
6	14.4 to 15.7

Annual average wind speeds corresponding to each of the normal 33-foot 8,760-hour wind speed datasets developed for this project are presented in Table 13 alongside the corresponding wind power class.

Table 13: Annual Average Wind Speeds and Wind Power Classes for Monitored Sites (& SFO)

Monitored Site	Normal 33-Foot Annual Average Wind Speed (Miles/Hour)	Wind Power Class
Pier 39	8.2	1
S.F. Zoo	8.9	1
Treasure Island	10.4	2
Hunters Point	8.4	1
Twin Peaks	12.7	4
S.F. Airport	10.1	2

From the standpoint of economic feasibility of prospective wind energy generation facilities a wind power class equal to 1 is generally considered 'very poor' or 'poor'. In the case of small turbines, under the right circumstances (e.g., valuation of generated electricity at a high retail rate) a wind power class of 2 may be sufficient to justify development on financial grounds. When generated electricity is valued at wholesale rates a wind power class of at least 3 (and possibly higher) has generally been required to support cost-effective development of wind energy generation capacity.

4.2. Commercialization Potential

The scope of this wind resource assessment project included research that yielded information that could be used by others to make decisions concerning investment in wind energy generation equipment at five monitored sites in the City of San Francisco. In the case of the Hunters Point site, the available data suggest a poor wind energy resource. It must be noted that these data were collected by a third party and the project team had no control over these data. It is possible – although not likely– that these data suffer from problems unknown to the project team. It is also possible that the wind energy resource at some other location within the general Hunters Point area (i.e., other parcels exposed directly to the bay's N/S channel and prevailing NW winds) could offer a substantially better wind energy resource. A short-term data collection effort utilizing multiple measurement points might be used by the City to ascertain the likelihood of another viable site in the Hunters Point area.

While the available data suggest that the Treasure Island wind energy resource is modest, results of this project may justify collection of additional wind speed data at a height (e.g., 30 meters) more representative of the wind turbines hub height that could conceivably be installed at the northwest corner of Treasure Island. The existing available wind speed data for this site were collected in close proximity (above) an apartment building. While this structure is not believed to have had a significant impact on measurement of winds from the north and northwest, to the extent that measurement of winds from other directions was influenced by this and other structures nearby, actual unobstructed wind speeds are likely to be higher. Finally, measurements were made at a height of approximately 33 feet above the ground. Due to the uncertainty in extrapolation of these data to much higher levels, it is possible that the wind energy resource at 30 meters or higher could be more favorable than those suggested by the existing data available for this analysis.

Wind energy resource at the Twin Peaks site appears quite good from a purely technical standpoint. While wind energy development potential is limited by political, aesthetic, and other land use issues, information yielded by this study could factor into decisions regarding the development of some wind energy capacity at the Twin Peaks. Such development, if desired, might have the potential to serve demonstration or public education purposes, while at the same time producing electricity cost effectively.

4.3. Recommendations

City and County of San Francisco staff responsible for making decisions concerning investment in wind energy generation equipment at the five monitored sites should incorporate results of this urban wind resource assessment project into their technical and financial analyses. It is conceivable that now or at some time in the future installation of wind energy generation systems on the roofs of high-rise buildings may be technically feasible. In this eventuality the Commission or others may want to augment the present research with an urban high-rise rooftop wind resource assessment.

4.4. Benefits to California

Economic, political, electric transmission system loading, Renewable Portfolio Standards (RPS), fuel diversity, and other factors have combined to create an atmosphere of increased interest in developing wind energy generation facilities in California and elsewhere throughout the US and Europe. However, economic feasibility of particular, prospective wind energy projects is highly site specific. In the absence of satisfactory information concerning wind energy resource there is an elevated risk of investing in wind energy generation facilities that are located sub-optimally. This project developed site-specific wind energy resource information for five prospective wind energy generation sites within the City of San Francisco. This information will help the City and County of San Francisco to make better decisions regarding their future investments in renewable distributed generation, thereby benefiting California.

