WIND STUDY AT HILL ANNEX MINE

for

Iron Range Resources and Rehabilitation Mineland Reclamation

by

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ACKNOWLEDGMENTS

The author of this report wishes to acknowledge the contributions made to this project by Dan Dodge and John Hawkinson, research assistants in electronics and data reduction.

INTRODUCTION

A program was undertaken to monitor the wind speed and direction during the months October through December, 1980-81, in northeastern Minnesota at the Hill Annex Mine near Calumet, to obtain new information about the wind profile in this area. This work was done for the Iron Range Resources and Rehabilitation Mineland Reclamation Agency, under Contract No. 0189.

The instruments were installed at two sites near the mine, where each had good exposure to the surface winds. The approximate location of the instruments is shown in Fig. 1, a section copy of a Jones and Laughlin Steel Corporation general surface map of the Hill Annex Mine vicinity.

INSTRUMENTATION AND DATA REDUCTION

One of the two sites selected by IRRRMR near the Hill Annex Mine is on a water tower at 585 feet above mean sea level, and the other site is on the roof of a shed at the crest of a hill about 2600 feet east of the water tank, at about 976 feet above mean sea level. Beckman-Whitney model M1564B wind speed and model M156B wind direction sensors were mounted on a supporting aluminum pipe, two inches in diameter, which extends above the supporting structures, as shown in Figure 2. One multiple conductor cable with coax shields on the signal lines connected the sensors to a data processor in a shelter at each site. The data processor converts the electrical signals from the sensors into the form and level required for the chart recorders. A pair of Esterline-Angus model AW, 0-1 mA recorders, operated at a chart paper speed of 3/4 inch per hour, were employed to record data from one set of sensors.

The wind speed sensor output is a frequency proportional to the wind speed. The response is linear up to 60 mph, as shown in Fig. 4. A frequency to voltage converter provides 0-1.40 ±0.01 V DC output for wind speeds from 0-60 mph, with a linear response of better than 0.5%. The accuracy of the wind speed system is about ±2.0% for full scale deflection of the chart recorder. However, rapid, continuous variations of even a steady wind limit the accuracy of mean hourly values read from a full scale deflection of the chart to about ±3.0%. This will increase with more turbulence and/or lower wind speeds to ±10% at 1/4 of full scale deflection.

The wind direction sensor puts out a DC signal of 0-1.40 ±0.01 V DC for positions of 0-360 degrees, which matches the input requirements of the 0-1 mA, 1400 ohm recorders. The accuracy of the chart record of the measured parameters is about ±3.0% for a full scale deflection of the chart recorder.

A semi-automatic analog-to-digital converter, attached to a 026 IBM keypunch, is used to reduce the analog chart data, i.e., wind speed and direction, to digital form. A cursor is lined up with one-hour intervals of the ink-line record on the chart. An analog signal proportional to the cursor position is converted into a three-digit number and punched onto a card so that one day of data may be place on one card. An effort was made to line the cursor up on the low side of what appeared to be the actual value by a few percent to provide a conservative value for the hourly averages for the wind speed. A deck of cards for each month of data is then fed to a CDC 3200 or Cyber 74 computer for a printout of hourly mean values for each month.

THE MEASUREMENTS

Beckman-Whitney wind speed and direction units, a cup anemometer, and a wind arrow were placed at the two sites near the Hill Annex Mine. Model AW Esterline-Angus 0-1.0 mA recorders were used to record wind speed and direction. Analog data on the charts were reduced to digital form, as described above under Data Reduction. The sites are on the western end of the Laurentian Divide. The climatological records for Duluth and International Falls do not show a significant change in wind direction with the seasons (Figs. 3-4). It is reasonable to assume that this would also be true for the Hill Annex Mine sites. The site elevations do vary over a range of about 390 feet.

Average hourly values have been determined and are presented in a series of hourly average wind speed, wind direction, and energy density plots for each site, with the prevailing wind shown on a wind rose for each month. Gusty winds use up ink rapidly and also break the ink feed to the recorder pens at times; remedial measures were taken to eliminate these problems.

It is of interest to consider the average wind power for this region on the basis of the measurements made during this period. The power in the wind-per-unit area can be computed in the following manner:

$$\text{Kinetic energy of the wind} = (1/2)mV^2 = (1/2)(\rho A V^2) = (1/2)\rho V^3,$$

where m = mass, V = velocity and ρ = density of air. So power per unit area = watts per square meter = KV^3 where $K \simeq 0.61$ for V in meters per second, and 0.055 for V in miles per hour.[2,3]

Wind power surveys have shown that the energy in the wind over northeastern Minnesota averages 100-150 watts per square meter.[4,5] These surveys are generally based on wind speed measurements made at 20-30 feet above ground, providing data of limited value in selection of suitable sites for wind-powered generators. In particular, it has been pointed out that wind speed measurements over extended periods of time, at least one year, at the site and elevation above ground proposed for the wind generator, should be made before design considerations can be undertaken.[6,7] The measurements submitted in this report were made at 20 and 60 feet above ground and show average wind speeds, $\overline{V}$, greater than 12 miles per hour at each site.

Determination of the available energy in the wind is an estimate based on the computation of expected values of the wind speed cubed, $E(V^3)$. Amplification of the effect variability in wind speed has on the expected wind power, E(P), by the cube, is the non-trivial problem in site evaluation.[8] Variation in the density of air with temperature and altitude has not been considered significant in wind energy surveys made up to the present time because of the problems associated with wind speed measurements. However, it is of interest to note that one may expect about 20 percent more energy in the wind over northeastern Minnesota during the winter months, due to the greater air density at lower temperatures.

Wind power surveys for the United States have been based on yearly, seasonal, and monthly mean values computed from the climatological data which is an estimate of the one-minute average wind speed made five minutes before each hour by the station observers at National Oceanic and Atmospheric Administration (NOAA) weather stations. The observers read a standard model AW Esterline-Angus chart recorder at some time five minutes before the hour to obtain the one-minute value.[9] At some stations a wind speed meter of equivalent accuracy is employed instead of the model AW unit. The recorder or meter sensitivity is set at 0-100 mph. Most of the time, the recorder pen will deflect less than 1/4 of full scale and limit the accuracy of the wind speed measurement to about ±10 percent.[9] The anemometers are placed 30 feet above ground, but not uniformly at obstruction-free locations at all sites.[10] It should also be pointed out that the NOAA data were compiled for use in climatological analysis and not for wind power surveys. Therefore, the Sandia Labs estimate that the E(P) due to gusting may be two or three times greater than the values obtained from average wind speeds, is justified.[11]

In the boundary layer of the atmosphere, about 100 meters in depth, friction between the moving air and the ground produces a turbulent, disordered flow of air.[12] Surface roughness and wind intensity contribute to an increase in turbulence or gustiness in a complex manner. It must be pointed out that in geophysics there are no strictly random events in a statistical sense[13] and therefore, gustiness will likely yield to analytical analysis and an orderly summary when sufficient data become available. Nevertheless, anemometer responses to wind gusts have been summarized under large scale changes with periods up to one hour; medium scale, of several minutes, and gusts lasting a few seconds.[14] The contribution of medium and short period gusts is unfortunately smoothed out in computed mean values of wind speed. An example to illustrate the effect this has on the computed latent energy in the wind will be given.

