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This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

The data collected over the title period were used to establish the accuracy of the long term measurements at the site, the protocol for the use of the Weatherpak mobile anemometer, the fit of the data with a Gumbel Type I distribution, the optimum of the 15-minute averaging period, and the invariance of the gust: average wind speed ratio.

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Floating Bridge Design Forces

WIND ON THE EVERGREEN POINT BRIDGE: JANUARY 27 TO MARCH 31, 1994

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Transportation Commission, Department of Transportation, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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EXECUTIVE SUMMARY

Washington State contains all but one of the continuous floating bridges that now exist. In the case of other types of structures, research and novel design experiences are occurring elsewhere, and the results are published in the engineering literature. In the case of continuous floating bridges, the research is of local interest and will have to be conducted locally; development of design criteria will be much aided by that research. This study dealt with existing and newly collected wind records at the Evergreen floating bridge. The wind batters the superstructure of the bridge and generates waves that also batter the bridge.

A fixed anemometer exists on the bridge's control tower. It has been recording for over 20 years, and questions have arisen about the accuracy of these measurements. In this study a contemporary mobile anemometer (Weatherpak) was used to calibrate the existing instrument. The results showed that the old instrument recorded speeds that were about 20 percent lower than those recorded by the new, calibrated Weatherpak when they were placed adjacently on the control tower. When the Weatherpak was placed away from the tower (100 ft east) and at the same level, the results were much the same as those of the existing instrument on the tower. This means that the existing tower instrument records well the clear field wind speeds. These wind speeds are of most interest to the designer.

Collection of wind speeds from January 27 to March 31, 1994, allowed the researchers to compare data with a theoretical probability distribution that predicts how often the wind will blow at a certain speed. This comparison showed that the measurements fitted well the Gumbel Type 1 extreme distribution, and this confidence allowed the speed of storms that would occur once in a definite numbers of years to be calculated. For example, the speed of a 50-year return period storm can be calculated.

In an effort to reduce the amount of data required for analysis, the averaging period was studied. The investigation showed that a 15-minute period provided results that were as good as the 5-minute period used in the previous analysis.

The final part of the study attempted to understand the wind behavior in that part of Lake Washington. This analysis showed that the ratio of the gust speed to the average speed remained invariant. This means that the wind in that region has average and gust speeds which are log normally distributed with the same standard deviation.

These results were based on a few measurements. However, the protocol for the use of the Weatherpak and the subsequent analysis of the results will allow the continuing effective use of the instrument both at the Evergreen Point Bridge and at other sites. The methodology developed here will be effective elsewhere.

INTRODUCTION AND RESEARCH APPROACH

THE PROBLEM

Although floating bridges are not uncommon, continuous ones exist only in Washington State and British Columbia; statements on practice and design conditions do not, therefore, exist in the usual engineering literature. Evidence on these matters must be generated locally. The bridges are battered by wind crossing the water surface over the fetch and by wind on the superstructure. The Washington State Department of Transportation (WSDOT) has historically supported various studies on the analyses of these bridges and the measurement of wind to determine the most dangerous situations and the organization of maintenance programs. These have been reported in the open literature (Hartz and Richey, 1970; Hartz and Mukherji, 1971; Mukherji, 1972; Brown, Christensen and Demich, 1976; Hartz, 1981; Hartz, 1981; Brown, Christensen, Heavner, Landy and Vasũ, 1981; Hartz and Georgiadis, 1981; Georgiadis, 1981; Hartz and Georgiadis, 1982). These studies have begun to provide an understanding of the behavior of such bridges and, together with experience in major storms, to indicate the importance of gathering and analyzing wind data if new structures or significant changes to existing structures are to be contemplated. The Department has continued to collect wind information at single locations on existing bridges and to organize consulting studies. The existing wind anemometers are typically similar to the one on the Evergreen Point Bridge. This is located on the control tower and provides a continuous chronicle on a recording chart. Evidence has suggested that the data collected do not state the real wind speeds near the bridge, the instrument could be faulty and favor high speed readings. WSDOT was concerned that its long-term wind data could not be used with confidence.

OBJECTIVES

Four objectives were suggested by the problem: checking the validity of the data stream obtained from the existing anemometer, investigating the sensitivity of those data to instrument location on the bridge, establishing a protocol for the use of a mobile contemporary instrument, and analyzing wind data provided by the existing and new instruments.

METHODOLOGY

The original intention was to calibrate the existing anemometer on the Evergreen Point Bridge in a wind tunnel. However, the instrument proved to be hard wired and permanently installed. This aspect of the work was replaced by comparing the measurements from the existing instrument with those from one of known validity placed adjacently. The following steps were taken to meet these objectives:

1) A contemporary, mobile anemometer was obtained, and a protocol for its use was established.

2) The validity of the data from the Evergreen Point Bridge instrument was checked by comparing those data with data obtained by the new instrument in an adjacent location.

3) The sensitivity of the wind data to the location of the tower was determined by moving the new instrument to a new location on the bridge and comparing its measurements with those taken at the same time in the original location

4) These data were analyzed to provide

a) statistical information

b) determination of an appropriate time averaging period

c) determination of possible invariance in the statistics of these data in particular, a relationship between gusts and long-term averages.

FINDINGS

INSTRUMENTS

Existing Anemometer

The existing instrument located on the control tower of the Evergreen Point Bridge is a rotator, three-cup anemometer, which provides a continuous record of vector averaged wind speeds and directions printed out on rolled tapes. The instrument is hard-wired to the recording device located inside the tower. Any study of these data requires the subjective interpretation of a print out on a continuous roll. Figure 1 displays a typical data stream.

This scroll-like recording chart will be referred to as "wind speed tapes." The tapes are divided into 1/4-inch increments. Each 1/4-inch increment along the width of the tape denotes 10 mph. The tape is further subdivided into five sections along the width, each line representing 2 mph. The 1/4-inch increments along the length of the tape represent 15 minutes. Each hour is marked at the bottom of the tape. Each roll of tape contains one month of data.

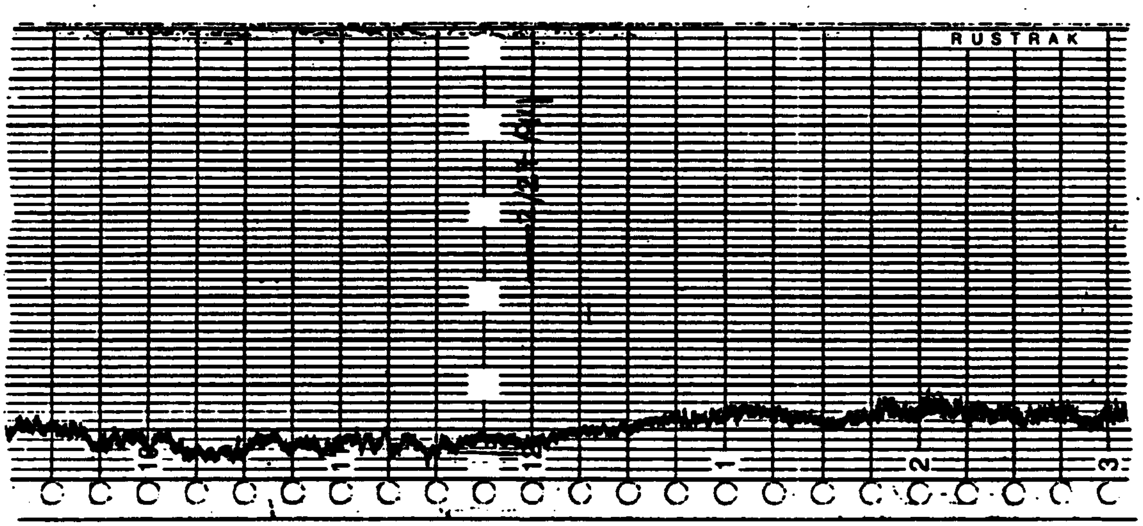

Figure 1. Sample Wind Speed Tape Recorded by the Rotator Cup Anemometer.

The continuous format of the tapes caused difficulty in comparing the anemometer data with the 5-minute averages recorded by the Weatherpak. Five-minute averages were estimated from the tapes by dividing the 15-minute increments into three sections and estimating the average of the scattered points for each section.

Weatherpak

The new instrument used was the Weatherpak R-100 Automatic Weather Station developed by Coastal Environmental Systems, Seattle, Washington. Appendix A provides the information in the Weatherpak User Guide. The Weatherpak is a battery powered, stand alone weather station. Figure 2 shows a schematic drawing of the instrument. The system reports vector averaged wind speeds and directions that are averaged over user specified time intervals. The sampling intervals and parameters were adjusted using the software PROCOMM and a portable laptop computer carried to the site.

The Weatherpak-100 consists of four main components. First, the wind monitor that records wind speed and direction is model 05103 made by the R.M. Young Company. Second, the air temperature is recorded by the YSI 44203 Thermilinear Component made by YSI Incorporated. Third, the compass is the HS8000 Heading Sensor made by Navico Ltd. Fourth, the Weatherpak-100 hardware has 256Kb RAM memory.

The Weatherpak is powered by 9 D-cell batteries. The batteries are placed end to end in a long (3 foot) tube-like battery tower that threads into the bottom of the instrument. The battery tower is equipped with a junction box housing an outlet that connects to a computer with a cable provided by Coastal Environmental Systems. The battery tower was connected to a 1 1/2-inch threaded pipe that WSDOT fabricated on the bridge.

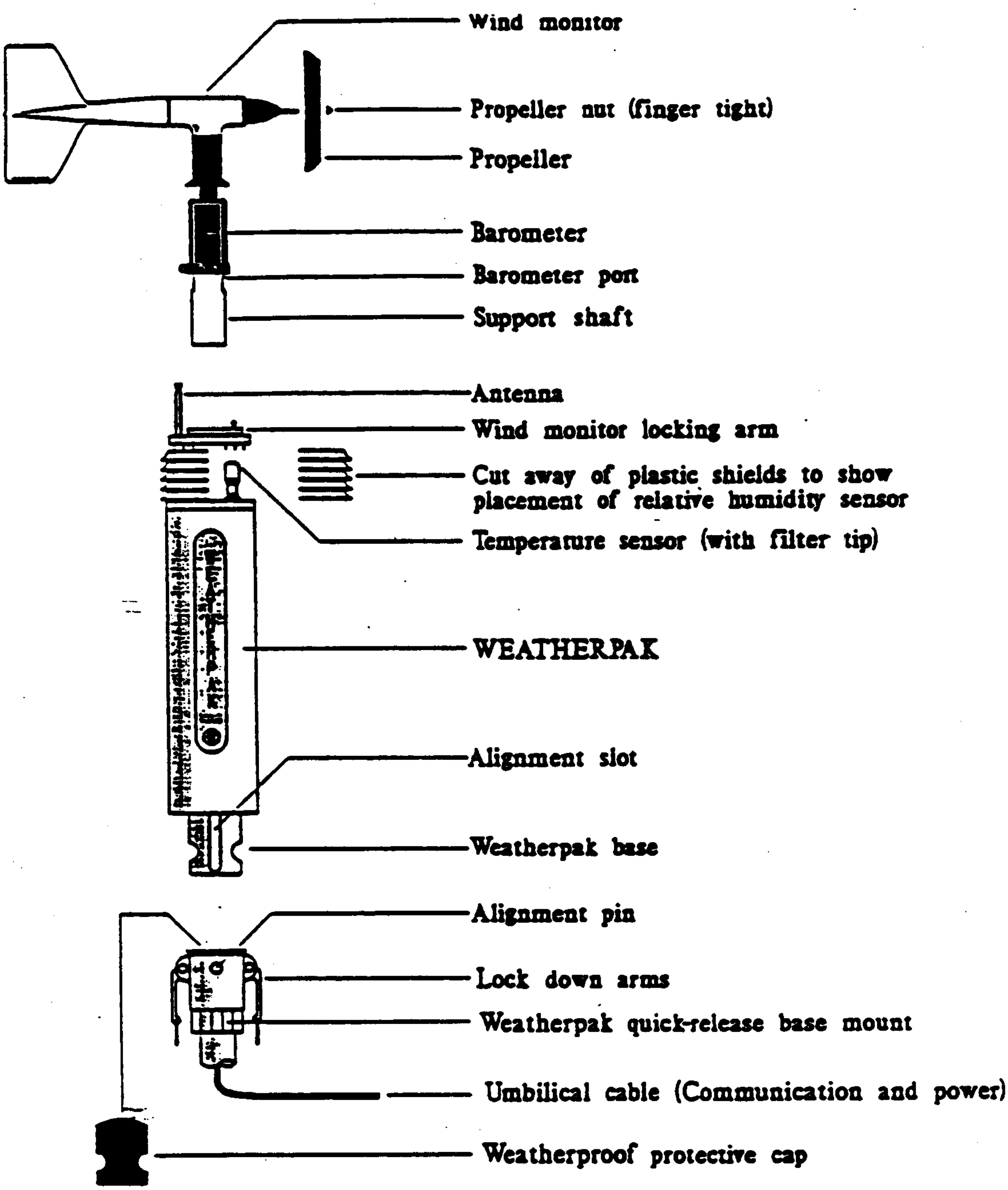

Figure 2. Schematic Drawing of the Weatherpak-100 (Coastal Environmental Systems, 1993).