REFERENCES

Wind Energy Resource Atlas of the United States (prepared by Pacific Northwest Laboratory for the U.S. Department of Energy), DOE/CH10093-4, March 1987.

APPENDIX A: WIND SPEED DATA

APPENDIX A

Wind Speed Data

Accompanying this report is a CD containing wind speed datasets described in the body of the report. Wind speed data are saved in two comma-delimited files: one for observed wind speed measurements (observed.csv), and one for normal 33-foot estimated wind speeds (normal_33.csv). Fields in the wind speed data files are described in Table 1.

Table 1: Fields in the Wind Speed Data Files

Field Name	Values	Description
Type	Observed, Normal	Basis of wind data
Site	SFO, TWIN ZOO, PIER TI, HP	S. F. International Airport, Twin Peaks S.F. Zoo, Pier 39 (Aquarium of the Bay) Treasure Island, Hunters Point
D_LST	1/1/92 to 12/30/03	Date, local standard time
H_LST	0 to 23 by 1	Hour of day (hour beginning), local standard time
WSP	0 to 51	Average Wind Speed, in miles/hour
WSP_STD	0.0 to 13.2	Standard Deviation of Average Wind Speed, in miles/hour
WSP_MAX	0 to 46	Maximum Wind Speed, in miles/hour
DIR	0 to 360	Wind Direction, in degrees (N = 0 or 360, E = 90, S = 180, W = 270).

APPENDIX B: TASK 2.1 SITE TOUR AND SELECTION REPORT AND PHOTOGRAPHS

APPENDIX B

Task 2.1 Site Tour and Selection Report and Photographs

Accompanying this report is a CD containing the Task 2.1 Final Report Site Tour and Selection, as well as photographs taken at the sites toured.

Technical Assistance for the PIER Renewables Program

ICF Consulting Contract Number 500-01-006

City and County of San Francisco Wind Resource Assessment Project

Task 2.1: Site Tour and Selection Report

WA#18-AB-01

Prepared for:

ICF Consulting and the California Energy Commission
PIER Program
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Prepared by:

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1104 Main Street, Suite 630
Vancouver, Washington 98660

RER
TURNING DATA INTO INFORMATION

Site Tour Date: August 21, 2002

San Francisco Wind Resource Assessment Project

Task 2.1 Deliverable: Site Tour and Site Selection Proposal

1.1 Overview

This memo summarizes RER's recommendations concerning selection of sites for wind speed monitoring within the City of San Francisco, as directed under ICF Work Authorization No. 18-AB-01, Task 2.1. These recommendations are based on 1) the selection criteria identified below, 2) data gathered from the City of San Francisco, and 3) the findings from the visit of prospective sites held August 21, 2002. Six potential monitoring sites were visited during this tour. Of the six visited sites, five are recommended for monitoring. The recommended sites include one roof-mounted system and four ground-mounted systems. At least one of these sites would require a tall tower (30M or 50 M), which is outside the original scope of this work as envisioned at the time of work authorization development. In addition, one site (NW Treasure Island) may have adequate commercial wind speed data monitoring in place for other purposes that is available for purchase at a lower cost than required for this effort.

1.2 Site Selection Criteria

Site selection criteria were summarized in materials discussed during the July 19, 2002 conference call with all key team members. Following this conference call, Peter O'Donnell (City of San Francisco – Dept. of Environment) assembled a list of possible monitoring locations based on the results of the conference call, preliminary discussions with the San Francisco PUC, and discussions with prospective Hosts[1]. On August 21st, staff from the California Energy Commission, the City of San Francisco, the San Francisco PUC, and the RER technical support team toured the five prospective Host sites and the communications towers located atop Twin Peaks. Site selection criteria that proved particularly critical in the assessment of possible Host sites are summarized below.

- Building Top Mounts:
  - Physical characteristics of existing, available instrument mounts
  - Location with respect to prevailing winds
  - Location with respect to edge of roof
    - *Flow separates at leading roof edge*

[1] See PowerPoint presentation delivered July 29 to all members.