Periods of gusts lasting seconds or a number of minutes require special consideration because of their intensity and the effects related to their short duration. Increases in wind speed of 20-80 percent in 0.25-4.0 seconds have been reported for $\overline{V}$ values in the 30-55 mph range. While some fraction of the latent energy in the short period gust would be converted into electrical power, stress on the wind generator structure has been a matter of primary concern.[15] However, the net latent energy in gusts-of-a-few-seconds periods passing through the area swept by a large windmill, about 3×10^4 square feet, may warrant some preliminary considerations in design for more favorable conversion into electrical energy. If small gusts pass at a fairly constant rate and are uniformly scattered in the wind, stress may not be as great, and the latent E(P) would be greater than previous expectations.

Wind gusts are variable by their nature, and in general, the medium scale gusts appear at a fairly constant rate and consist of three- to six-minute periods in which the wind speed increases from 20-50 percent of the mean value for that hour, as shown in Figs. 5 and 6 . A 50 percent increase in wind speed provides a greater increase in wind energy than a 50 percent decrease in wind speed will reduce the energy in the wind. This can be illustrated in the following example where $\overline{V}$ is the average wind speed; with a 50 percent increase in wind speed there is a $(1.5\overline{V}/1.0\overline{V})^3 \times 100 = 12.5\%$ of energy in the wind.

A set of computations was made of $\overline{V}^3$ by three different methods to further illustrate the need for care in evaluation of wind speed cubed. Mean values of $\overline{V}^3$ were computed:

1. from the arithmetic mean value of $\overline{V}$ for a day
2. from the sum of hourly average values cubed
3. from the exact expectation of $E(\overline{V})^3$ and then from the exact expectation of $E(\overline{V})^3$ neglecting the skew of σ.[16]

For a small set of values, such as 24, to be used in the illustration, this method is equivalent to Weibull's for this purpose and much less time consuming.[16]

The expression to give the exact expectation for $(\overline{V})^3$ has been derived from an identity based on the third moment of the wind speed about zero. The mean of the wind speed cubed can readily be computed from this expression:

$$E(V)^3 = \sigma\{\sqrt{\beta_1} + 3\mu/\sigma + (\mu/\sigma^3\}.$$

σ = the standard deviation for a day computed from the hourly mean values of $\overline{V}$ for that day.

μ = the arithmetic mean value of the wind speed for that day, i.e., $\overline{V}$.

β = the skew of σ.

An estimate of the variance for a set of measurements is the standard deviation for the set. The skewness of the mean for the set provides an estimate of the asymmetry in the distribution of this set. The skewness of the mean for a set of measurements is defined in the following manner:[17]

$$\text{skewness} = \beta = \frac{\mu - M}{S}$$

where μ = the mean, $\overline{V}$

M = the mode for the set

S = the number in the set

If the mode is greater than the mean, this fact must be related to the computation of $E(\overline{V})^3$.

<u>Computation of V^3 (for 1 day)</u>
(Using the Wind Speed Data from the Site at Hill Annex Mine)

1. $E(V^3) = (25)^3 = \underline{1.56 \times 10^4 \text{mi}^3/\text{hr}^3}$ (V = 25 mph)

2. $E(V^3) = (\sum_{j=1}^{24} \overline{V}_j^{\,3})/24 = \underline{1.71 \times 10^4 \text{mi}^3/\text{hr}^3}$

3. $E(V^3) = \sigma^3\{\beta + 3\mu/\sigma + (\mu/\sigma)^3\}$

σ = 16.2 mi/hr
μ = 25 mi/hr
β = 0.123

$$E(V^3) = (16.2)^3\{(0.123) + 3(25)/(16.2) + (25/16.2)^3\} = \underline{3.58 \times 10^4 \text{mi}^3/\text{hr}^3}$$

Let $\beta = 0$, i.e., the skew of σ is assumed to be negligible in this case.
$E(V^3) = 3 \times \mu\sigma^2 + \mu^3 = 3(25)(16.2)^2 + (25)^3 = \underline{3.53 \times 10^4 \text{mi}^3/\text{hr}^3}$

The magnitude of σ will be proportional to the gustiness of the wind, since $3\mu\sigma^2 \simeq 3\mu^3$ and contributes to a larger value of $E(V^3)$.

A few comments on the Weibull model are appropriate because of the recent effort to demonstrate how it may be useful in predicting the available power in the wind for a site.[16, 17] Often it is necessary to use whatever data are available and obtain as much applicable information as possible. The Weibull model provides a family of distribution functions which can be fitted to sets of wind speed distributions. By selection of the proper shape parameter and the use of gamma functions, the frequency distribution of wind speed cubed may be approximated. The manner in which this model may be doubly truncated for the cut-in and cut-out wind speeds is useful in predicting the expected available power density in the wind; i.e., W/m^2, in the wind for a site. However, application of the Weibull distributions with some sets of wind data have not been satisfactory.[18] It does at times produce tolerable approximations, but the tolerance for deviations must also take into account the increase in computer cost.[19] No further consideration will be given to the use of the Weibull distribution model, other than to point out that it appears to have been applicable in some wind energy surveys.[16,17]

SUMMARY

The set of plots submitted in this report portrays a profile of the wind over a period of two and one-half months for 1980 and about six months in 1977, for the area around Calumet, Minnesota and eastward along the Laurentian Divide. It is noteworthy that at Calumet the wind is greater at the hilltop site. Greater average wind speed at greater altitude is also apparent at some of the other elevated sites. This indicates that the wind generator should be up on the highest hill available in the area.

There appear to be three or four extended periods, greater than 12 hours each week, when the wind is well over 15 mph and the wind direction is fairly constant during these periods of time. This would permit a wind generator to perform close to its maximum capacity. From JL data[20] on the Hill Annex Mine it appears that about 200 kW will be required to handle the pumps that have been used in the past.[21] At this stage, a windmill farm with, say, four or five smaller units is recommended, rather than one or two larger wind generators. There is always some uncertainty with a new venture of this type. Therefore, starting out with a number of smaller units would demonstrate the reliability and output performance of the system, which could then be expanded to meet new power requirements as they develop. However, when the means with which to go on with this project become available, it is recommended that a professional consultant be employed to prepare a feasibility study and a preliminary system design with a cost estimate.[22]

In closing, there are a few related topics to consider. It is not reasonable to consider the use of a mechanical pumping system because of the high volume of water which must be handled. The placement of wind generators at suitable sites within a few miles of a central control building near the pumps would permit convenient operation of the system. Consideration should

also be given to utilization of more power than can be used for pumping when the wind blows hard.

A number of wind generator manufacturers have been listed and are enclosed in the appendix with some additional related material.

REFERENCES AND NOTES

1. ESSA, Weather Atlas of United States, 1968, pp. 237-49.
2. Golding, E. W. The Generation of Electricity by Wind Power. Halstad Press, p. 22 (1955).
3. Reed, J. W. Wind Power Climatology of the United States. National Technical Information Service, Springfield, Va. 22151, pp. 5,6 (1975).
4. Reed, op. cit., pp. 9-12.
5. Eldridge, F. R. Wind Machines. Superintendent of Documents, Washington, D.C., p. 41 (1975).
6. Pettersson, Sverre. Some Aspects of Wind Profiles. New Sources of Energy Conference, Proceedings; United Nations/Nations UNIES, pp. 133-36, (1961).
7. Reed, op. cit., p. 13.
8. Merriam, M. F. "Wind Power for Human Needs," Technology Review, pp. 29-39, (1/19/77).
9. Personal communications: Mr. K. Peterson, Officer in Charge at Duluth Weather Bureau Office, and Mr. J. Graff, Officer in Charge at Minneapolis Weather Bureau Office, consider the estimate of accuracy for climatological wind speed data, i.e., ± 10%, to be reasonable.
10. Corotes, J. W. Stochostic Modeling of Site Wind Characteristic. National Technical Information Service, Springfield Va. 22151, pp. 137-39 (1976).
11. Eldridge, op. cit., p. 44
12. Hidy, George M. The Winds: The Origins and Behavior of Atmospheric Motion. D. Van Nostrand Company, Inc.: Princeton, N.J., p. 146 (1967).
13. Lyons, T. J. "Mesossale Wind Spectra," Quart. J. R. Met. Soc. (1975), 101, p. 903.
14. Scrase, F. J. "Some Characteristics of Eddy Motion in the Atmosphere," Meteorological Office Geophysical Memoir No. 52 (1930).