The measurements of the Weatherpak are accessed by connecting the instrument to a portable computer. Data are recorded every second and reported at 5-minute intervals.

Researchers established the protocol for the use of the Weatherpak. The first step at each visit was to connect the portable computer to the Weatherpak through the junction box. Then, the program PROCOMM was initiated on the computer. The Weatherpak computer was reached by typing the character *#*. The system changed from the run mode to the dialog mode and replied with the prompt M>. At this point, the portable computer had successfully reached the Weatherpak.

A log file could be opened each time data were retrieved by typing *Alt F1* (simultaneously), then naming the file. The log files for this project were all named with the date of data retrieval and the extension "wpk". For example, all data retrieved on February 8, 1994, were named "020894.wpk". After the log had been opened, all correspondence with the Weatherpak were recorded in this file.

The symbol M> designated the main menu of the Weatherpak. This menu branched off to four sub-menus. The data menu was reached by typing the capital letter *D [Enter]*. When the Weatherpak responded with D>, the user could retrieve all of the data in the computer's memory by typing ** [Enter]*. The portable computer then showed each line of data as it was being recorded and finished with D> after the last line. At this point, the data were saved in the log file and could be deleted from the Weatherpak memory by re-initializing the internal clock. To do this, the user typed *P [Enter]*, which switched the Weatherpak to the parameters menu. The time and memory were initialized by typing *I [Enter]*. The screen displayed the current date and time, which could be changed, or if correct, left as it was. By typing *[Enter]* the memory was erased of all previous data. The final step was to tell the Weatherpak to return to sampling. Typing *R [Enter]* exited the dialog mode, returning the Weatherpak to the run mode. To close the session with PROCOMM and return to DOS, *Alt* and *X* were typed simultaneously.

After the Weatherpak data had been saved in a log file, the file could be read directly into a spread sheet such as Microsoft Excel (Microsoft Corp., 1992). Table 1 shows one hour of data taken on January 31, 1994, in its form as an Excel file. If the text was chosen to be comma delimited, the program automatically assigned each data field to a separate cell.

Each column in Table 1 contains one data field that is labeled at the top, while the rows contain all data recorded at each 5-minute interval. The first two columns contain the date and time the sampling started. "YYMMDD" is the year, month, and date of record, and "hhmmss" is the hour, minute, and second given in the 24-hour format. The following is a brief summary of the data fields (Coastal Environmental Systems, 1993):

- ID is the instrument identification number
- VS is the vector averaged wind speed in m/s*10
- VD is the vector averaged wind direction in degrees
- SD is the standard deviation of the direction (also in degrees)
- SP is the average scalar wind speed (m/s*10)
- G is the maximum 5-second wind gust (m/s*10) recorded in the sample
- TG is the time the gust occurs as a percentage of total interval time
- LC is the last compass reading (degrees)
- TA is the air temperature (°C*10)
- TI is the Weatherpak internal temperature (ambient temperature, °C*10)
- BT is the battery voltage (volts DC*10)

The wind speed (VS) and direction (VD) were vector averaged for each sampling period. The Weatherpak measured the wind speed and vane direction at 1-second intervals, then computed the wind statistics. First, the unit vector components for the east (x_i) and the north (y_i) were computed.

$$x_i = \sin(\theta_i' + \alpha_i) \qquad \text{(Eq. 1)}$$
$$y_i = \cos(\theta_i' + \alpha_i)$$

Table 1. Example Data Output from Weatherpak-100

YYMMDD	hhmmss	ID	VS	VD	SD	SP	G	TG	LC	TA	TI	BT
940131	2	498	23	8	70	23	28	62	4	41	27	111
940131	501	498	18	15	88	18	22	6	4	41	23	110
940131	1002	498	18	29	86	19	23	89	2	41	23	111
940131	1501	498	20	39	52	20	24	32	4	39	23	111
940131	2002	498	22	45	54	22	27	32	4	37	23	111
940131	2501	498	16	48	69	16	21	4	4	35	23	111
940131	3002	498	14	64	91	14	17	33	4	35	23	111
940131	3501	498	11	60	67	11	15	79	4	33	23	111
940131	4002	498	9	57	123	10	15	11	4	33	19	110
940131	4501	498	9	46	37	9	12	50	4	33	19	111
940131	5002	498	9	39	71	9	13	43	4	33	19	111
940131	5502	498	11	28	124	11	17	54	4	33	19	110
940131	10002	498	14	15	136	14	20	80	4	33	19	111

In Equation 1, $\theta_i' + \alpha_i$ is the instantaneous wind direction relative to true north. θ_i' is the measured vane direction relative to the sensor, and α_i is the computed azimuth (corrected compass angle). The wind speed vector components were

$$u_i = s_i x_i \qquad \text{(Eq. 2)}$$

$$v_i = s_i y_i$$

where s_i is the wind speed measurement. At the end of each 5-minute sampling block the vector components were averaged as follows to yield U and V:

$$U = (1/N)*\Sigma u_i \qquad \text{(Eq. 3)}$$

$$V = (1/N)*\Sigma v_i$$

where N = number of measurements in averaging period (for 5-minute averages, N = 300).

The vector-averaged wind speed reported in the data file (VS) was:

$$S_V = (\mathbf{U}^2 + \mathbf{V}^2)^{1/2} \quad \text{(Eq. 4a)}$$

and the vector averaged wind direction (VD) was:

$$\Theta_V = \arctan(\mathbf{U},\mathbf{V}) \quad \text{(Eq. 4b)}$$

The signs of **U** and **V** were used to determine the exact angle (1). The Weatherpak also reported the scalar mean speed ($SP = (1/N)*\Sigma s_i$) as a backup if the vane or compass failed.

The maximum gust recorded (G) was the highest 5-second running average wind speed. The time that the maximum gust occurred was reported as a percentage of the 5-minute sampling block. For example, the first data line in Table 1 lists G as 28 and TG as 62. This means the highest gust recorded was 2.8 m/s occurring at 62 percent of the time interval. Sixty-two percent of 5 minutes is 3.1 minutes into the sample.

After the data were down loaded and opened in an Excel file, spread sheets were made for each day. Table 2 shows part of the spread sheet for January 31, 1994.

The columns containing the time, vane speed (VS), vane direction (VD), standard deviation of the direction (SD), maximum gust (G), and time of maximum gust (TG) were copied from the data files. The vane speed and maximum gust were converted from m/s*10 to miles per hour (mph = (m/s*10) * (2.237/10)). The wind speed recorded from the rotator cup anemometer was reported in the column next to the Weatherpak 5-minute vane speed data and was labeled *5 min DOT Spd, mph.*

The columns to the right of the time of maximum gust (*Time %, TG*) were calculations performed on the data. The column labeled *5 min% different, wpk-dot* was the difference in recorded wind speed between the Weatherpak and the WSDOT rotator cup anemometer as a percentage of the Weatherpak value. The average of this percentage for all samples taken each day (labeled *avg % diff*) was reported in the column headed *day max*. The columns headed *10 min, 15 min, 30 min*, and *60 min* were averages

Table 2. Sample Weatherpak Calculation Spread Sheet for January 31, 1994, 12:00 a.m. to 2:05 a.m.

31-Jan-94							5 min						
	5 min	5 min			5 min		% different		5 min				
Time	Speed	DOT Spd			Max Gust		wpk-dot	day max	gust/avg	10 min	15 min	30 min	60 min
sec	mph	mph	Direction	St Dev	mph	Time %							
2	5.1451	4	8	70	6.2636	62	22.2561272	5 min	1.217391	4.5859	4.3994	4.3622	3.3555
501	4.0266	3.5	15	88	4.9214	6	13.0780311	5.1451	1.222222	4.0266	4.1757	4.0266	3.1877
1002	4.0266	3	29	86	5.1451	89	25.4954552		1.277778	4.2503	4.474	3.7656	3.225
1501	4.474	4	39	52	5.3688	32	10.5945463	10 min	1.2	4.6977	4.3249	3.4301	3.225
2002	4.9214	4.5	45	54	6.0399	32	8.56260414	4.6977	1.227273	4.2503	3.8775	3.02	3.1691
2501	3.5792	3	48	69	4.6977	4	16.1823871		1.3125	3.3555	3.0572	2.5353	3.0945
3002	3.1318	2.5	64	91	3.8029	33	20.173702	15 min	1.214286	2.7963	2.5353	2.3489	3.1318
3501	2.4607	2	60	67	3.3555	79	18.7223148	4.474	1.363636	2.237	2.1624	2.3489	3.1877
4002	2.0133	2	57	123	3.3555	11	0.66060696		1.666667	2.0133	2.0133	2.6844	3.2623
4501	2.0133	1.5	46	37	2.6844	50	25.4954552	30 min	1.333333	2.0133	2.1624	3.02	3.3555
5002	2.0133	1.5	39	71	2.9081	43	25.4954552	4.36215	1.444444	2.237	2.5353	3.3182	3.4301
5502	2.4607	2	28	124	3.8029	54	18.7223148		1.545455	2.7963	3.3555	3.6538	3.5046
10002	3.1318	2.5	15	136	4.474	80	20.173702	60 min	1.428571	3.8029	3.8775	3.9148	3.5419
10502	4.474	3.5	14	61	5.8162	92	21.770228	3.5419167	1.3	4.2503	4.1012	4.0266	3.4487
11001	4.0266	3.5	15	72	4.6977	52	13.0780311		1.166667	3.9148	3.952	3.8402	3.3555
11502	3.8029	3.5	19	75	5.1451	44	7.9649741	avg % diff	1.352941	3.9148	3.952	3.6911	3.02
12001	4.0266	3	22	95	5.1451	66	25.4954552	36.047215	1.277778	4.0266	3.952	3.5419	2.703
12502	4.0266	3.5	26	84	4.9214	38	13.0780311		1.222222	3.9148	3.7283	3.3555	2.3675
13001	3.8029	3	29	52	5.1451	66	21.1128349		1.352941	3.5792	3.4301	3.1691	2.0319
13502	3.3555	2.5	31	96	4.474	67	25.4954552		1.333333	3.2437	3.1318	2.8708	1.715
14001	3.1318	2	40	142	4.0266	94	36.1389616		1.285714	3.02	2.9827	2.8708	1.4354
14502	2.9081	2	35	188	4.2503	67	31.2265741		1.461538	2.9081	2.9081	2.3489	1.1744
15001	2.9081	2	38	184	4.9214	90	31.2265741		1.692308	2.9081	2.6098	1.8642	0.9321
15502	2.9081	2.5	45	281	5.1451	29	14.0332176		1.769231	2.4607	2.759	1.3795	0.6897
20001	2.0133	2.5	45	137	4.474	34	-24.174241		2.222222	2.6844	1.7896	0.8948	0.4474
20502	3.3555	2	40	109	4.474	78	40.3963642		1.333333	1.6778	1.1185	0.5593	0.2796

computed for longer periods from the 5-minute Weatherpak wind speeds. The longer averaging periods were a running average. For example, the *30 min* column was computed by summing the first six measurements in the 5-minute column and dividing by six. The second value was similarly computed using measurements 2 through 7. The maximum daily value for each averaging period was reported in the *day max* column.