  - Height
    - *Instrument placement above separation streamline*

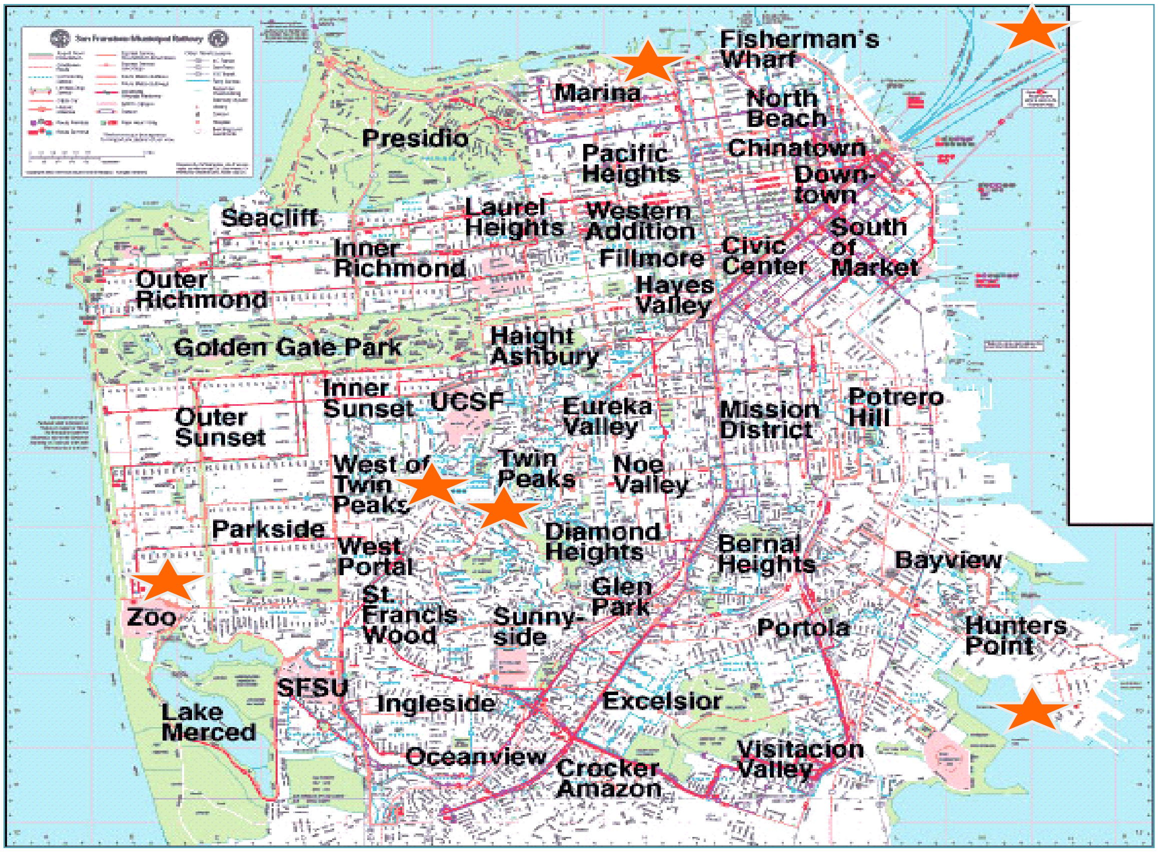
- Degree of Exposure to SW/NW Prevailing Winds During Peak Season
- Building or property manager interest and cooperation
  - Equipment installation support
  - Security/Controlled roof access
  - Opportunities for promotion/education
- Ground-mounted Tower Sites
  - Land use, topography, soil properties
  - security, controlled access to towers and data loggers
  - Zoning, aesthetics, obstructions within 300 ft.
- Proximity to Turbulence-causing Obstructions
  - Other buildings/structures
  - Hills/ridgelines
  - Trees

1.3 Proposed Sites

A listing and small scale map of the six sites visited and the five sites proposed for wind resource assessment monitoring (see Figure 1) is followed below by brief descriptions of site conditions and proposed monitoring approaches.