15. Golding, op. cit.

16. Hennessey, J.P. "Some Aspects of Wind Power Statistics," J. of Appl. Meteorol., pp. 119-28 (2/1977).

17. Justus, C.G., W.R. Hargraves, and A. Yalcin. "Nation Assessment of Potential Output from Wind-Powered Generators," J. of Appl. Meteorol, pp. 673-78, July, 1967.

18. Personal communications: Dr. Jack Reed, Sandia Laboratory, Albuquerque, N.M.

19. Essenwanger, O.M. Applied Statistics in Atmospheric Sciences. American Elsevier, pp. 116-20, 186-88, (1976).

20. Data on motor taken from Bill Betzler's (JL) letter to Orlyn Olson. Copy attached.

21. A 450 hp motor has been used to pump water at the mine. Assume it operates close to its maximum capacity. Round 450 to 500. One hp equals 746 or say 700 watts. So about 500 x 700 (350,000 watts or 35 kW) would be required to run the pumps. This is about as close as one can come with an estimate of the power required from available information.

22. Syverson Consulting, 2007 Roe Crest Drive, North Mankato, MN 56001. Letter attached.

SYVERSON CONSULTING
2007 ROE CREST DRIVE / NORTH MANKATO, MINNESOTA 56001 / PHONE 507 387-1641
DESIGN AND DEVELOPMENT ENGINEERING

February 5, 1981

Prof. Don Olson
Dept. of Physics
UMD
Duluth, MN 55812

Dear Prof. Olson:

I have enclosed several pieces of literature on our current 4 KW Hummingbird wind generator and should like to indicate that we have a 12 KW unit to come out later this year. Whether either of these would fit the bill for the Calumet/Nashua project, I don't know at this point.

Personally, I have been involved to one degree or another in electric wind generation since 1973. I am the designer of the Hummingbird, am a registered electrical engineer in the State of Minnesota and hold my BSEE(power option) degree from the U of Minnesota in 1961.

I have been actively involved as an adviser for the Minnesota Energy Agency for a period of time and still on a regular basis give seminars, lectures and the like around the state on the general topic of energy, alternative sources and specifically wind energy. I have one scheduled in early February here at Mankato State University and one for late March at the U sponsored seminar at the new ST. Paul Radison.

I spent fifteen years designing motors and generators for a variety of manufacturers and still do consult with several on design work. I would very much like to be involved in the project you speak of. As an active member of the two standards committees currently working in the A.W.E.A.(American Wind Energy Association), I feel I am familiar with the industry, what is going on in it and could probably be a help in the technical aspects of the project.

Besides, I have an ongoing interest in projects of this type. I would be glad to make myself available should that seem desireable. Incidently, as I told you on the phone, one of our Hummingbirds is now erected on the grounds of the Indianhead technical institute in Superior, Wisc.

Until I hear from you.

Yours truly,

Charles D. Syverson, P.E.

STEEL

November 7, 1978

To: Orlyn Olson
IRRRC

From: Bill Betzler

Subject: Pumping Data - Hill Annex Mine

Our records indicate that an average of 972,445,000 gallons of water have been pumped per year. This is based on the data of the last 5 years (reports enclosed).

Assuming continuous pumping, this would calculate at 1850 gpm, therefore a pump with a capacity of 2000 or 2500 gpm would be in order.

The pertinent data on the existing pumping arrangement is:

Diameter of pipe -- 12"
Total length of pipe -- 3000' (Black Spiral)
Line contains 4 90° L's and 5 45° L's
Elevation of discharge -- 800'
Elevation of Pit Water -- 420'

Estimated total dynamic head -- 455'
Present pump data: 2500 gpm - 450 H.P. motor, 1775 RPM, 4000 Volt

You also asked for information on the cost of heating the mine office building. The average fuel oil consumption for the last two years ('76 & '77) was 3860 gallons per year. I am sure insulation and window work would reduce this. The brick shop building is a different problem - just an inefficient building. It has averaged 89,000 gallons of fuel oil per year.

If there are further questions, please call.

Figures

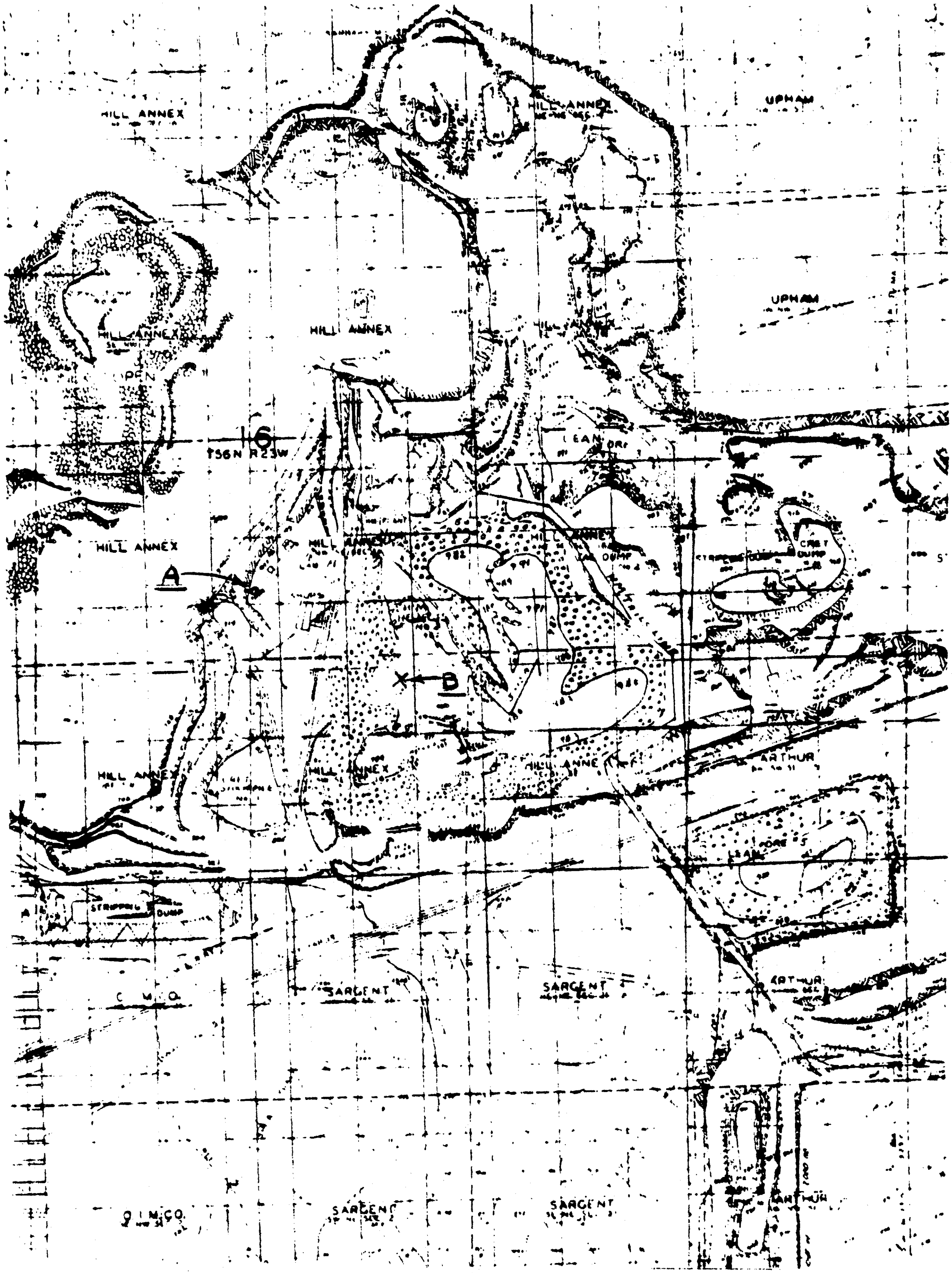


Fig. 1. This map covers a section of the Hill Annex Mine property. The wind speed and direction measurements were made at A (on top of a water tower) and at B on a hilltop.