The spread sheets also contained ratios of maximum gust to average wind speed. The column titled 5 *min gust/avg* was the 5-second maximum gust (G) divided by the 5-minute average wind speed (VS).

The Weatherpak was calibrated using the wind tunnel located at More Hall, University of Washington. Its measurements were compared with those of the three axis

Sonic Anemometer/Thermometer model number SWS-211/3K made by Applied Technologies Inc. The two instruments were carefully centered horizontally and vertically at the end of the wind tunnel for each test.

The wind speed readings were taken from the test menu of the Weatherpak and from the software provided for the Sonic Anemometer. The Sonic Anemometer gives three readings, one for each vector in space. The vector used in this test was the vector parallel to the wind tunnel. The Weatherpak reading used for this test was the scalar wind speed, SP. The laboratory contained many power cables, which affected the internal Weatherpak compass. The vector averaged wind speed (VS) and direction (VD) gave incorrect values. The scalar wind speed is the value of wind speed recorded parallel to the vane, thus it gave a reliable reading for the same vector recorded by the Sonic Anemometer.

The Weatherpak gave consistent wind speed readings within 5 percent of the Sonic Anemometer. The calibration test began by producing the maximum wind speed capable of being generated by the wind tunnel. The Weatherpak recorded a wind speed of 5.0 meters per second, and the Sonic Anemometer recorded 5.2 m/s. The second test was performed at half the maximum speed capable of being produced by the wind tunnel. The Weatherpak measured 2.47 m/s, and the Sonic Anemometer recorded 2.4 m/s. The Weatherpak was 4 percent lower than the Sonic Anemometer in the first test and 3 percent higher in the second test. Even though the threshold of the Weatherpak is 1.0 m/s, the accuracy of the instrument at the lower wind speed was more questionable than at the higher speed. Therefore, the researchers concluded that the Weatherpak recorded wind speeds accurate to 5 percent, with a tendency to be slightly low.

The instrument was also tested for gust sensitivity. The Weatherpak recorded a wind speed of 5.0 m/s for the first test and a maximum gust of 5.1 m/s. The maximum gust value was constant and nearly equal to the average. Therefore, the method of recording the gust by the Weatherpak was independent of the average and was assumed to be correct.

INSTRUMENT COMPARISON

This comparison was between the calibrated Weatherpak and the existing three-cup anemometer, which had been making measurements for over 20 years. Two matters were of concern:

a) the accuracy of the existing instrument

b) the significance of the location of the existing instrument and whether the presence of the tower had an effect on the wind speed measured.

Table 3 shows the maximum daily wind speeds over various averaging periods and, in the last column, the comparison between the existing and Weatherpak instruments for 5-minute averaging. The values through February 5th are the measurements taken when the Weatherpak was located on the tower. The remaining values are for the Weatherpak located 100 feet east of the tower on a steel walkway of the same height as the tower. The two locations of the Weatherpak were at the same height as the existing instrument. When located on the tower, it measured the accuracy of the existing instrument; when located on the light steel walkway, it measured the effect of the tower location on the existing instrument.

The results in Table 3 show that the existing anemometer took measurements that were 21.57 percent lower than those taken by the Weatherpak when that instrument was located on the tower. Thus, the researchers concluded that the measurements provided by the existing instrument have been about 22 percent low. The measurements of the Weatherpak were 1.15 percent lower than those of the existing instrument when the Weatherpak was located 100 feet east. This suggests that the uncorrected, long-term measurements of the existing instrument have been much the same as the wind speed 100 feet east. Note that the Weatherpak calibration showed the instrument to measure 4 percent low.

Table 3. Maximum Daily Wind Speed Values.

	Date	AVERAGING PERIODS 5 MIN	10 MIN	15 MIN	30 MIN	60 MIN	Wpk vs DOT AVG % DIFF
Weatherpak at Tower Location	27-Jan	15.6590	14.9880	15.6670	14.2420	12.7320	6.5800
	28-Jan	12.3040	12.3040	12.2290	11.6320	11.2600	10.2100
	29-Jan	8.7243	8.7243	8.4260	7.9414	7.5312	22.9000
	30-Jan	11.1850	11.1850	10.8120	10.3650	10.0480	36.5100
	31-Jan	11.1850	11.0730	10.9610	10.7750	10.3460	31.2100
	1-Feb	8.5006	8.5006	8.5006	8.2769	7.9600	NA
	2-Feb	8.0532	7.8295	7.6804	7.2330	6.3755	NA
	3-Feb	9.6191	9.5073	9.1717	8.5752	7.7549	NA
	4-Feb	12.5270	12.1920	11.9310	11.4830	11.2220	NA
	5-Feb	9.6191	9.3954	9.0971	8.3888	7.7922	21.9900
Weatherpak at 100 ft. east of Tower	9-Feb	16.7780	16.3300	16.1060	15.8450	15.6590	1.8800
	14-Feb	24.6070	23.8240	23.1900	21.5870	20.6920	-15.9300
	15-Feb	23.2650	23.0410	22.6680	22.1840	20.1890	-13.9000
	18-Feb	21.9230	20.9160	20.5060	20.3190	20.0030	-13.7800
	19-Feb	17.8960	17.0010	16.7030	15.5840	14.9510	-15.7300
	20-Feb	17.8960	17.7840	17.7470	16.6660	15.6220	6.1300
	21-Feb	22.5940	21.8110	21.4750	21.3630	21.0280	-17.7400
	22-Feb	28.4100	28.1860	28.1120	27.3290	26.7690	-16.7100
	23-Feb	20.5800	20.2450	20.2820	19.9090	18.7720	-7.8100
	24-Feb	14.5410	13.3100	12.7510	11.0730	9.9700	10.0800
	25-Feb	15.6590	15.4350	15.2120	14.6900	14.5780	-3.8200
	26-Feb	15.6590	15.6590	15.5840	15.3980	14.9510	2.4200
	27-Feb	14.7640	14.6520	14.3910	14.0190	13.5340	-8.1500
	28-Feb	22.5940	21.9230	21.7730	21.5120	20.4130	-17.3000
	1-Mar	17.2250	17.2250	16.9270	16.1440	15.3230	15.5100
	2-Mar	20.5800	20.2450	19.9090	19.2380	18.4930	10.4300
	3-Mar	24.3830	23.9360	23.6380	22.7800	21.8290	2.1400
	4-Mar	23.2650	23.0410	22.8920	22.0720	21.2890	-3.6100
	5-Mar	17.2250	16.6660	16.4790	16.2180	15.6030	2.3000
	6-Mar	12.3040	11.9680	11.7070	11.3710	11.1660	7.1700
	7-Mar	12.3040	12.1920	11.9310	11.5580	11.3900	7.6000
	8-Mar	9.1717	9.1717	8.8734	8.5752	7.6617	5.0700
	9-Mar	13.4220	13.4220	12.9000	12.3040	10.4390	6.0800
	10-Mar	13.8690	13.1980	13.3470	12.6020	11.5020	15.6700
	11-Mar	8.0532	7.9414	7.8295	7.4194	7.1211	24.7000
	12-Mar	12.3040	11.8560	11.4830	9.9547	8.1651	12.4900
	13-Mar	9.6191	9.5073	9.3954	9.2090	7.5685	5.9600
	18-Mar	22.8170	22.2580	22.0720	21.9230	20.9350	-9.3800
	19-Mar	20.1330	19.6860	19.4620	18.8650	18.4740	-8.8200
	20-Mar	35.5680	33.2190	32.4370	31.8030	30.8710	-10.8100
	21-Mar	36.2390	35.2330	34.1520	33.5180	32.1380	-21.6800
	22-Mar	14.0930	13.9810	13.7200	13.1240	12.6200	-6.1800
	23-Mar	13.8690	12.4150	11.6320	9.5445	9.0785	-3.4600
	24-Mar	19.0150	18.4550	18.0450	17.6720	17.3550	2.7400
	25-Mar	15.2120	14.9880	14.6900	13.9070	13.4410	6.1600
	26-Mar	9.3954	9.1717	9.0226	8.4260	7.2330	10.9000
	27-Mar	8.5006	8.3888	8.3515	7.7922	6.8042	-5.5000
	28-Mar	14.0930	13.9810	13.8690	13.1980	12.6390	3.1800
	29-Mar	14.5410	14.5410	14.3910	13.9810	13.2910	-6.9300
	30-Mar	9.1717	8.8362	8.5752	8.1278	7.3821	2.6600
	31-Mar	7.6058	7.6058	7.2330	6.4500	5.8908	-1.1900
	MEAN	16.049	15.666	15.411	14.788	14.036	
	ST DEV	6.5795	6.3263	6.2392	6.2324	6.1734	
	Wpk vs. Cup Anem.			on tower	on structure		
	Ave. % Difference:			21.57	-1.15		
	Std Der:			10.58	10.67		

Thus, it can be concluded that the long-term wind data collected on the Evergreen Point Floating Bridge have been within 5 percent of the actual wind speed away from the tower.

STATISTICAL ANALYSIS

The 51 samples of maximum daily 5-minute wind speeds that were collected with the Weatherpak are the basis for this discussion. From these data, time averages over 10, 15, 30, and 60 minutes were computed, and the 51 maximum daily wind speeds for all these averaging times are shown in Table 3. Figure 3 is the histogram for the maximum daily 5-minute wind speeds collected.

The Gumbel Type I distribution of the largest values is a method of modeling extreme wind speeds in well-behaved climates (climates in which unusual winds such as hurricanes are not expected to occur). The cumulative distribution function as estimated by the Type I distribution is as follows:

$$F(x) = \exp\{-\exp[-(x-\mu)/\sigma]\} \quad \text{(Eq. 5)}$$

for $-\infty < x < \infty$, $-\infty < \mu < \infty$, and $0 < \sigma < \infty$. The symbols μ and σ denote the location and scale parameters, respectively. These parameters are defined as

$$\sigma = \frac{(6)^{1/2} SD(X)}{\pi} \quad \text{(Eq. 6)}$$

$$\mu = E(X) - 0.5772\sigma \quad \text{(Eq. 7)}$$

where X is the set of measurements, E(X) is the mean of X, and SD(X) is the standard deviation. Table 4 shows the parameters for all averaging periods considered in this analysis.

The statistics and parameters in Table 4 were calculated from the data listed in Table 3. The mean E(X) is the average of the 51 maximum daily wind speeds for each averaging period, as calculated in Table 3. The standard deviation SD(X) of these values is also shown in Table 3. The values for σ and μ were calculated using Equations 6 and 7.