- Aquarium of the Bay
- San Francisco Zoo
- Treasure Island (Redevelopment Project)
- Hunters Point Naval Shipyard
- Twin Peaks (Communication Towers)
- Laguna Honda Hospital

Figure 1: Location of Wind Assessment Sites Visited on August 21, 2002



Aquarium of the Bay

The aquarium is located near Pier 39 in the Fisherman's Wharf area on the North side of San Francisco, where it is exposed to prevailing W and NW breezes. The aquarium is located on Pier 39 port property, and the aquarium management is very interested in participating in the project. The aquarium split-level roof is at least 50 feet above the bay and unobstructed from the prevailing westerly winds during the spring and summer months. There are at least two possible locations for wind speed monitoring equipment: 1) a new pole affixed to existing steel framework that supports ventilation equipment, and 2) new pole affixed with two or three wall mounts in the vicinity of the 4 foot tall wall where the roof's levels split (just a few feet W of the approach ladder access to the upper roof). Note: the potential third placement option, an existing (composite-based material) flag pole was ruled out, as there is concern that the pole's considerable flexibility that was observed under moderate breezes could represent a significant barrier to its use for collection of wind resource data.

Proposed Monitoring Approach: Wind measurement instruments provided by the RER team will be mounted on a new (1.5 to 2 inch diameter) pole/mast to be affixed at the SW corner of the existing steelwork that supports HVAC/ventilation equipment. The aquarium's engineering staff (e.g., Chris, et. al.) will fabricate any needed mounting brackets and install a new 10 meter tall galvanized steel pole and secure it to the existing steelwork located on the roof. The Host has indicated a willingness to insure the pole/mast installation – however this arrangement needs to be reviewed with aquarium management and finalized. Depending on other insurance-related details, either RER or Rich Simon (Consulting Meteorologist) will work with aquarium staff to ensure the new pole/mast is compatible with the monitoring instruments, and to install the wind sensors and data logger.

San Francisco Zoo

The San Francisco Zoo is located in the southwest corner of the city, where it is exposed to prevailing ocean breezes from the SW, west, and NW. Two possible areas for wind turbine siting and wind speed monitoring: 1) a small (10M) tower on the embankment located adjacent to the old Fleischaker Pool Building (on the North side) immediately west of the Zoo's main parking lot, and 2) a tall tower (i.e., 30 to 50 meters) located on the undeveloped SW corner of the Zoo property (in close proximity and/or directly above the city's wastewater storm overflow underground reservoir tanks). Both of these potential sites are immediately adjacent to the Great Highway and installed turbines would be visible and require appropriate setbacks from the highway right of way.

The zoo's General Manager and Director of Education (Emily) are excited about the possibility of installing wind speed monitoring equipment near the parking lot on the embankment separating the parking lot from the Great Highway and tying in the recording instruments to their Education Center. This embankment is about 60 to 80 feet in width and rises approximately 20 to 30 feet above the surrounding area and might possibly be a suitable location for installation of small-scale vertical axis wind turbines in the future.

At the tall tower location near the SW corner of the zoo, there are open fields of 4 foot deep sand in proximity to the underground storage reservoirs, which are also covered with a vapor barrier. Installation of tall towers is outside the scope of this current project, but the City of San Francisco might consider pursuing installation of tall towers in the future through other channels. For example, support may be available through the California Energy Commission's upcoming Tall Tower Program within the Public Interest Energy Research Renewables Program, or through the City's other Technical Support contracts.

Proposed Monitoring Approach: The RER team will install a 10 meter met tower on the ridgeline of the embankment located at the Western edge of the main parking lot. Installation of the guyed met tower, wind speed and direction sensors, and data logger will be handled by R. Simon. The met tower will be provided by either RER or R. Simon.