DETAIL OF INSTRUMENT INSTALLATION

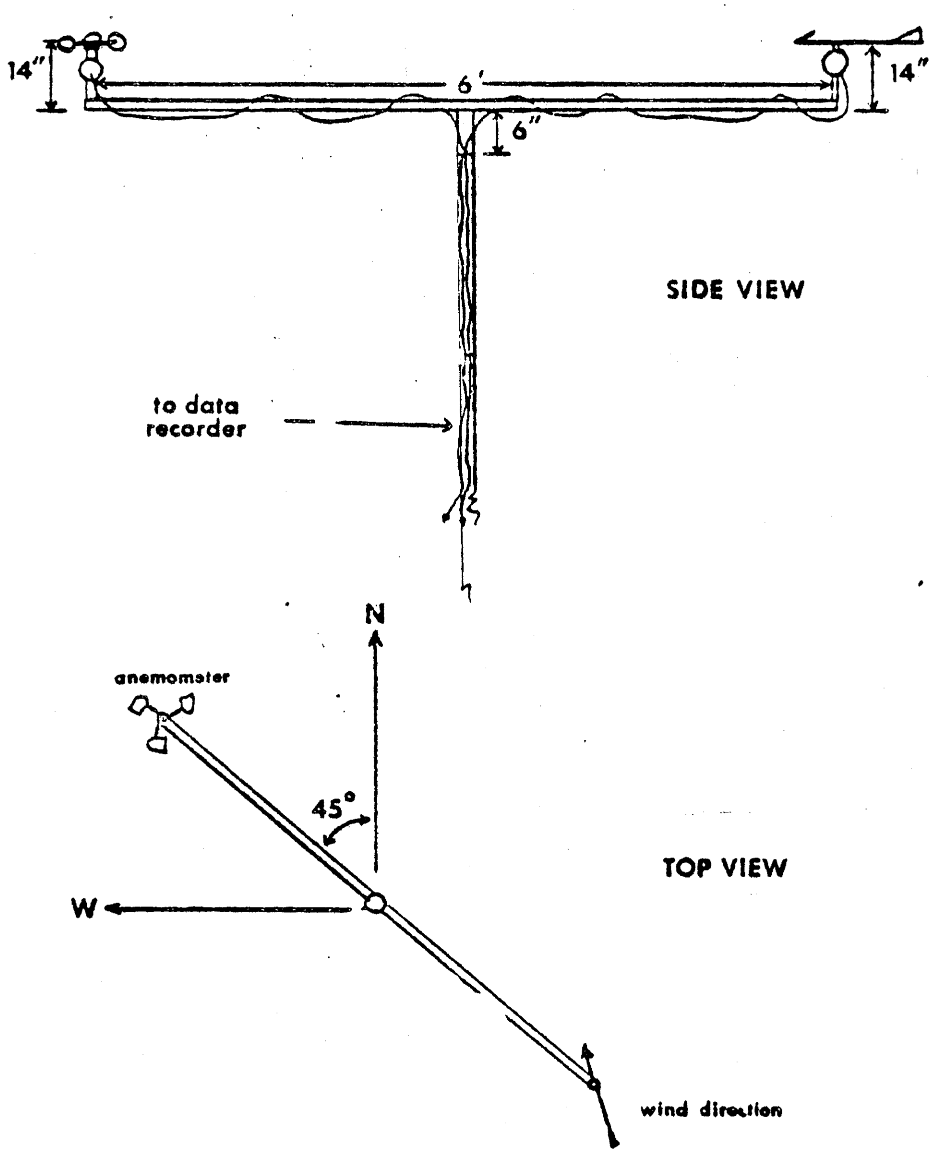


Fig. 2

WIND ROSE FOR DULUTH

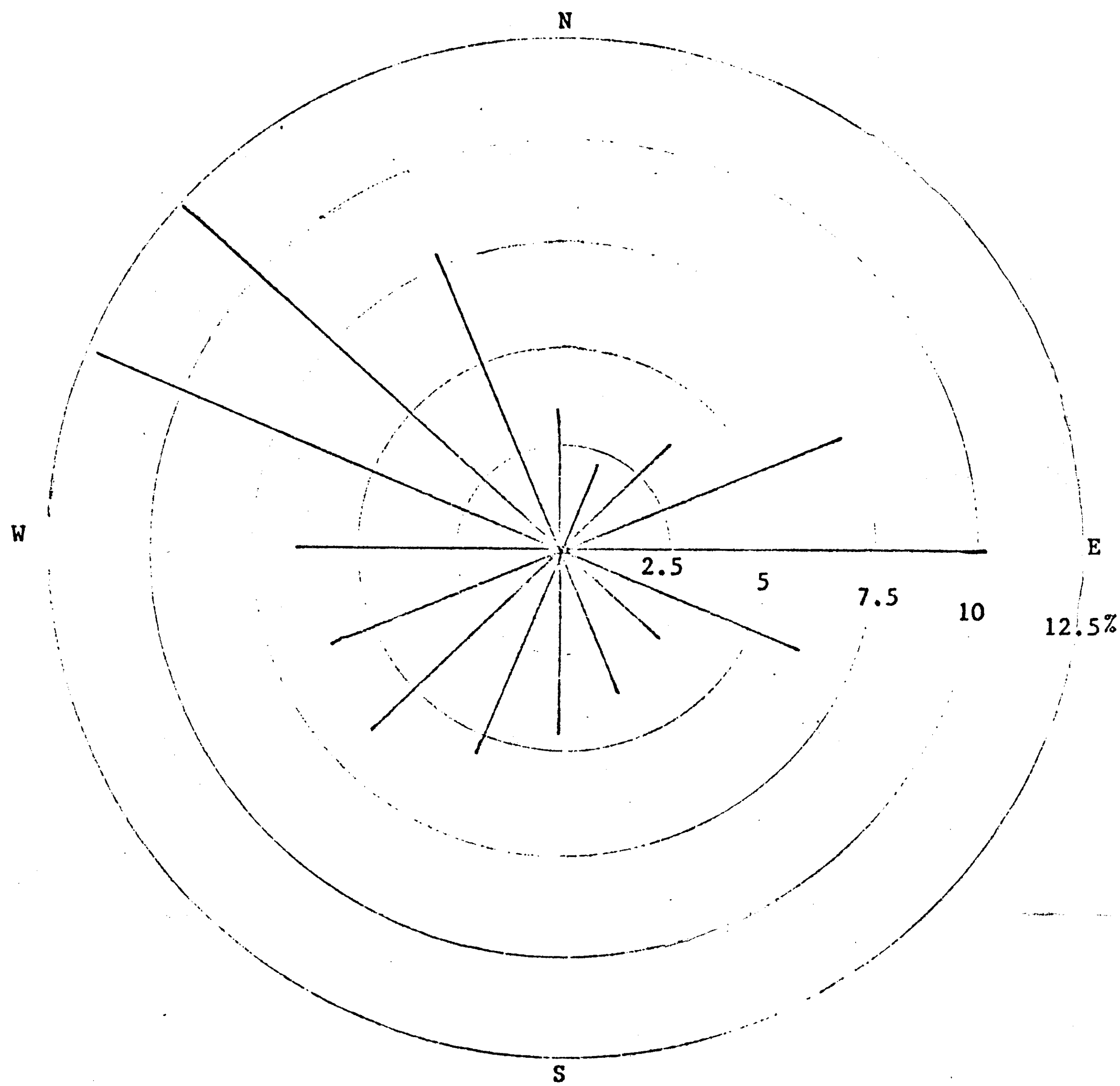


Figure 3. Shows the percent of the time that the wind blows in a given direction for 1976. Data for this wind rose was supplied by the officer in charge at the station.

WIND ROSE FOR INTERNATIONAL FALLS

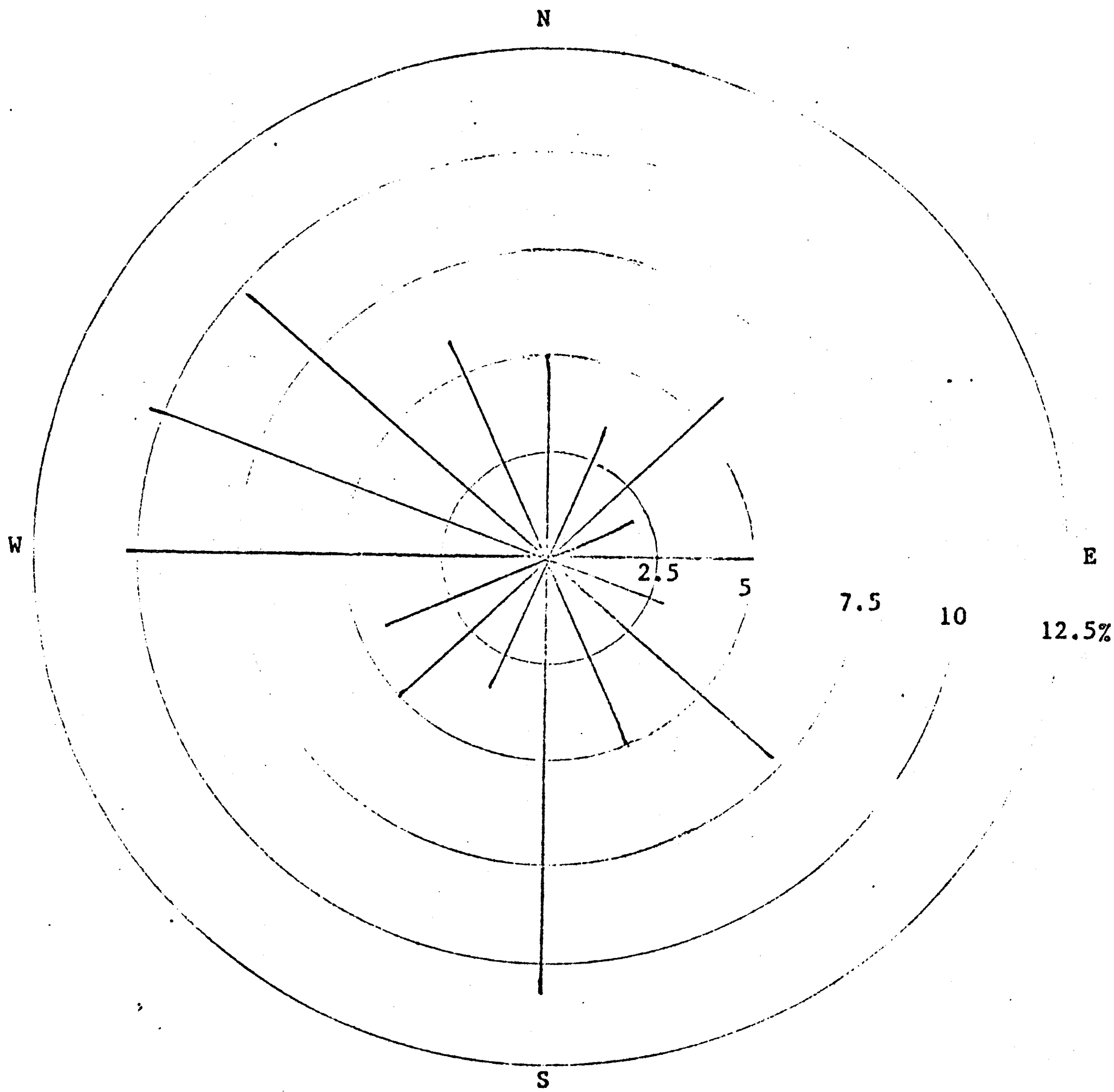


Figure 4. Shows the percent of the time that the wind blows in a given direction for 1960-68. Data for this wind rose was supplied by the officer in charge at the station.