Table 4. Type I Cumulative Distribution Function Parameters

Averaging Period	Mean	Std Dev	Scale	Location	Samples
	E(X)	SD(X)	σ	μ	n
5 minutes	16.049	6.5795	5.1300	13.088	51
10 minutes	15.666	6.3263	4.9326	12.819	51
15 minutes	15.411	6.2392	4.8647	12.603	51
30 minutes	14.788	6.2324	4.8594	11.983	51
60 minutes	14.036	6.1734	4.8134	11.258	51

n = number of observations

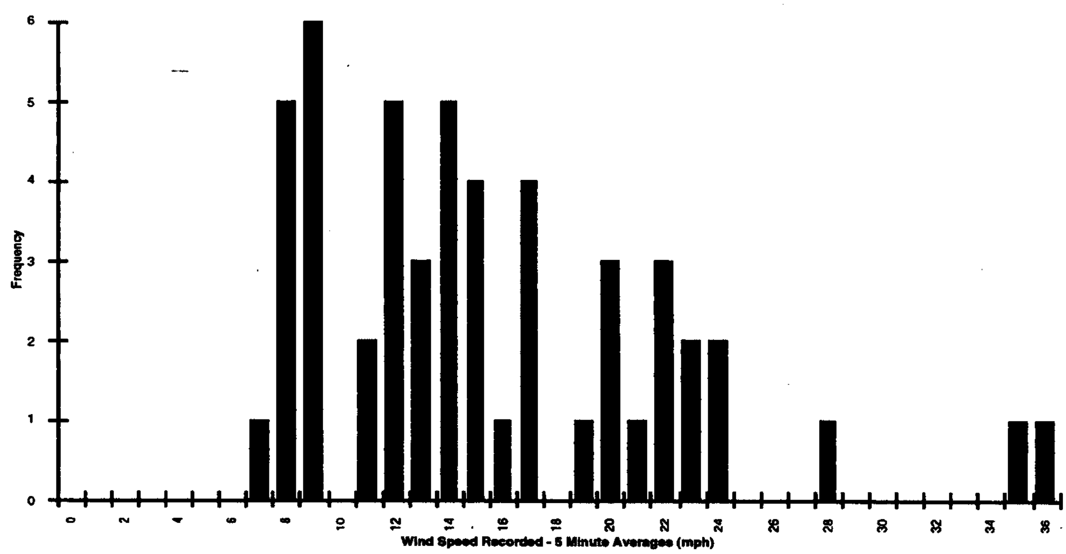

Figure 3. Daily Maximum 5-Minute Wind Speed Histogram for 51 Samples

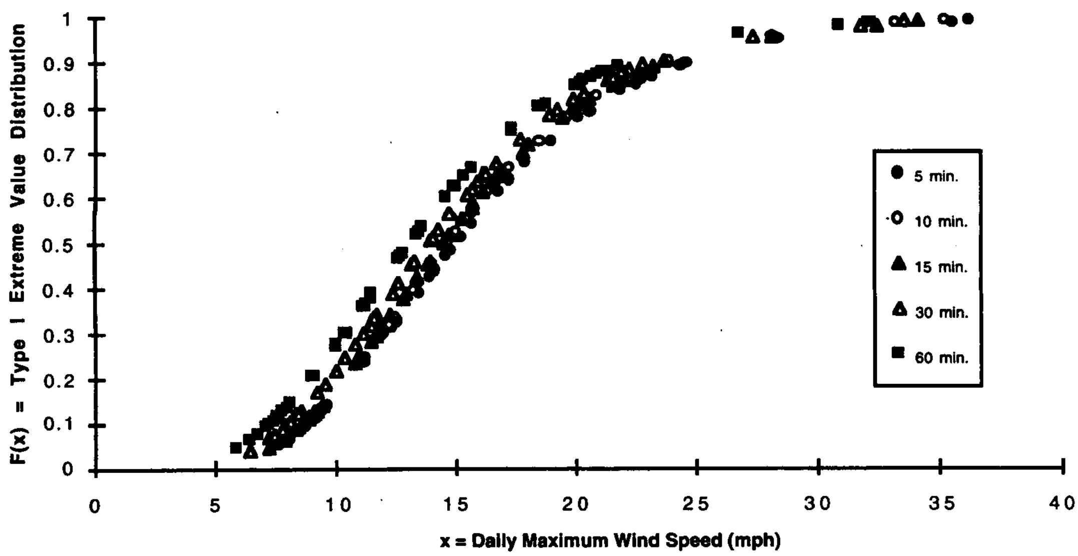

Figure 4. Type I Cumulative Distribution Function of Extreme Wind Speeds

Equation 5 and the parameters listed in Table 4 were used to calculate the Type I cumulative distribution function. Table 1 in Appendix B lists the daily maximum wind speed (x) and the corresponding value of the cumulative distribution function F(x) for the data sampled. Figure 4 shows a plot of the cumulative distribution function (F(x)) for all averaging periods considered in this analysis.

The cumulative distribution function and its plot can be used to estimate expected wind speeds. After F(x) is determined for a sample, Equation 5 can be inverted to give wind speeds occurring at any specified probability. This equation is

$$x(F) = \mu - \sigma \ln(-\ln F) \quad \text{(Eq. 8)}$$

The probability, p, can be substituted for F, and the estimated wind speed, x(F), can be written as $G_x(p)$ (Simiu and Scanlan, 1986). Therefore,

$$G_x(p) = \mu - \sigma \ln(-\ln p) \quad \text{(Eq. 9)}$$

A probability plot can be employed in predicting the extreme wind speeds. This plot shows the Type I distribution calculated from Equation 9, along with the actual data sampled. Also, a test for goodness of fit can be computed using the plotted values. This test shows how well the Type I distribution represents the actual wind speeds.

Figure 5 is the probability plot for the 5-minute averages. The line on the plot represents the expected values from the Type I distribution. The points are the measured wind speeds. The x axis is the exponential probability of occurrence, and the y axis is the maximum daily 5-minute wind speed in mph. This plot shows the Type I distribution provides a good fit for the extreme daily wind speeds.

Table B in Appendix B shows the calculations of the plotted values in Figure 5. The wind speed values (y axis) for the Type I distribution were calculated using Equation 9, where p is defined as

$$p = 1 - 1/N \qquad \text{(Eq. 10)}$$

where N is the mean recurrence interval. The values of the x-axis for the type I distribution are obtained from the expression

$$-\mathrm{Ln}\,[-\mathrm{Ln}(1-(\frac{1}{N})] \qquad \text{(Eq. 11)}$$

which is the exponential of Equation 9. The values of the x axis for the data points are the probability of occurrence of each measured wind speed, relative to all of the data. This value is calculated by sorting the measurements, then determining the percentile rank of each value. The percentile rank is the value of p. Equation 10 is used to convert p to N, which is then inserted into Equation 11 to yield the value for the x axis.

Figure 5 can be used to determine the goodness of fit of the Type I distribution to the data collected. The correlation coefficient, r_D, defined as

$$r_D = \frac{\Sigma(X_i-E(X))[M_i-E(M)]}{[\Sigma(X_i-E(X))^2\Sigma(M_i-E(M))^2]^{1/2}} \qquad \text{(Eq. 12)}$$

indicates the error between the Type I distribution and the actual measured wind speeds. If r_D is unity, then there are no errors. The closer r_D is to unity, the better the fit. Table 5 shows the probability plot correlation coefficient and the percentage of error calculated for each averaging period from Equation 12, where X_i is each measured maximum daily

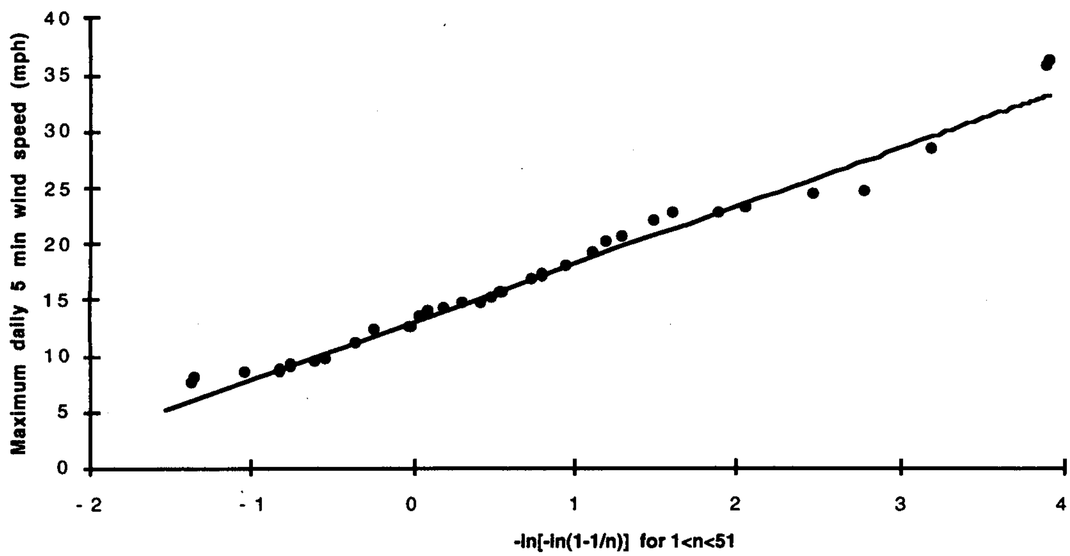

Figure 5. Probability Plot of Largest Daily 5-Minute Wind Speeds

wind speed, E(X) is the mean of X, M_i is the Type I distribution expected wind speed value that has the same probability as X_i, and E(M) is the mean of M_i. M_i was calculated using Equation 9 and p, as computed by the percentile rank of X_i described above. The calculations can be found in Table B.2.

Table 5 indicates that the use of the Type I distribution as the statistical representation of the behavior of local wind speeds is justified. It suggests that the Type I distribution can be used to predict accurately extreme wind speeds.

The prediction of extreme wind speeds by the Gumbel Type I distribution requires the use of Equation 9. The scale and location are computed as for Table 4, and the probability, p, remains. This is obtained from Equation 10, where N is selected as the recurrence interval of interest. Examples are given here to account for 1-year and 50-year storms.

Table 5. Probability Plot Correlation Coefficients

Averaging Period	r_D	**% Error**
5 Min.	0.9896	1.05
10 Min.	0.9915	0.85
15 Min.	0.9919	0.81
30 Min.	0.9901	0.99
60 Min.	0.9890	1.10

Using the definitions of α and μ given in Equations 6 and 7, the equation estimating wind speed (Equation 9) can be reduced to

$$V_N = E(X) + 0.78[1n(N)-0.5772]*SD(X) \qquad \text{(Eq. 13)}$$

where V_N is the estimated wind speed ($V_N = G_X(p)$). Following this method of calculating the wind speed, the standard deviation of the sampling errors in the estimation of V_N is approximately (Simiu and Scanlan, 1986)

$$SD(V_N) \approx 0.78[1.64+1.46(1n(N)-0.5772)+1.1(1n(N)-0.5772^2]^{1/2} \frac{*SD(X)}{n^{1/2}} \qquad \text{(Eq. 14)}$$

Equations 13 and 14 are preferred when estimating extreme wind speeds, as confidence intervals for V_N can easily be attained from $SD(V_N)$. The confidence intervals are computed as $V_N \pm SD(V_N)$ for 68 percent confidence, $V_N \pm 2SD(V_N)$ for 95 percent confidence, and $V_N \pm 3SD(V_N)$ for 99 percent confidence.

An example is presented for a 1-year storm. Table 6 shows the tabulated values for a 1-year storm for each averaging period. The value of N is 365 rather than 1, since the data are daily records instead of annual records. Equations 13 and 14 are used to calculate the estimated wind speed and standard deviation.

Table 6 shows the difference in calculated wind speed among the averaging periods. The maximum difference between the 5-minute and 60-minute estimates is 8.5 percent. This error level is considered reasonable, given the approximate nature of the analysis. The difference between the 5-minute and 15-minute average is 4.7 percent, which is on the order of the standard deviation of the estimated wind speed. The confidence intervals and the error levels associated with Table 6 are listed in Table 7.

A check of the data available can be obtained by using the 50-year storm prediction. Even though the prediction of the 50-year storm is based on only 51 days of observations, a comparison with known or code values can establish a reality check of the data.

Three steps must be followed to estimate the maximum 50-year wind speed and convert the value to a form used by codes. First, the 50-year wind speed is calculated from Equation 13 for the 5-minute average. This is the time interval recorded by the Weatherpak. Second, the 5-minute average, 50-year wind speed is converted to an hourly average. The 5-minute records are averaged in the last column of Table 2 to determine 60-minute averages. Rather than estimating the maximum 50-year, hourly wind speed using the parameters calculated for 60-minute averages, linear regression is used to develop a relationship between the two time intervals. This relationship may provide a useful reference for future studies. Finally, the hourly wind speed is converted to a fastest mile wind speed as explained in Simiu and Scanlan (1986). This method uses a plot of the ratio of probable maximum speed averaged over t seconds to hourly mean speed, based on experimental results. Each step described above will be discussed in the 50-year example.

The extreme value for a 50-year wind speed is calculated using Equation 13. The mean recurrence interval, N, is 365*50 = 18,250 days. The 50-year extreme wind speed based on the 5-minute averages in 63.4 mph ± 7.50 mph.