Treasure Island

Treasure Island, which is located to the northeast of San Francisco in the San Francisco Bay, has recently been turned over to the City by the US DOD and is in the very early stages the of the redevelopment process by the City of San Francisco. The island is exposed to W-NW bay breezes and the northwest quadrant has the best exposure to these prevailing westerly winds. According to one redevelopment plan drawing provided by city staff, much of the existing residential housing units on the far north end of the island are slated for removal. This area may in the future become undeveloped wetlands or of related land use nature. In the area toured by the project team on August 28, nearby obstructions (i.e., embankment, walkway, and playground) preclude the installation of a guyed met tower. The team identified a 2-story apartment building at 1205-F Bayside that is equipped with a roof-mounted pole (approximately 12 feet above the roofline) where an existing anemometer is mounted. Wires from the anemometer feed into a locked enclosure on the N. side of the building. It was unknown at the time who owns this equipment, whether or not it is in good working order, or whether or not it includes a data logger. Michael Kim (City of San Francisco PUC) contacted the met tower owner (*iWindSurf.com*) and was able to determine that this is a new commercial met site with only one month of historical data. Since the historical wind data is of a secondary use for this business, archived data can be purchased at this site for $36 per month or $432 per year. RER will purchase the first month of available data at the NW TI location and confirm our ability to use this existing interval data for our wind resource assessment purposes.

<u>Proposed Monitoring Approach:</u> Given its lower costs, RER will use the available data from the existing met tower owned by *iWindSurf.com* given that it meets our assessment needs. Following a brief review of the first month's data, a final decision will be made regarding whether a separate CEC anemometer station is required for the TI location.

In the unlikely event that a new met tower is required for this project, the Team proposes the following approach at the NW TI site: Due to constraints imposed by the TI site, the proposed alternative monitoring approach would require the City of San Francisco to install a 50 foot utility pole to which wind speed monitoring equipment will be attached. The RER team will supply wind measurement instruments and a data logger, and will work with the City's PUC engineering/operations staff to determine the most appropriate means of affixing the wind sensor instruments and the data logger to the utility pole.

Hunter's Point Naval Shipyard

The Hunters Point Naval Shipyard is in the early stages of being turned over to the City. The area is just south of the city, on the San Francisco Bay where it is exposed to winds from the Northwest. It is already vacated, and no concrete plans for its redevelopment yet exist. While redevelopment plans have not yet been finalized, they may include some or all of the following: cultural or educational facilities, open space, residential units, and a "Green" business park. There are three locations that could host a wind speed monitoring station: 1) near the waters edge in Parcel B (adjacent to #16 on the NW side) , 2) parcel E in the far southwest corner of the Hunters Point area that is still under US Navy control, and 3) the top of the large Outload crane at the waters edge of Parcel D (#44).

Security is a key concern with the Parcel B site location. Equipment installed at this location would run a significant risk of theft or vandalism. The concerns of turbulence interference affects and the feasibility/ risks of installing wind measurement instruments on the Outload crane within Parcel D make this option much less attractive than the other two. The Parcel E site on US Navy property is both secured and well exposed to prevailing westerly winds across Candlestick Point. City PUC staff would need to arrange access with the Navy for both installation and monthly data collection. The proposed tower location is within an old baseball field just to the west of Parcel D's lot #40 northern border and N. of a vacant Navy multi-story housing facility. Trees and bushes in the area are minimal, reaching a height of only approximately 6-8 feet. This area is much more secure than other possible locations at Hunters Point. One objective of placement of wind speed monitoring equipment in Parcel E would be to develop information representative of conditions in adjacent Parcel D, which may have a greater chance of wind project development. It is believed that past environmental contamination problems may preclude development on Parcel E for the foreseeable future.

Proposed Monitoring Approach: Due to the potential for large wind turbines to be sited at Hunters point (750 kW to 1+MW per turbine) and the resource/scope limitations of the CEC's ICF/RER PIER work authorization, RER recommends that the City's PUC consider acquiring and installing either a 30 meter or 50 meter tower, which RER would a fix our wind sensors at one or more standard heights and a data logger to the tower.