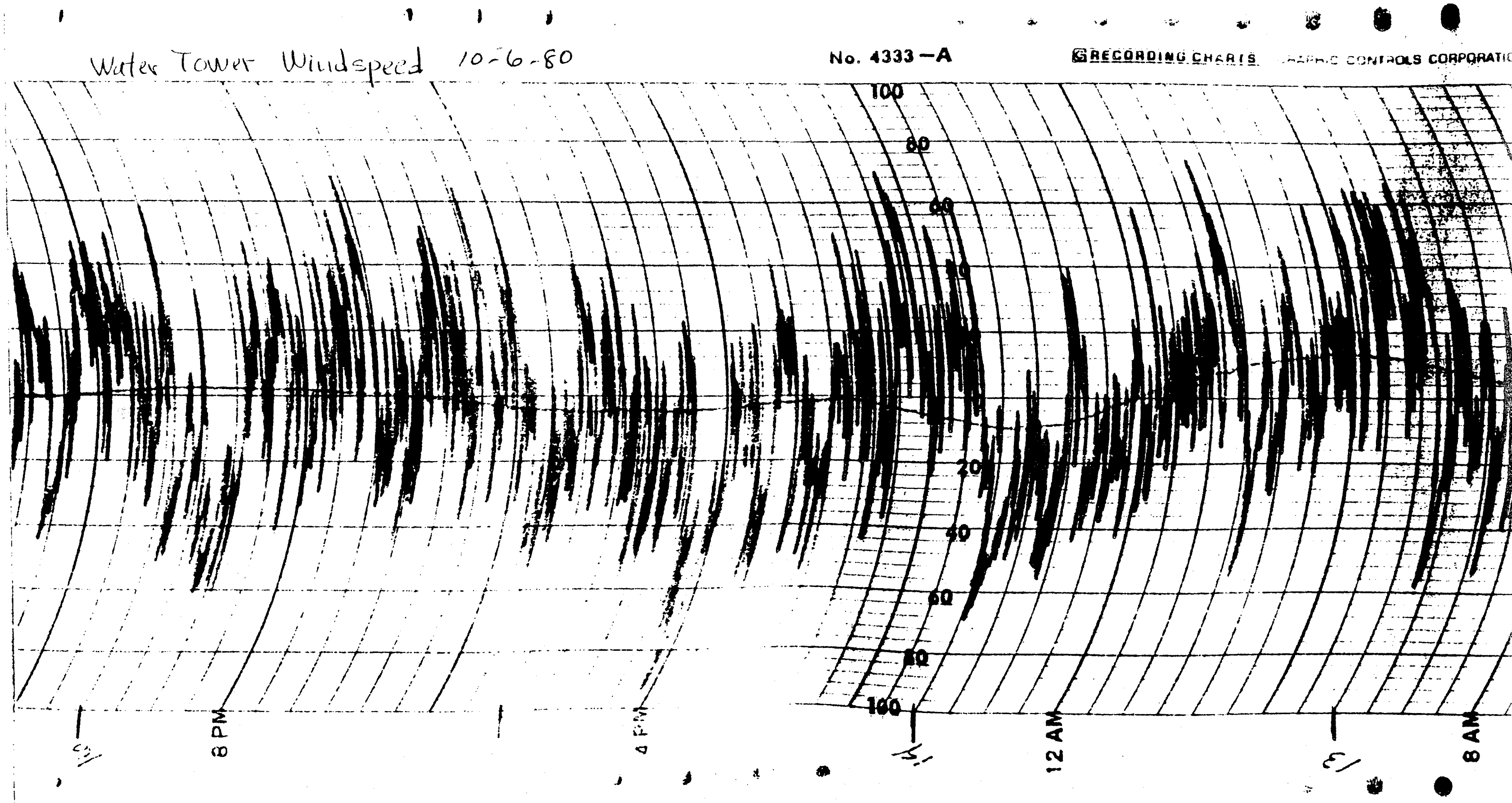


Fig. 5. Chart record of anemometer at Calumet, 6 October, 1980, showing typical gustiness of the wind.