The method of least squares regression is used to find a relationship between the 5-minute and 60-minute (hourly) average wind speed. Using the recorded 5-minute data, and the 60-minute data computed by averaging the 5-minute data, an equation can be

Table 6. One Year Storm Wind Speeds

Average Period	Mean E(X)	Std Dev SD(X)	1 year wind vN (mph)	Std dev SD(vN)
5 Min.	16.049	6.5795	43.4	4.58
10 Min.	15.666	6.3263	41.9	4.40
15 Min.	15.411	6.2392	41.3	4.34
30 Min.	14.788	6.2324	40.7	4.34
60 Min.	14.036	6.1734	39.7	4.30

Table 7. Confidence Intervals for One Year Storm

Average Period	1 Yr Wind Speed (mph) vN	68% confidence SD(vN)	error level %	95% confidence 2SD(vN)	error level %	99% confidence 3SD(vN)	error level %
5 Min.	43.4	4.58	10.6	9.16	21.1	13.7	31.7
10 Min	41.9	4.40	10.5	8.80	21.0	13.2	31.5
15 Min.	41.3	4.34	10.5	8.68	21.0	13.0	31.5
30 Min.	40.7	4.34	10.7	8.68	21.3	13.0	32.0
60 Min.	39.7	4.30	10.8	8.60	21.7	12.9	32.5

developed to convert the averaging periods. The equation relating the different time intervals is in the linear form $y_{est} = a + bx$, where b is the slope of the line defined by

$$b = \frac{n\sum xy - (\sum x)(\sum y)}{n\sum x^2 - (\sum x)^2} \qquad \text{(Eq. 15)}$$

where n = 51 samples, x is the 5-minute average, and y is the 60-minute average. The intercept of the line is calculated by

$$a = \frac{\sum y}{n} - b\frac{\sum x}{n} \qquad \text{(Eq. 16)}$$

Table B in Appendix B shows the calculation of the equation relating the 5-minute average to the 60-minute average. This is

$$\mathbf{U_{60} = -0.8548 + 0.9278{*}U_5} \quad \text{(Eq. 17)}$$

where U_{60} and U_5 are in mph.

Figure 6 is a plot of 60-minute averages versus 5-minute averages. Equation 17 is plotted as the straight line which best fits these values.

Figure 7 uses the notation U_{3600} for hourly mean speeds (seconds), while this document uses the symbol U_{60} (minutes). However, the value for the hourly mean speed is the same.

The fastest mile wind speed, U_f, for an hourly wind of 58.0 mph is 73 mph. This value is determined by estimating the value for U_f and then working backwards using the following method. The averaging time in seconds is $3600/U_f$, which is 3600/73 = 49 seconds. From Figure 7, the value for U_f / U_{3600} is about 1.25 (for t = 49 seconds). Therefore, $U_f = 1.25{*}U_{3600}$, which is 1.25*58.0 = 7.25 ≅ 73 mph; thus the initial estimate is correct.

The fastest mile wind speed calculated from the data is in accordance with the code values prescribed for this area. The Uniform Building Code, 1991, gives minimum basic wind speeds in mph (fastest mile, 50-year storm) in Figure No. 23-1. The western edge of Lake Washington (Seattle) is an 80 mph region, and the eastern edge (Bellevue) is a 70 mph region. Although extrapolating a 50-year storm from 51 days of data is not a reliable method of analysis, the values obtained provide a useful check on the viability of the data available.

APPROPRIATE AVERAGING PERIOD

Fewer data would be presented if a longer time interval could be used, thus reducing the analysis time involved for future use. Also, a different averaging period might represent the behavior of local winds better than the 5-minute averages.

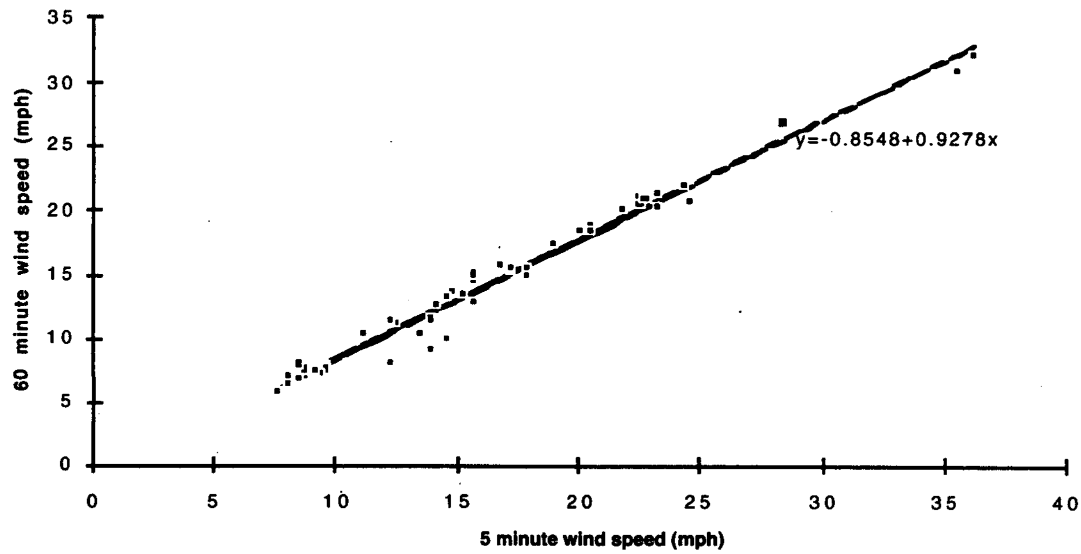

Figure 6. Least Squared Regression for Conversion of 5-Minute Average to 60-Minute Average Wind Speed

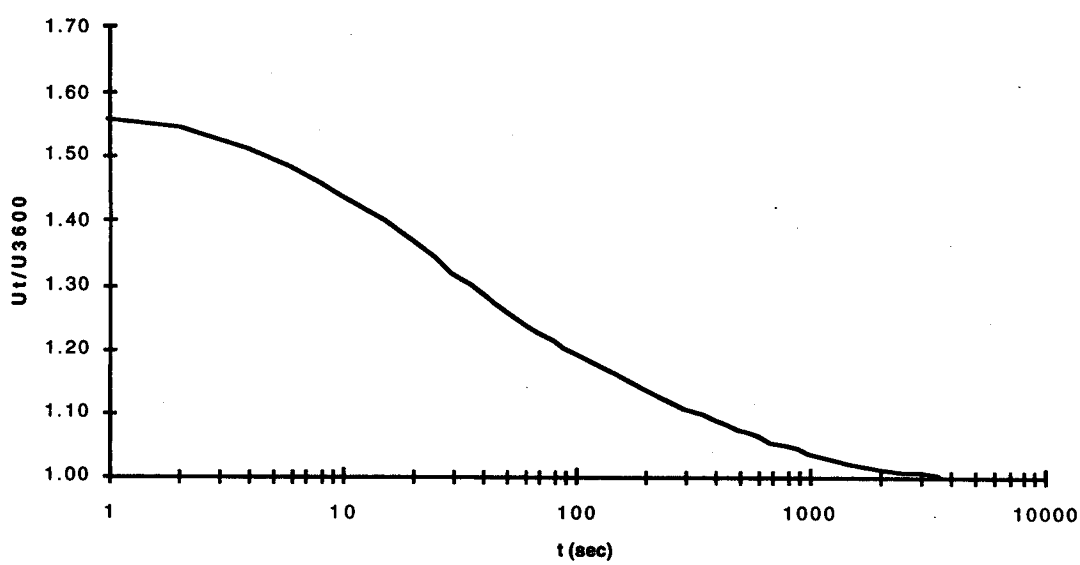

Figure 7. Ratio of Probable Maximum Speed Averaged over Period *t* to That Averaged Over One Hour (Simiu and Scanlan, 1983)

Two comparisons were used to assess the different time periods. First, the difference between each averaging period and the 5-minute average was computed. The total average of the 51 samples was used to compute the difference. Second, the probability plot correlation coefficient for each time interval was examined to determine which interval the Type I distribution best fit.

Table 8 lists the total average of the 51 maximum daily wind speeds. The difference between each averaging period and the 5-minute average is reported as a percentage of the 5-minute average.

The 10-, 15-, and 30-minute averages are all less than 10 percent different from the 5-minute average. The 60-minute average is 12.5 percent less than the 5-minute average. A time interval of this duration leads to less information about important events such as gusts. It is difficult to compare an hourly average with gusts on the order of a few seconds.

Table 5 provides the basis for optimizing the averaging period, given the objective of minimizing the error between the data available and the values computed by the Gumbel Type I distribution. The minimum error occurs after a 15-minute average wind speed period.

Thus an averaging period of 15 minutes will provide the analyst with accurate information. Fifteen-minute averages will reduce the number of daily records from 288 to 96. Also, the mean of the 15-minute averages collected in the 51 samples varies from the 5-minute averages by only 4 percent.

Equations are provided to convert the 15-minute average to a 5-minute and an hourly average for future reference. These relationships were determined by least square regression, as used to convert the 5-minute average to an hourly average. Equations 15 and 16 calculate the slope and the intercept of the lines defining the following

Table 8. Average Maximum Daily Wind Speed for 51 Samples in Miles Per Hour

	5 Min.	10 Min.	15 Min.	30 Min.	60 Min.
Average	16.049	15.666	15.411	14.788	14.036
Std Dev	6.5795	6.3263	6.2392	6.2324	6.1734
% Diff 5 Min.		2.39	3.98	7.86	12.54

relationships. The equation to convert a 15-minute average to a 5-minute average is

$$\mathbf{U_5 = -0.1537 + 1.0514 * U_{15}} \quad \text{(Eq. 18)}$$

To convert a 15-minute average to a 60-minute average the equation is

$$\mathbf{U_{60} = -1.1169 + 0.9833 * U_{15}} \quad \text{(Eq. 19)}$$

Calculations are in Tables B.4 and B.5 in Appendix B. The regression plots for Equations 18 and 19 are in Figure B.1, also in Appendix B.

MAXIMUM GUSTS

An examination was made to determine whether an invariant relationship between gust values and other descriptors of the wind existed. In this way the character of the wind behavior might be understood.

The Weatherpak recorded the largest 5-second gust occurring during each 5-minute sampling interval. The 5-second average was a running average replaced each time the current stored value was exceeded. The Weatherpak automatically gave the value of the maximum gust and the time it occurred in the output file. See Table 1 for an example output file.

The data used in the analysis were recorded by the Weatherpak. The thrust was to compare the gust speed with average wind speeds.

Two figures are presented below, illustrating the maximum gust plotted against the average wind speed. The ordinate is nondimensionalized by dividing the maximum gust for each 5-minute sample by the corresponding average of that same sample. The abscissa is the 5-minute average wind speed in miles per hour.

Figure 8 plots the normalized maximum gust versus average wind speed for the first ten days of record. The Weatherpak was located on the control tower next to the WSDOT rotator cup anemometer for these measurements. Each five-minute sample is represented as a point on the plot. Figure 9 is the same plot, except the Weatherpak was moved to another structure on the bridge. The data plotted are the remaining 41 days of measurements taken on this structure. The plots are separated to examine any difference in the gust values due to instrument location.

Figures 8 and 9 show the phenomenon that the maximum 5-second gust normalized by the average 5-minute wind speed (gust factor) occurring in each 5-minute sample is invariant at different wind speeds. The gust factor converges to about 1.4. This value is slightly less than the recommended value of 1.54 (Exposure D, H = 30 feet) by the Uniform Building Code's combined height, exposure, and gust factor coefficient (C_e) in Table No. 23-G (3) (Uniform Building code, 1991). The two plots converge to the same value, indicating that the gust factor is not dependent on instrument location along the bridge, but is a function of the driving force of the local winds.