As an alternative that lies within the scope of our work authorization, the RER team could install a 20 meter tower in the same Parcel E location. Installation of the tower, sensors, and data logger would be handled by R. Simon.

Twin Peaks

There are two existing City controlled communication towers located at the park/lookout area on Twin Peaks. The height of these towers is estimated to be greater than 100 feet. The NW tower is the best candidate for wind speed monitoring because it holds less equipment and it is located upwind from the prevailing W/NW peak season winds. If wind turbines (e.g., vertical axis) were installed in this area in the future, they would likely be installed on another hill in close proximity to Twin Peaks. The Twin Peaks data would provide a good indication of the quality of the wind resource in this higher exposed area, however. And this information may prove useful for determining whether there are potentially other good (economic) wind resource locations within the most exposed areas of the City. There are a few trees in the immediate area of the communications tower but their height is estimated at only approximately 20 feet. In addition to the small scale potential at this site, this Twin Peaks wind data would provide over a longer period of time important general information about the wind resource within San Francisco's highest and most exposed locations.

Proposed Monitoring Approach: Preferred Approach -- The City will use a boom truck to install a wind speed monitoring equipment boom on the NW tower. The wind speed monitoring equipment mounting arm will be supplied by the RER team, and will include wind speed and wind direction instrument sensors. The boom will be installed facing north or NW, at a height of approximately 50 feet above the ground.

Laguna Honda Hospital

The Laguna Honda Hospital is located below and west of the Twin Peaks lookout. Due to the fact that it is nestled in a valley open to the west but with higher ridges to the NW and SW, this local area appears to have less wind resource potential than the other five sites. Within the next few years, a green hospital building will be constructed just to the NW of the existing complex. Unfortunately, the local contact was not available during the site visits and the Team was not able to gain access to the existing buildings where the wind sensors would likely be placed. It was noted by City Dept. of Environment staff that an existing solar monitoring station had been placed on this building within the last year and it included an anemometer that is placed about 4 feet above the roof, and therefore not well exposed to the open wind profile above the building. Therefore, this wind data will be of little or no use in this current assessment. Rich Simons will coordinate with Judy at City PUC to gain access to the existing monitoring system and if possible to review some of the existing PV station wind data.

Proposed Monitoring Approach: The Team does not propose to monitor wind at this site, unless resources become available during the decision-making process with the Treasure Island and Hunters Point sites. Should this site be selected at a later date, the RER Team would likely mount a short (≤ 10M) pole to an existing communications stub base above the main entrance to the hospital.

1.4 Conclusions

Five sites have been recommended for collection of wind data. These sites and a description of proposed pole/mast/tower provisions are summarized in Table 1. While permission to collect data must be secured for all sites, in the case of several sites, the proposed met system installation approaches require a significant degree of Host involvement. These four sites are indicated with an asterisk in Table 1.

Table 1: Recommended City of SF Monitoring Sites/Mounting Approaches

Proposed Site	Mount Type	Description of Pole/Mast/Tower
Aquarium of the Bay	Roof	Attach pole to existing HVAC steelwork mount*
San Francisco Zoo	Ground	Erect conventional 10 M meteorological tower
Treasure Island	Ground	Use/purchase existing commercial met site data / If required, install new 20M utility pole* or s/s tower
Hunter's Point	Ground	Erect tall (30M or 50M) meteorological tower*/ If needed, install new 20M met tower
Twin Peaks	Ground	Attach boom to City communications tower @ ~50ft*
Laguna Honda Hospital	Roof	Lowest Priority Site—Lack of good exposure to prevailing winds. If site is selected: Attach pole to tile roof w/ existing mounts above the main front entry.

1.5 APPENDIX A (PHOTOS OF EACH SITE – per M. KIM SF PUC)

Site photographs and descriptions/notes are included in Appendix A of this task report.