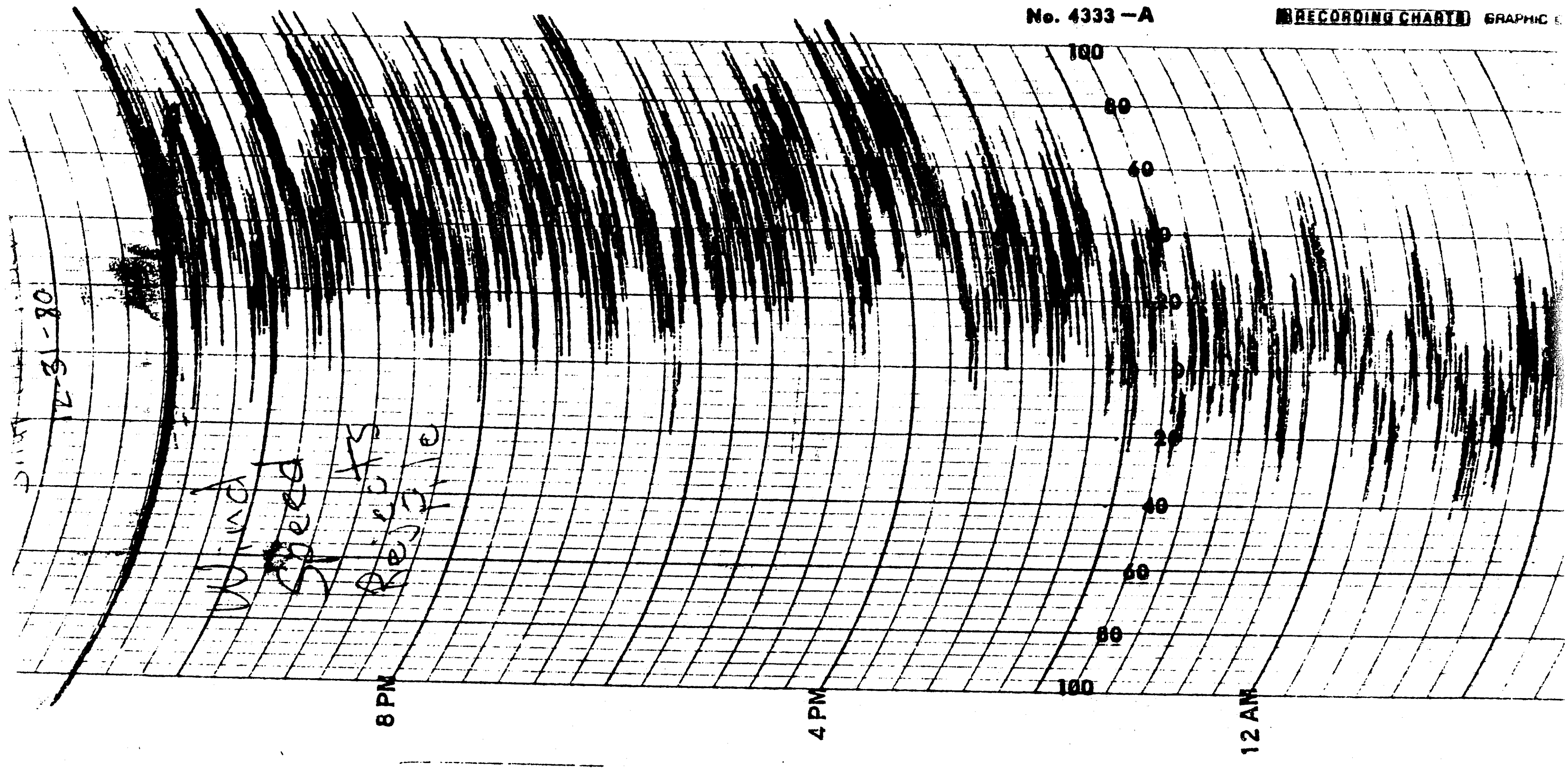


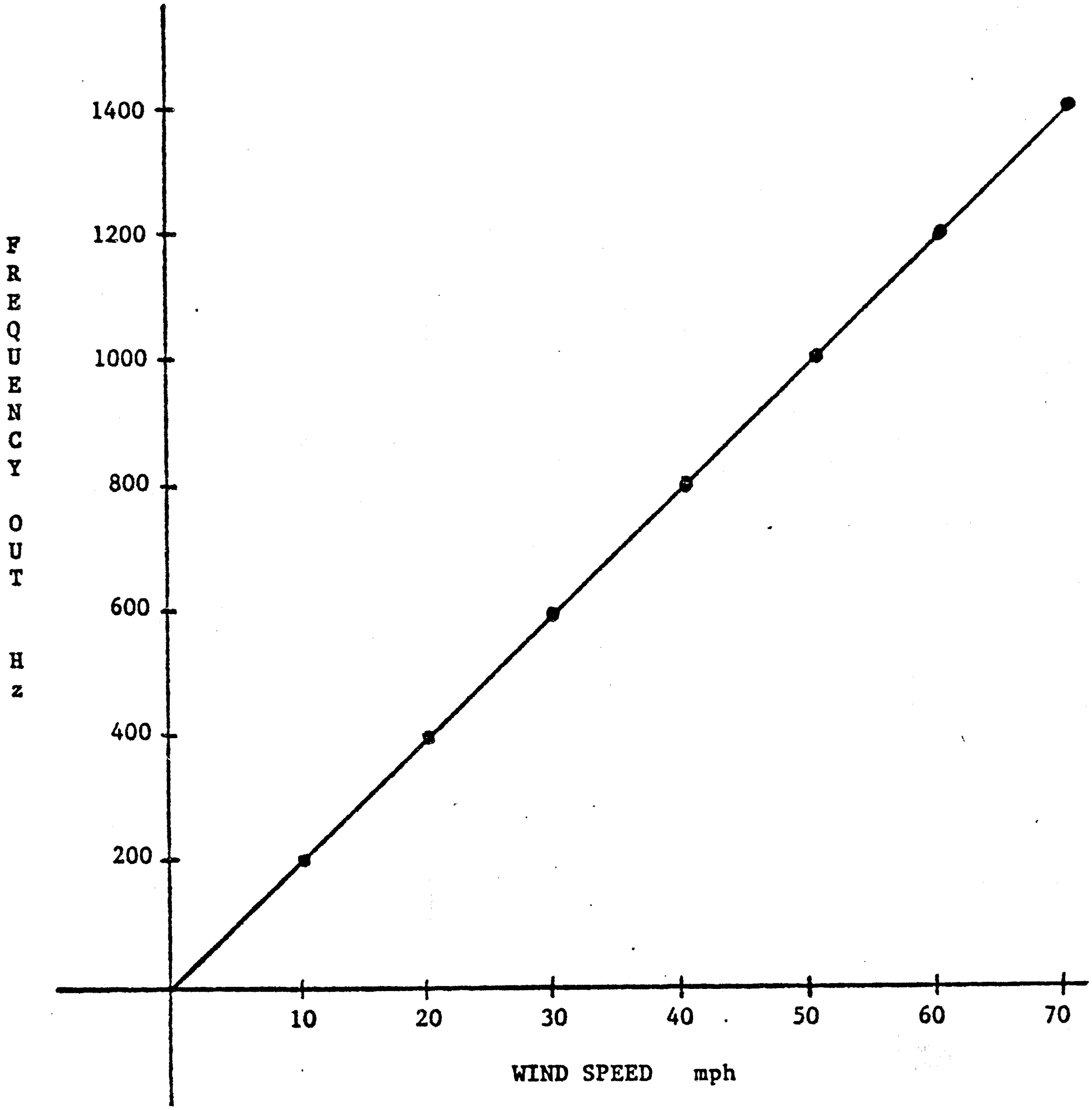
Fig. 6. Another example of wind gustiness at Calumet, 31 December, 1980.

Index to Appendix

1. Instrument calibration.
2. Calibration curve.
3. Average monthly wind speeds (a and b)
4. Details on anemometer sites.
5. Wind availability at other sites.
6. Wind speed data--continuous set of hourly average values.
7. Wind speed duration (by site per month).
8. Wind/hour availability (by sites per month).
9. Power density charts.
10. Wind rose data.
11. Mfgs. list (wind generators)

Instrument Calibration

The task of setting up and maintaining two wind-monitoring systems for continuous operation proved to be more difficult than anticipated. Repeated calibration of the anemometers and the supporting electronics have been made in a wind tunnel. The wind speed was measured with a Dwyer model 102 AV, 2% accuracy, and a Keuffel & Esser Company miniature anemometer, ± 2% accuracy. Anemometers were also mounted out 6 feet in front of a truck with a calibrated speedometer, and a set of calibration runs were made. The difference between the wind-tunnel