The gust factor is not constant in the range of low wind speeds. Heat and other mechanical properties such as objects distorting the flow cause more mixing to occur at low speeds. Thus, the wind system is less organized and may not display an invariant trend in the gust factor. The invariant gust factor found suggests that the driving force of the local winds is an organized system that is log normally distributed. Figures 8 and 9 show that the maximum gust value (max) divided by the average value (mean) is constant for increasing wind speeds. The log (max/mean), which is log(max)-log(mean), is also

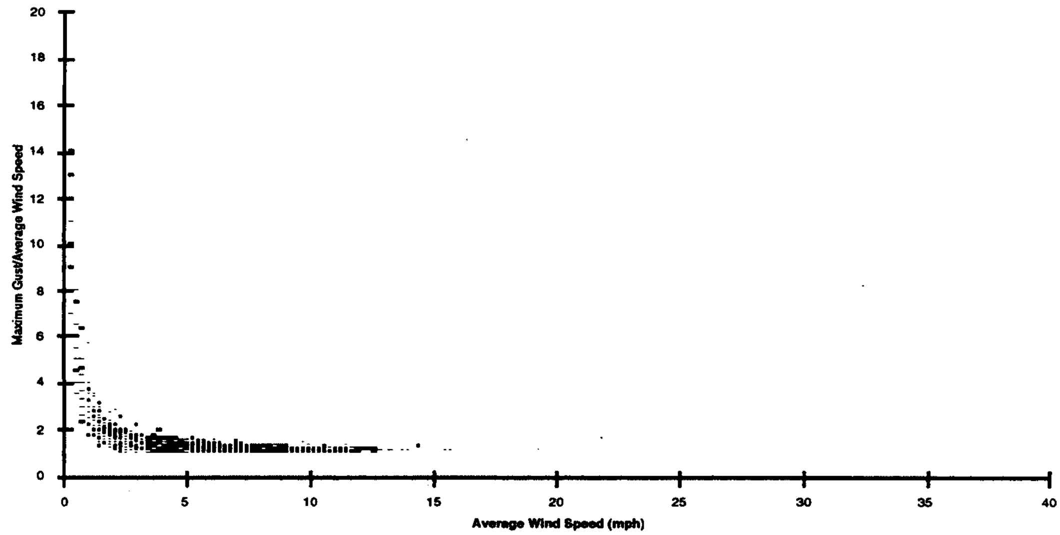

Figure 8. Normalized Maximum Gust vs. Average Wind Speed for Weatherpak on the Control Tower

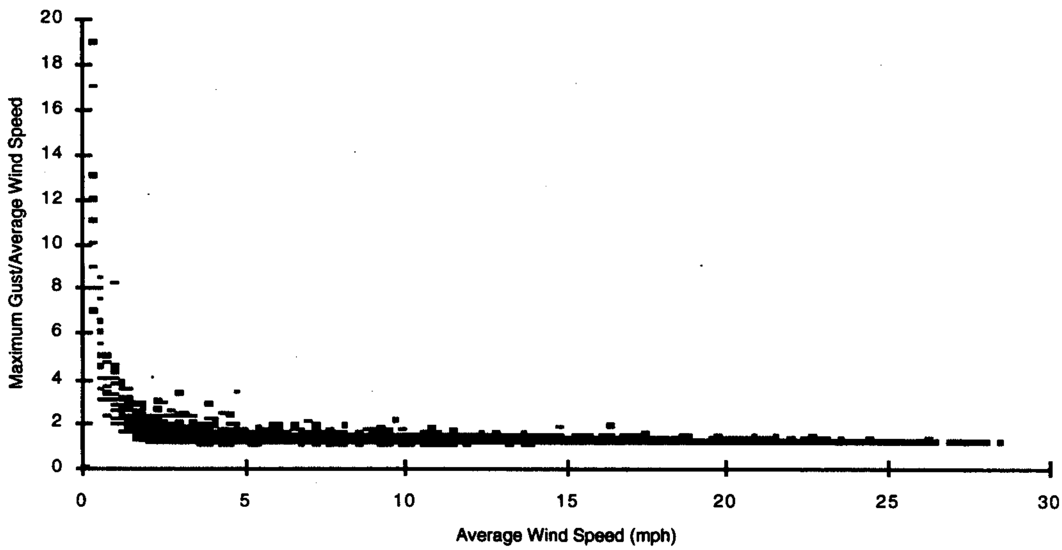

Figure 9. Normalized Maximum Gust vs. Average Wind Speed for the Weatherpak on the Bridge Structure

constant. For a typical distribution, the difference between the maximum value and the mean (max/mean) is a multiple of the standard deviation. In this case, for the log of the distribution, the standard deviation is constant, therefore, independent of the mean. If the geometric standard deviation is independent of the geometric mean, then the distribution is log normal. Therefore, the data indicate that the driving forces causing the winds over Lake Washington may be log normally distributed.

INTERPRETATION, APPRAISAL AND APPLICATION

The availability of the Weatherpak instrument will allow the WSDOT to collect wind data at various locations on all of the floating bridges. The protocol described can be applied to each of these situations. At the same time, the validity of measurements by the existing fixed instruments on each of these bridges can be ascertained by the same methodology reported here. The long-term data from these established instruments can be important, but clear evidence of the competency of these data has to be obtained. The instrument on the Evergreen Point Bridge has been shown to understate wind speeds by more than 20 percent, but its location on the top of the control tower results in an amplification of those speeds by about 20 percent in comparison to wind speeds away from the tower. Thus, the measurements over 20 years have been an accurate statement of the wind speeds at the bridge away from the tower. A possible reason for these differences is that the same unit length air mass passes in a given time at each location, but the tower reduces the vertical dimension of flow at that location, which requires a consequent increase in speed.

The data generated by the Weatherpak were shown to subscribe to a Gumbel Type I Extreme Value distribution. The confidence in this distribution allows the prediction of the return period of extreme winds. The available data only allow initial determination of the distribution parameters. Therefore, although confidence in the distribution form exists, more wind speed measurements will be necessary to have a similar confidence in the calculated parameters.

The frequency of data averaging is an important number in determining the time necessary to conduct analyses. The temptation is to use the shortest period available, yet the use of a longer period may involve less error and little loss of information. The study of this topic suggests that a 15-minute averaging period of the wind speed measurements on the Evergreen Point Bridge provides minimum error with respect to the Type I distribution and complete information for subsequent analyses. The same methodology for determining optimum averaging periods can be adopted at other sites.

One surprising result from the wind speed measurements was the invariance of the 5-second gust as a proportion of the 5-minute wind speed average containing the gust. There is no evidence to suggest that the same invariance occurs at other locations. However, if it does occur, then a definite statement can be made about the wind field, namely, that the average wind speed and the 5-minute gust are log normally distributed with the same standard deviation. If this is the case at any site, then focused measurements can completely describe the wind field.

RECOMMENDATIONS

Determining the effects of wind at the floating bridges requires that the following be accomplished:

1) The validity of the measurements of the existing, fixed anemometers must be confirmed.

2) The effect of location of these existing anemometers must be determined.

3) If confirmed, these existing measurements must be extended, by using adjacent wind measurements of longer history. For instance, the Sand Point Air Station had data going back much farther in time than the Evergreen Point Floating measurements. A correlation between these wind measurements would give an extended data stream for the bridge.

4) Continuing measurements must be taken at the Evergreen Point Bridge to determine accurately the parameters of the Type I distribution. Testing at other bridges would determine the applicability of that distribution at other locations.

5) The invariance of the gust: average wind speed ratio must be confirmed at the Evergreen Point Bridge and calculated for all sites to ascertain the wind field distributions.

These recommendations concern the wind environments at floating bridges. Certainly winds on the free board are important load sources. However, to a large extent the wind measurements are being used as a surrogate for wave forces. Therefore, additional recommendations are:

6) The wind-wave-force relationships should be explored by site measurements and by model tests in a wind generated wave tank.

7) The critical wave states from a safety viewpoint on floating bridges should be determined by wave tank tests on bridge models.

IMPLEMENTATION

The results analyzed in this study were based on limited data. However, the protocol employed and described here for the use of the Weatherpak and the subsequent analysis of the results are applicable elsewhere. Continuing collection and analysis of measurements at the Evergreen Point Floating Bridge will allow the return period wind speeds to be accurately deduced and the gust average speed ratio invariance to be confirmed. The Weatherpak can be used at other locations to address the same issues raised with respect to the Evergreen Point Floating Bridge.

MAKING USE OF KNOWLEDGE

The two main conclusions of this study on wind speeds at the Evergreen Point Bridge are

1. that the existing wind records at the tower location represent well the wind speeds in the tower vicinity, and

2. that an invariance of the gust to average wind speed ratios exists.

The first conclusion means that existing records can be incorporated into future discussions about changes to the bridge and can form the basis for the wind design record for new adjacent floating bridges. The second conclusion provides an understanding of gusting even when only long-term wind speed averages are available. This is of particular value when only a continuous record (as at the Evergreen Point Bridge) exists; under that circumstance, long-term averages are accurate, but gust speeds can only be obtained by estimation. The second conclusion allows a sharp statement to be made on the gust speeds.

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APPENDIX A

WEATHERPAK-100 INFORMATION

APPENDIX A

WEATHERPAK INFORMATION

All of the information provided in Appendix A is from the Weatherpak User Guide

System Description:

The Weatherpak is a stand-alone, intelligent automatic weather station. Every consideration has been given to make the Weatherpak the finest such device in the world.

The Weatherpak is designed to be completely automatic. When power is applied, if no terminal intervention occurs, the system will automatically initialize itself and begin sampling according to its predetermined schedule.

The Weatherpak has a hardware clock accurate to about 5 secs per day and an EEPROM portion of memory where sampling variables and system parameters are stored. Data are time marked with date/time.

All transient protection sensor signals and power lines are protected from transients and EMI by circuitry inside the Weatherpak. EMI filters are single pole RC filters (100 ohm and 0.1 microfarads). Transient protection is by 18 volt tranzorb diodes.

If for any reason--lightning, RF interference, power surge---the computer program is corrupted and the sampling loop is broken, then a watchdog timer will reset the entire system and the Weatherpak will go into its autoboot routine.

Wind Measurements

The winds are measured with an R.M. Young Model 05103 wind monitor which has become a standard for remote weather stations of high quality. The aerovane-style sensor has an AC motor output for wind speed, whereby the frequency is proportional to speed, and a potentiometer output for vane direction.

During its averaging period, Weatherpak samples the wind speed and vane each second except for one second at the end of each block. The vane measurement is added to the compass value (optional), then corrected for alignment, and orthogonal vector components are computed. Unit vector components, velocity vector components, and the average speed are accumulated during the sample period. At the end of the sample, a suite of wind statistics are computed.

Compass

The compass used in the Weatherpak is the Navico m/n HS8000. It is an electronic, gimballed flux-gate compass. The compass has a digital pulse steam output which the Weatherpak converts to degrees. The converted heading is corrected by a special calibration equation for offset, local variation and local disturbances. The compass is read during the first second of every block.

Air Temperature

The temperature element in the sensor is the Yellow Springs Instrument (YSI) Model 44203 thermistor. The Thermolinear Thermistor Network is a composite device consisting of resistors and a precise thermistor which produces an output voltage linear with temperature.

Temperature measurements are taken at the end of each block and averages are computed at the end of the averaging period.