Appendix A

Site Photographs and Descriptions

APPENDIX C: SITE INSTALLATION WORKSHEETS AND PHOTOGRAPHS

APPENDIX C

Site Installation Worksheets and Photographs

Accompanying this report is a CD containing photographs of the monitoring systems, which were installed by Rich Simon and Dave Matson of Windots, LLC. Below are two of the Installations Reports as can be found in Figure 0-1 and Figure 0-2.

Figure 0-1: Site Installation Worksheet – Twin Peaks

	MET TOWER INSTALLATION REPORT			**Site:**	**0020**
Met Tower Location:	Twin Peaks, San Francisco, CA	Tower Type:	200-ft lattice tower	Date Installed:	2/27/2003
Project Name:	CEC/ICF/Itron, City of San Francisco	Logger Cell #:	N/A	Installed By:	D. Matson/R. Simon/SF Crew
Project Number:	N/A	Tower Ref. Name / #:	Site #0020	Inspected By:	D. Matson/R. Simon
ogger Type & Ser. #	NRG 9000RMY S/N 4116	Tower Lat/Long:	37°45.303'N,122°26.764'W, ± 8 m	Local Contact:	Mike Hauck
Landowner(s):	City of San Francisco	Elevation:	900 feet ASL	Tel #:	415-285-1486
Tel #:		GPS location datum:	NAD27	Fax:	

Instrument Type (ano/vane/temp)	Instrument Height (AGL)	Instrument Orientation relative to True North	NOTES (slope/offset, etc.)
RMY Wind Monitor	60 feet	North	side boom provided by City - 6-ft from leg of tower
Anemometer			Slope 0.2135, Offset .00, Side mount boom
RMY Wind Monitor	60 feet	North	side boom provided by City - 6-ft from leg of tower
Wind Vane			Magnetic compass read 335° (350°° true), but may not be accurate due to heavy RF in area.
			Site installation finished just before 1300 PST
			EEPROM #9094 inserted to start data logging.
			Winds at 1248 PST were West at 7 mph, battery voltage 9.50 V, logger set for hourly averaging.
			Site # (Fcn 9) = 2 (Fcn 9Alt) = 0

Figure 0-2: Site Installation Worksheet – San Francisco Zoo

	MET TOWER INSTALLATION REPORT			***Site:***	***0026***
Met Tower Location:	SF Zoo, San Francisco, CA	Tower Type:	30-foot NRG TallTower	Date Installed:	2/27/2003
Project Name:	CEC/ICF/Itron, City of San Francisco	Logger Cell #:	N/A	Installed By:	D. Matson/R. Simon
Project Number:	N/A	Tower Ref. Name / #:	Site #0026	Inspected By:	D. Matson/R. Simon
ogger Type & Ser. #	NRG 9200 S/N 4152	Tower Lat/Long:	37°44.107'N,122°30.312'W, ± 4 m	Local Contact:	John Aikin
Landowner(s):	City of San Francisco	Elevation:	25 feet ASL	Tel #:	415-753-7035
Tel #:		GPS location datum:	NAD27	Fax:	

Instrument Type (ano/vane/temp)	Instrument Height (AGL)	Instrument Orientation relative to True North	NOTES (slope/offset, etc.)
Maximum #40	30 feet	N/A	Slope 1.7083 mph/Hz, Offset 0.0 mph, Top mount boom. Post processing will correct
3-cup Anemometer			data to new calibration standards (slope 1.711 mph, offset 0.78 mph).
NRG #200P	30 feet	15 degrees east	Top mount boom, Z mast
Wind Vane			
			Site installation finished 15:59 PST.
			EEPROM #9408 inserted to start data logging.
			Winds at 1600 PST were 260° at 10 mph, battery voltage 9.20 V, logger set for hourly averagi
			Site # (Fcn 9) = 2 (Fcn 9Alt) = 6
			Tower stands atop a sand ridge between the north end of the Zoo parking lot and the
			Great Highway. It is approximately 80 feet north-northeast of the northeast corner of the
			pumping station. This is the best local exposure we could find. There are scattered trees
			north, east and south of the tower, but their influence should be minimal.