and truck calibration was within ± 3%. The truck was driven over a level road when the atmospheric wind was zero. The truck was used as a double check on our anemometer calibration. Therefore, we feel that the wind speed measurements presented in this report are accurate to better than ± 3% for full scale deflection of the chart recorder.



This curve shows a typical calibration made of the anemometers in a wind tunnel. The wind speed was measured to an accuracy of about ±2.0% and the frequency output of the sensor to better than ±1%.

Table 1.

The Average Hourly Wind Speed Per Month for Each Site (1977)

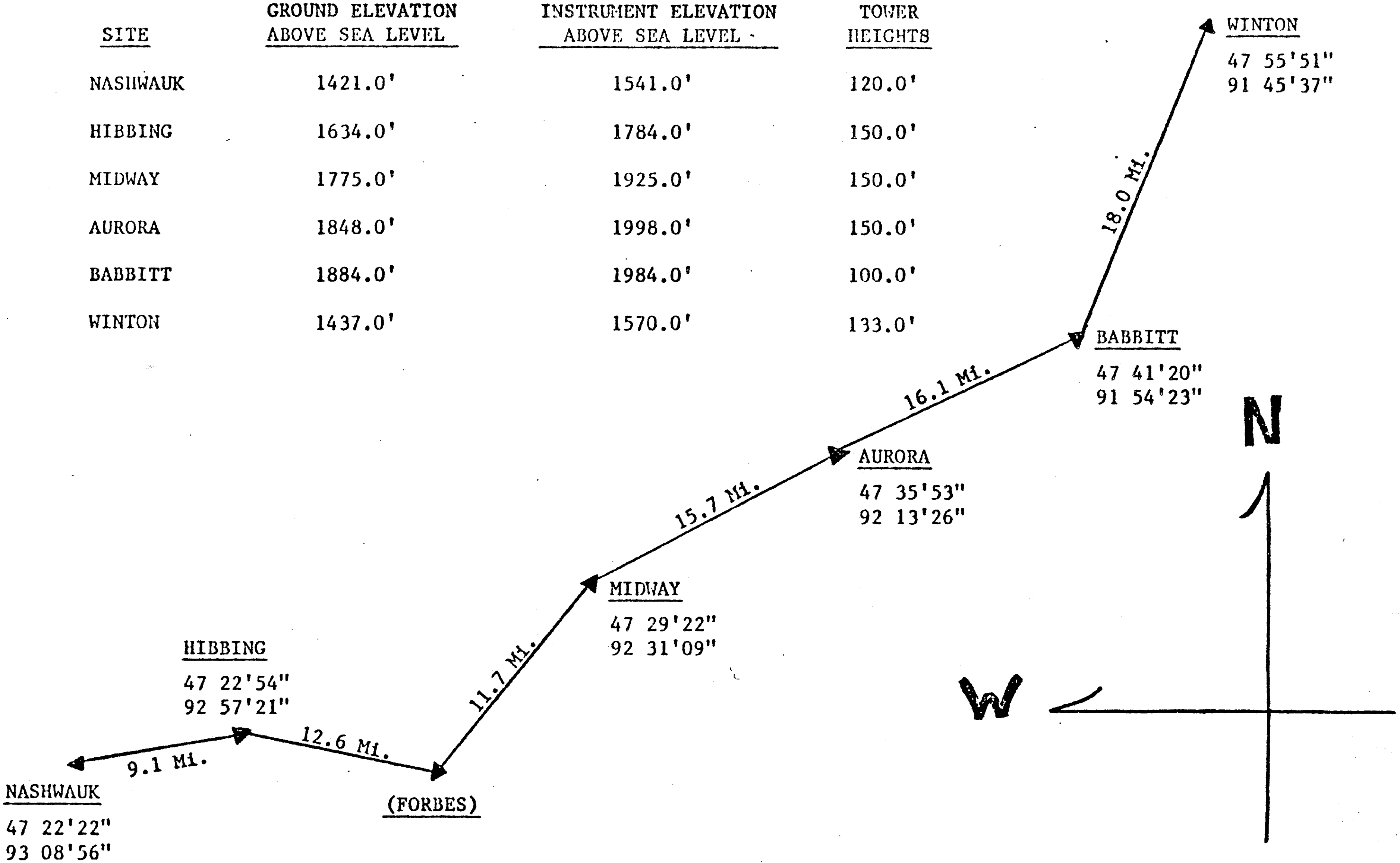
Site	Average Hourly Wind Speed		
Aurora	17.4 mph	May	1977
	14.4	June	
	15.3	July	
	15.7		
Babbitt	16.0 mph	February	1977
	13.2	April	
	12.0	June	
	13.7		
Hibbing	20.0 mph	March	1977
	21.8	April	
	20.3	May	
	19.8	June	
	20.7	July	
	20.5		
Midway	15.6 mph	March	1977
	14.2	April	
	13.5	May	
	11.6	June	
	13.7		
Nashwauk	14.7 mph	February	1977
	17.1	March	
	12.7	April	
	10.5	May	
	13.8		
Winton	15.4 mph	February	1977
	14.0	March	
	14.7	April	
	14.7	May	
	10.0	June	
	10.5	July	
	13.2		