APPENDIX B

CALCULATIONS

Table B.1. Cumulative Distribution Function Calculations

Cum. Dist. Calcs.

sigma = SD(x)*sqrt(6)/pi   mu = mean(x)-0.5772*sigma

Average Period	Mean	Std Dev	sigma	mu
5 minutes	16.049	6.5795	5.1300151	13.087955
10 minutes	15.666	6.3263	4.9325959	12.818906
15 minutes	15.411	6.2392	4.8646843	12.603104
30 minutes	14.788	6.2324	4.8593823	11.983165
60 minutes	14.036	6.1734	4.8133802	11.257717

x = specified wind speed
F(x) = cumulative distribution function

F(x) = exp{-exp[-(x-mu)/sigma]}

5 minute		10 minute		15 minute		30 minute		60 minute	
x	F(x)	x	F(x)	x	F(x)	x	F(x)	x	F(x)
15.659	0.5456283	14.988	0.5250828	15.667	0.5870264	14.242	0.5335323	12.732	0.4789428
12.304	0.3118877	12.304	0.3295486	12.229	0.3396172	11.632	0.3413181	11.26	0.3680539
8.7243	0.0962236	8.7243	0.1009051	8.426	0.0944208	7.9414	0.1005276	7.5312	0.1143084
11.185	0.2347806	11.185	0.2484029	10.812	0.2357203	10.365	0.2477972	10.048	0.2764497
11.185	0.2347806	11.073	0.2405836	10.961	0.2462228	10.775	0.2774093	10.346	0.298633
8.5006	0.0866893	8.5006	0.0907192	8.5006	0.0978735	8.2769	0.1171777	7.96	0.1375182
8.0532	0.069372	7.8295	0.0639426	7.6804	0.0638706	7.233	0.0700975	6.3755	0.0634543
9.6191	0.1399643	9.5073	0.1412929	9.1717	0.1320471	8.5752	0.1331332	7.7549	0.1261397
12.527	0.3277349	12.192	0.3212536	11.931	0.3172202	11.483	0.330083	11.222	0.3651497
9.6191	0.1399643	9.3954	0.135089	9.0971	0.1279798	8.3888	0.1230389	7.7922	0.1281718
16.778	0.6144113	16.33	0.6121654	16.106	0.6146392	15.845	0.6365394	15.659	0.6698088
24.607	0.8995299	23.824	0.8981568	23.19	0.892737	21.587	0.8705986	20.692	0.8686137
23.265	0.8714975	23.041	0.8817128	22.668	0.8813367	22.184	0.8846582	20.189	0.8552402
21.923	0.8363835	20.916	0.8239216	20.506	0.8211895	20.319	0.8353622	20.003	0.8499874
17.896	0.6759013	17.001	0.6515928	16.703	0.6501782	15.584	0.6208699	14.951	0.6285956
17.896	0.6759013	17.784	0.6938749	17.747	0.7065514	16.666	0.6828428	15.622	0.6677406
22.594	0.8549073	21.811	0.8508314	21.475	0.8509332	21.363	0.8649258	21.028	0.8769025
28.41	0.9508001	28.186	0.9566095	28.112	0.9595874	27.329	0.9583794	26.769	0.9609298
20.58	0.7928385	20.245	0.800993	20.282	0.8136015	19.909	0.8222372	18.772	0.8106653
14.541	0.4707933	13.31	0.404447	12.751	0.379062	11.073	0.2993956	9.97	0.2707035
15.659	0.5456283	15.435	0.5552216	15.212	0.5571546	14.69	0.5638841	14.578	0.6055156
15.659	0.5456283	15.659	0.5699164	15.584	0.58167	15.398	0.6094299	14.951	0.6285956
14.764	0.4861245	14.652	0.5017716	14.391	0.5003509	14.019	0.5180221	13.534	0.5362323
22.594	0.8549073	21.923	0.8539226	21.773	0.8591342	21.512	0.8687242	20.413	0.861343
17.225	0.639899	17.225	0.6641024	16.927	0.6628975	16.144	0.6539314	15.323	0.6506796
20.58	0.7928385	20.245	0.800993	19.909	0.8003359	19.238	0.7987496	18.493	0.8005742
24.383	0.895289	23.936	0.9003252	23.638	0.9016933	22.78	0.8972614	21.829	0.8947402
23.265	0.8714975	23.041	0.8817128	22.892	0.8863609	22.072	0.8821339	21.289	0.8830033
17.225	0.639899	16.666	0.6322713	16.479	0.6371211	16.218	0.6581426	15.603	0.6666749
12.304	0.3118877	11.968	0.3047451	11.707	0.3005132	11.371	0.3216618	11.166	0.3608701
12.304	0.3118877	12.192	0.3212536	11.931	0.3172202	11.558	0.3357343	11.39	0.3779884
9.1717	0.1170026	9.1717	0.1231075	8.8734	0.1161783	8.5752	0.1331332	7.6617	0.1211357
13.422	0.3918175	13.422	0.4127505	12.9	0.3903177	12.304	0.3921509	10.439	0.3056197
13.869	0.4236814	13.198	0.3961255	13.347	0.4239243	12.602	0.414606	11.502	0.3865417
8.0532	0.069372	7.9414	0.0680106	7.8295	0.0694005	7.4194	0.0774714	7.1211	0.0942559
12.304	0.3118877	11.856	0.2965411	11.483	0.2839613	9.9547	0.2191368	8.1651	0.1493839
9.6191	0.1399643	9.5073	0.1412929	9.3954	0.1446259	9.209	0.1703605	7.5685	0.1162382
22.817	0.8606272	22.258	0.8628228	22.072	0.8669455	21.923	0.878696	20.935	0.8746581
20.133	0.7762582	19.686	0.7799455	19.462	0.7833632	18.865	0.7845575	18.474	0.7998702
35.568	0.9875782	33.219	0.9841369	32.437	0.9831867	31.803	0.9832126	30.871	0.983147
36.239	0.9890929	35.233	0.9894263	34.152	0.9881522	33.518	0.988175	32.138	0.9870219
14.093	0.4395154	13.981	0.4537991	13.72	0.4516457	13.124	0.4535032	12.62	0.470714
13.869	0.4236814	12.415	0.33779	11.632	0.294952	9.5445	0.1917105	9.0785	0.2075013
19.015	0.729831	18.455	0.726889	18.045	0.7212861	17.672	0.7333351	17.355	0.7544625
15.212	0.5163488	14.988	0.5250828	14.69	0.5214368	13.907	0.5101384	13.441	0.5297524
9.3954	0.1282196	9.1717	0.1231075	9.0226	0.1239831	8.426	0.1250207	7.233	0.0995127
8.5006	0.0866893	8.3888	0.0858628	8.3515	0.0910439	7.7922	0.0935787	6.8042	0.0802615
14.093	0.4395154	13.981	0.4537991	13.869	0.4626054	13.198	0.4589553	12.639	0.4721133
14.541	0.4707933	14.541	0.493958	14.391	0.5003509	13.981	0.5153541	13.291	0.5192049
9.1717	0.1170026	8.8362	0.1062321	8.5752	0.1013971	8:1278	0.1096053	7.3821	0.1067688
7.6058	0.0543981	7.6058	0.0562839	7.233	0.0490021	6.45	0.0440439	5.8908	0.0473794

Table B.2. Probability Plot Calculations

5 Min Probability Distribution Calcs

mu = mean(x)-0.5772*sigma
sigma = SD(x)*sqrt(6)/pi

Average Period	Mean	Std Dev	sigma	mu	n
5 minutes	16.049	6.5795	5.1300151	13.087955	51

x = exponential probability = -ln(-ln(1-1/N)) or -ln(-ln(p))
N = recurrence interval, p = probability of recurrence
y = maximum daily 5 minute wind speed
n = sample size

-ln(-ln(1-1/N)) mu+x*sigma   -ln(-ln(p)) sorted data   M(D) = 15.85679

Xavg = 16.04943
% error 1.04476
rD = 0.98955

5 min daily max wind speed mph	N recurrence year	Type I Plot daily x prob	y est speed	p percentile of y	Recorded Vals. x prob fcn from p	y measured speed	correlation coeff Xi	Mi(D)	Top	Bottom1	Bottom2
15.66	1.01	-1.53	5.24	0.02	-1.37	7.61	7.61	6.06	82.68	71.29	95.89
12.30	2.00	0.37	14.97	0.02	-1.36	8.05	8.05	6.09	78.09	63.94	95.38
8.72	3.00	0.90	17.72	0.02	-1.36	8.05	8.05	6.09	78.09	63.94	95.38
11.19	4.00	1.25	19.48	0.06	-1.03	8.50	8.50	7.78	60.96	56.98	65.21
11.19	5.00	1.50	20.78	0.06	-1.03	8.50	8.50	7.78	60.96	56.98	65.21
8.50	6.00	1.70	21.82	0.10	-0.83	8.72	8.72	8.81	51.62	53.66	49.67
8.05	7.00	1.87	22.68	0.12	-0.75	9.17	9.17	9.23	45.56	47.30	43.88
9.62	8.00	2.01	23.42	0.12	-0.75	9.17	9.17	9.23	45.56	47.30	43.88
12.53	9.00	2.14	24.06	0.16	-0.61	9.40	9.40	9.98	39.10	44.28	34.53
9.62	10.00	2.25	24.63	0.18	-0.54	9.62	9.62	10.32	35.59	41.35	30.64
16.78	11.00	2.35	25.15	0.18	-0.54	9.62	9.62	10.32	35.59	41.35	30.64
24.61	12.00	2.44	25.61	0.18	-0.54	9.62	9.62	10.32	35.59	41.35	30.64
23.27	13.00	2.53	26.04	0.24	-0.36	11.19	11.19	11.26	22.34	23.66	21.10
21.92	14.00	2.60	26.44	0.24	-0.36	11.19	11.19	11.26	22.34	23.66	21.10
17.90	15.00	2.67	26.80	0.28	-0.24	12.30	12.30	11.85	15.01	14.03	16.06
17.90	16.00	2.74	27.15	0.28	-0.24	12.30	12.30	11.85	15.01	14.03	16.06
22.59	17.00	2.80	27.47	0.28	-0.24	12.30	12.30	11.85	15.01	14.03	16.06
28.41	18.00	2.86	27.77	0.28	-0.24	12.30	12.30	11.85	15.01	14.03	16.06
20.58	19.00	2.92	28.05	0.36	-0.02	12.53	12.53	12.98	10.14	12.41	8.29
14.54	20.00	2.97	28.33	0.38	0.03	13.42	13.42	13.26	6.83	6.90	6.76
15.66	21.00	3.02	28.58	0.40	0.09	13.87	13.87	13.54	5.06	4.75	5.38
15.66	22.00	3.07	28.83	0.40	0.09	13.87	13.87	13.54	5.06	4.75	5.38
14.76	23.00	3.11	29.06	0.44	0.20	14.09	14.09	14.10	3.44	3.83	3.09
22.59	24.00	3.16	29.28	0.44	0.20	14.09	14.09	14.10	3.44	3.83	3.09
17.23	25.00	3.20	29.50	0.48	0.31	14.54	14.54	14.67	1.78	2.28	1.40
20.58	26.00	3.24	29.70	0.48	0.31	14.54	14.54	14.67	1.78	2.28	1.40
24.38	27.00	3.28	29.90	0.52	0.42	14.76	14.76	15.27	0.76	1.65	0.35
23.27	28.00	3.31	30.09	0.54	0.48	15.21	15.21	15.57	0.24	0.70	0.08
17.23	29.00	3.35	30.27	0.56	0.55	15.66	15.66	15.88	-0.01	0.15	0.00
12.30	30.00	3.38	30.45	0.56	0.55	15.66	15.66	15.88	-0.01	0.15	0.00
12.30	31.00	3.42	30.62	0.56	0.55	15.66	15.66	15.88	-0.01	0.15	0.00
9.17	32.00	3.45	30.79	0.62	0.74	16.78	16.78	16.87	0.74	0.53	1.04
13.42	33.00	3.48	30.95	0.64	0.81	17.23	17.23	17.23	1.61	1.38	1.88
13.87	34.00	3.51	31.10	0.64	0.81	17.23	17.23	17.23	1.61	1.38	1.88
8.05	35.00	3.54	31.25	0.68	0.95	17.90	17.90	17.98	3.91	3.41	4.49
12.30	36.00	3.57	31.40	0.68	0.95	17.90	17.90	17.98	3.91	3.41	4.49
9.62	37.00	3.60	31.54	0.72	1.11	19.02	19.02	18.80	8.72	8.79	8.65
22.82	38.00	3.62	31.68	0.74	1.20	20.13	20.13	19.25	13.84	16.68	11.48
20.13	39.00	3.65	31.82	0.76	1.29	20.58	20.58	19.72	17.51	20.53	14.93
35.57	40.00	3.68	31.95	0.76	1.29	20.58	20.58	19.72	17.51	20.53	14.93
36.24	41.00	3.70	32.08	0.80	1.50	21.92	21.92	20.78	28.93	34.50	24.26
14.09	42.00	3.73	32.20	0.82	1.62	22.59	22.59	21.38	36.18	42.83	30.55
13.87	43.00	3.75	32.32	0.82	1.62	22.59	22.59	21.38	36.18	42.83	30.55
19.02	44.00	3.77	32.44	0.86	1.89	22.82	22.82	22.79	46.94	45.80	48.10
15.21	45.00	3.80	32.56	0.88	2.06	23.27	23.27	23.64	56.16	52.06	60.59
9.40	46.00	3.82	32.67	0.88	2.06	23.27	23.27	23.64	56.16	52.06	60.59
8.50	47.00	3.84	32.78	0.92	2.48	24.38	24.38	25.83	83.13	69.45	99.52
14.09	48.00	3.86	32.89	0.94	2.78	24.61	24.61	27.36	98.46	73.23	132.39
14.54	49.00	3.88	33.00	0.96	3.20	28.41	28.41	29.50	168.59	152.78	186.04
9.17	50.00	3.90	33.10	0.98	3.90	35.57	35.57	33.10	336.66	380.97	297.50
7.61	51.00	3.92	33.21	0.98	3.92	36.24	36.24	33.21	350.30	407.62	301.05
								S =	2159.704	2207.791	2157.51
								rD =	0.989552		

Table B.3. Conversion of 5 Min. Avg. to 60 Min. Avg.