Appendix C

Site Installation Worksheets and Photographs

Enclosed in Appendix C are site photographs of the monitoring systems, which were installed by Rich Simon and Dave Matson of Windots, LLC. Additionally, below two of the Site Installations Worksheets can be found in Figure C-1 and Figure C-2.

Figure C-1: Site Installation Worksheet – Twin Peaks

	MET TOWER INSTALLATION REPORT			***Site:***	***0020***
Met Tower Location:	Twin Peaks, San Francisco, CA	Tower Type:	200-ft lattice tower	Date Installed:	2/27/2003
Project Name:	CEC/ICF/Itron, City of San Francisco	Logger Cell #:	N/A	Installed By:	D. Matson/R. Simon/SF Crew
Project Number:	N/A	Tower Ref. Name / #:	Site #0020	Inspected By:	D. Matson/R. Simon
ogger Type & Ser. #	NRG 9000RMY S/N 4116	Tower Lat/Long:	37°45.303'N,122°26.764'W, ± 8 m	Local Contact:	Mike Hauck
Landowner(s):	City of San Francisco	Elevation:	900 feet ASL	Tel #:	415-285-1486
Tel #:		GPS location datum:	NAD27	Fax:	

Instrument Type (ano/vane/temp)	Instrument Height (AGL)	Instrument Orientation relative to True North	NOTES (slope/offset, etc.)
RMY Wind Monitor	60 feet	North	side boom provided by City - 6-ft from leg of tower
Anemometer			Slope 0.2135, Offset .00, Side mount boom
RMY Wind Monitor	60 feet	North	side boom provided by City - 6-ft from leg of tower
Wind Vane			Magnetic compass read 335° (350°° true), but may not be accurate due to heavy RF in area.
			Site installation finished just before 1300 PST
			EEPROM #9094 inserted to start data logging.
			Winds at 1248 PST were West at 7 mph, battery voltage 9.50 V, logger set for hourly averaging.
			Site # (Fcn 9) = 2 (Fcn 9Alt) = 0

Figure C-2: Site Installation Worksheet – San Francisco Zoo

	MET TOWER INSTALLATION REPORT				**Site:**	**0026**
Met Tower Location:	SF Zoo, San Francisco, CA		Tower Type:	30-foot NRG TallTower	Date Installed:	2/27/2003
Project Name:	CEC/ICF/Itron, City of San Francisco		Logger Cell #:	N/A	Installed By:	D. Matson/R. Simon
Project Number:	N/A		Tower Ref. Name / #:	Site #0026	Inspected By:	D. Matson/R. Simon
ogger Type & Ser. #	NRG 9200 S/N 4152		Tower Lat/Long:	37°44.107'N,122°30.312'W, ± 4 m	Local Contact:	John Aikin
Landowner(s):	City of San Francisco		Elevation:	25 feet ASL	Tel #:	415-753-7035
Tel #:			GPS location datum:	NAD27	Fax:	

Instrument Type (ano/vane/temp)	Instrument Height (AGL)	Instrument Orientation relative to True North	NOTES (slope/offset, etc.)
Maximum #40	30 feet	N/A	Slope 1.7083 mph/Hz, Offset 0.0 mph, Top mount boom. Post processing will correct
3-cup Anemometer			data to new calibration standards (slope 1.711 mph, offset 0.78 mph).
NRG #200P	30 feet	15 degrees east	Top mount boom, Z mast
Wind Vane			
			Site installation finished 15:59 PST.
			EEPROM #9408 inserted to start data logging.
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			Site # (Fcn 9) = 2 (Fcn 9Alt) = 6
			Tower stands atop a sand ridge between the north end of the Zoo parking lot and the
			Great Highway. It is approximately 80 feet north-northeast of the northeast corner of the
			pumping station. This is the best local exposure we could find. There are scattered trees
			north, east and south of the tower, but their influence should be minimal.

Figure C-3: Twin Peaks Site Photograph

Figure C-4: San Francisco Zoo Site Photograph