Linear Regression

x	y	y hat
5 min	**60 min**	**60 min est**
15.66	12.73	13.67
12.30	11.26	10.56
8.72	7.53	7.24
11.19	10.05	9.52
11.19	10.35	9.52
8.50	7.96	7.03
8.05	6.38	6.62
9.62	7.75	8.07
12.53	11.22	10.77
9.62	7.79	8.07
16.78	15.66	14.71
24.61	20.69	21.98
23.27	20.19	20.73
21.92	20.00	19.49
17.90	14.95	15.75
17.90	15.62	15.75
22.59	21.03	20.11
28.41	26.77	25.50
20.58	18.77	18.24
14.54	9.97	12.64
15.66	14.58	13.67
15.66	14.95	13.67
14.76	13.53	12.84
22.59	20.41	20.11
17.23	15.32	15.13
20.58	18.49	18.24
24.38	21.83	21.77
23.27	21.29	20.73
17.23	15.60	15.13
12.30	11.17	10.56
12.30	11.39	10.56
9.17	7.66	7.66
13.42	10.44	11.60
13.87	11.50	12.01
8.05	7.12	6.62
12.30	8.17	10.56
9.62	7.57	8.07
22.82	20.94	20.32
20.13	18.47	17.83
35.57	30.87	32.15
36.24	32.14	32.77
14.09	12.62	12.22
13.87	9.08	12.01
19.02	17.36	16.79
15.21	13.44	13.26
9.40	7.23	7.86
8.50	6.80	7.03
14.09	12.64	12.22
14.54	13.29	12.64
9.17	7.38	7.66
7.61	5.89	6.20

n =	51	
b =	**0.927831**	**SLOPE**
a =	**-0.85477**	**INTERCEPT**
mean x =	16.04943	
mean y =	14.03639	
SD(x) =	6.644984	
SD(y) =	6.234872	
r =	**0.988861**	**Corr. Coeff.**
SD(YX) =	**0.937413**	**Std. Error of Reg.**

b = [n*sum(x*y)-sum(x)*sum(y)] / [n*sum(x^2)-(sum(x))^2]

a = mean(y)-b*mean(x)

r = [sum(x*y)-1/n*sum(x)*sum(y)] / [(n-1)*SD(x)*SD(y)]

Table B.4. Conversion of 15 Min. Avg. to 5 Min. Avg.

Linear Regression

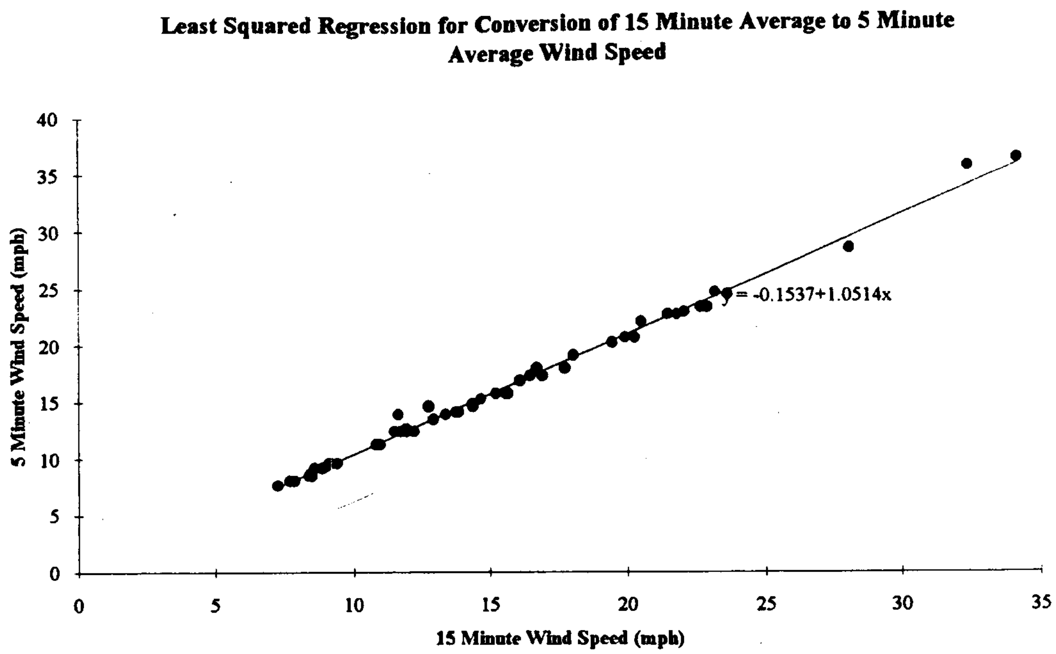
x	y	y est
15 min	**5 min**	**5 min est**
15.67	15.66	16.32
12.23	12.30	12.70
8.43	8.72	8.71
10.81	11.19	11.21
10.96	11.19	11.37
8.50	8.50	8.78
7.68	8.05	7.92
9.17	9.62	9.49
11.93	12.53	12.39
9.10	9.62	9.41
16.11	16.78	16.78
23.19	24.61	24.23
22.67	23.27	23.68
20.51	21.92	21.41
16.70	17.90	17.41
17.75	17.90	18.51
21.48	22.59	22.43
28.11	28.41	29.40
20.28	20.58	21.17
12.75	14.54	13.25
15.21	15.66	15.84
15.58	15.66	16.23
14.39	14.76	14.98
21.77	22.59	22.74
16.93	17.23	17.64
19.91	20.58	20.78
23.64	24.38	24.70
22.89	23.27	23.92
16.48	17.23	17.17
11.71	12.30	12.16
11.93	12.30	12.39
8.87	9.17	9.18
12.90	13.42	13.41
13.35	13.87	13.88
7.83	8.05	8.08
11.48	12.30	11.92
9.40	9.62	9.72
22.07	22.82	23.05
19.46	20.13	20.31
32.44	35.57	33.95
34.15	36.24	35.75
13.72	14.09	14.27
11.63	13.87	12.08
18.05	19.02	18.82
14.69	15.21	15.29
9.02	9.40	9.33
8.35	8.50	8.63
13.87	14.09	14.43
14.39	14.54	14.98
8.58	9.17	8.86
7.23	7.61	7.45

n =	51	
b =	**1.0514**	**Slope**
a =	**-0.1537**	**Intercept**
mean x =	15.4106	
mean y =	16.0494	
SD(x) =	6.2392	
SD (y) =	6.5795	
r =	**0.9970**	**Corr. Coeff.**
SD(yx) =	**0.5161**	**Std. Error of Reg.**

Table B.5. Conversion of 15 Min. Avg.

Linear Regression		
x	y	y est
15 min	60 min	60 min est
15.67	12.73	14.29
12.23	11.26	10.91
8.43	7.53	7.17
10.81	10.05	9.51
10.96	10.35	9.66
8.50	7.96	7.24
7.68	6.38	6.44
9.17	7.75	7.90
11.93	11.22	10.61
9.10	7.79	7.83
16.11	15.66	14.72
23.19	20.69	21.69
22.67	20.19	21.17
20.51	20.00	19.05
16.70	14.95	15.31
17.75	15.62	16.33
21.48	21.03	20.00
28.11	26.77	26.53
20.28	18.77	18.83
12.75	9.97	11.42
15.21	14.58	13.84
15.58	14.95	14.21
14.39	13.53	13.03
21.77	20.41	20.29
16.93	15.32	15.53
19.91	18.49	18.46
23.64	21.83	22.13
22.89	21.29	21.39
16.48	15.60	15.09
11.71	11.17	10.39
11.93	11.39	10.61
8.87	7.66	7.61
12.90	10.44	11.57
13.35	11.50	12.01
7.83	7.12	6.58
11.48	8.17	10.17
9.40	7.57	8.12
22.07	20.94	20.59
19.46	18.47	18.02
32.44	30.87	30.78
34.15	32.14	32.46
13.72	12.62	12.37
11.63	9.08	10.32
18.05	17.36	16.63
14.69	13.44	13.33
9.02	7.23	7.76
8.35	6.80	7.10
13.87	12.64	12.52
14.39	13.29	13.03
8.58	7.38	7.32
7.23	5.89	6.00

n =	51	
b =	0.9833	Slope
a =	-1.1169	Intercept
mean x =	15.4106	
mean y =	14.0364	
SD(x) =	6.2392	
SD (y) =	6.1734	
r =	0.9938	Corr. Coeff.
SD(yx) =	0.7017	Std Error of Reg.



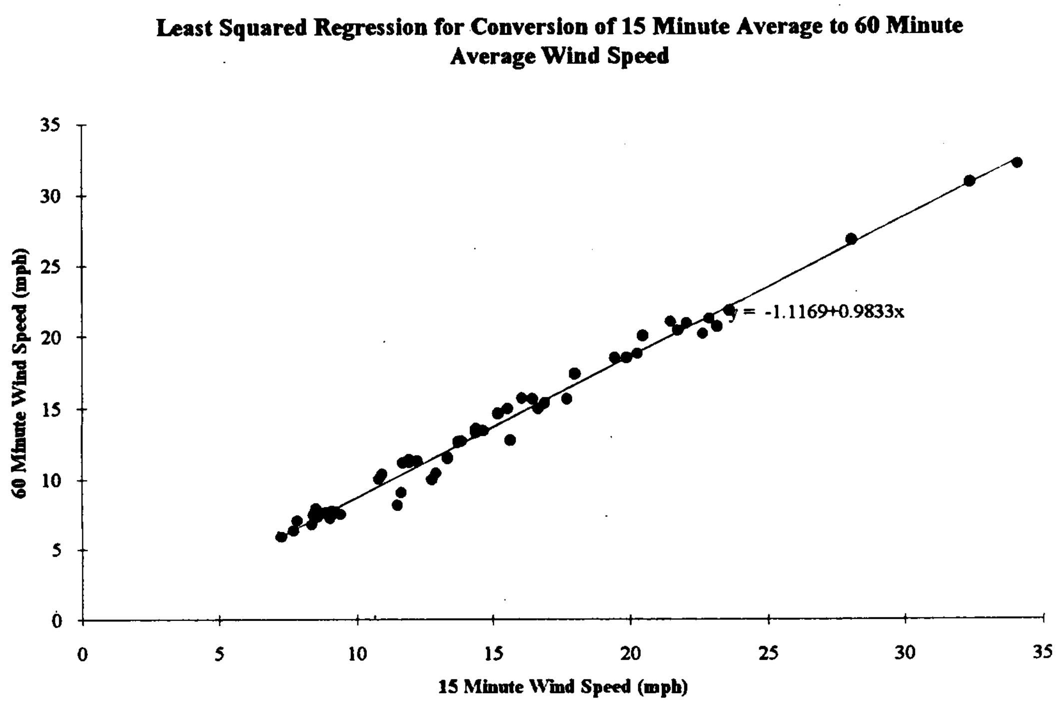


Figure B.1. Linear Regression Plots