Calumet, Minnesota Mine Draining Project
Monthly Wind Speed Averages

month	Water Tower	Tailings Pile
September	8 mph	9 mph
October	10 mph	10 mph
November	9 mph	11 mph
December	9 mph	11 mph

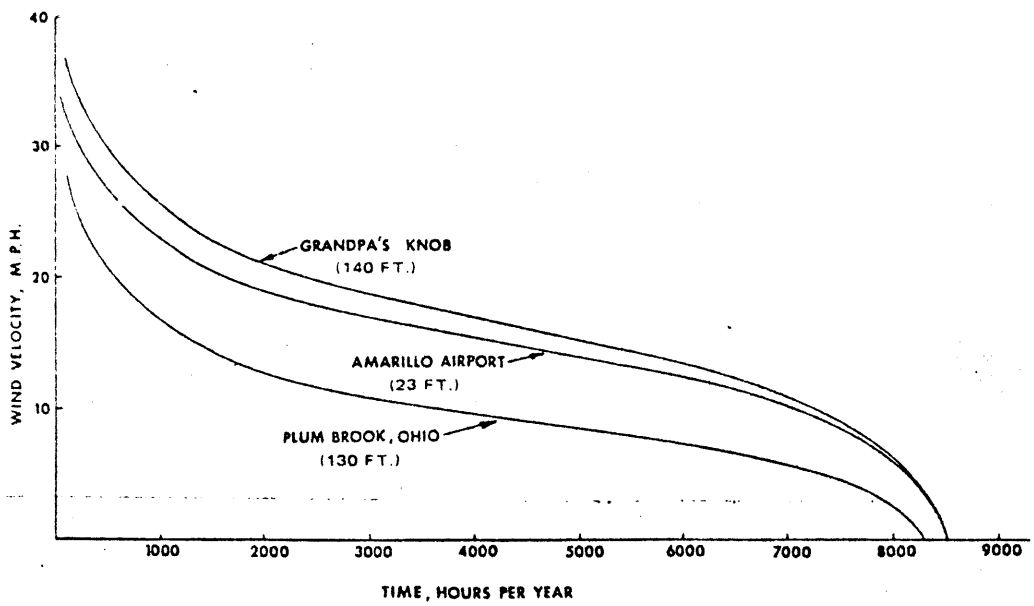
Wind Speeds are in miles per hour. Monthly averages are for the period September 20-December 5, 1980.

SITE	GROUND ELEVATION ABOVE SEA LEVEL	INSTRUMENT ELEVATION ABOVE SEA LEVEL	TOWER HEIGHTS
NASHWAUK	1421.0'	1541.0'	120.0'
HIBBING	1634.0'	1784.0'	150.0'
MIDWAY	1775.0'	1925.0'	150.0'
AURORA	1848.0'	1998.0'	150.0'
BABBITT	1884.0'	1984.0'	100.0'
WINTON	1437.0'	1570.0'	133.0'



Appendix 4

DETAILS ON ANEMOMETER SITES



Annual Average Velocity Duration Curves for Three Sites.

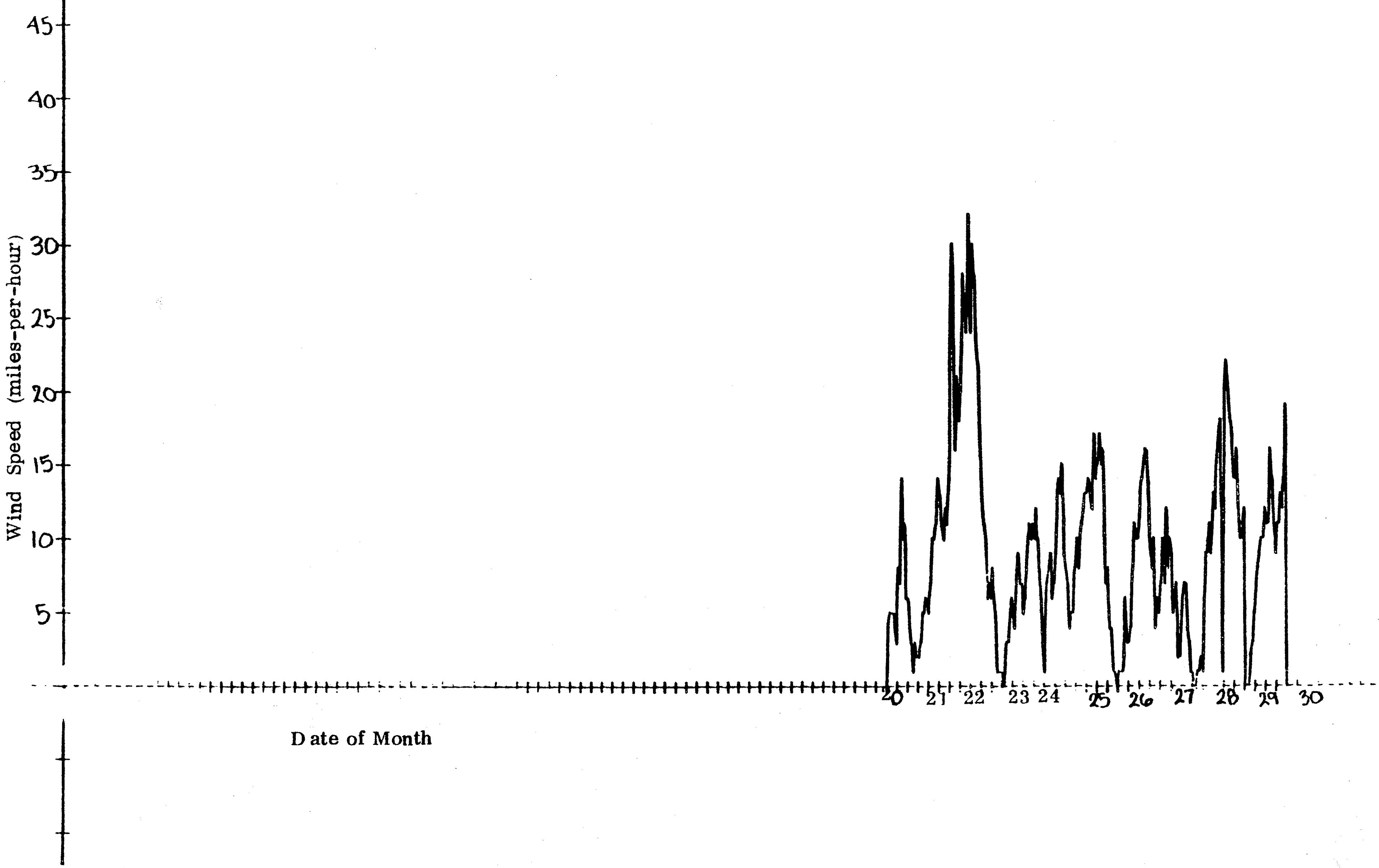
Appendix 6

Wind Speed Data--continuous set of hourly average values.

CALUMET, MN MINE DRAINING PROJECT

WIND SPEED DATA 20 SEPTEMBER-30 SEPTEMBER 1980

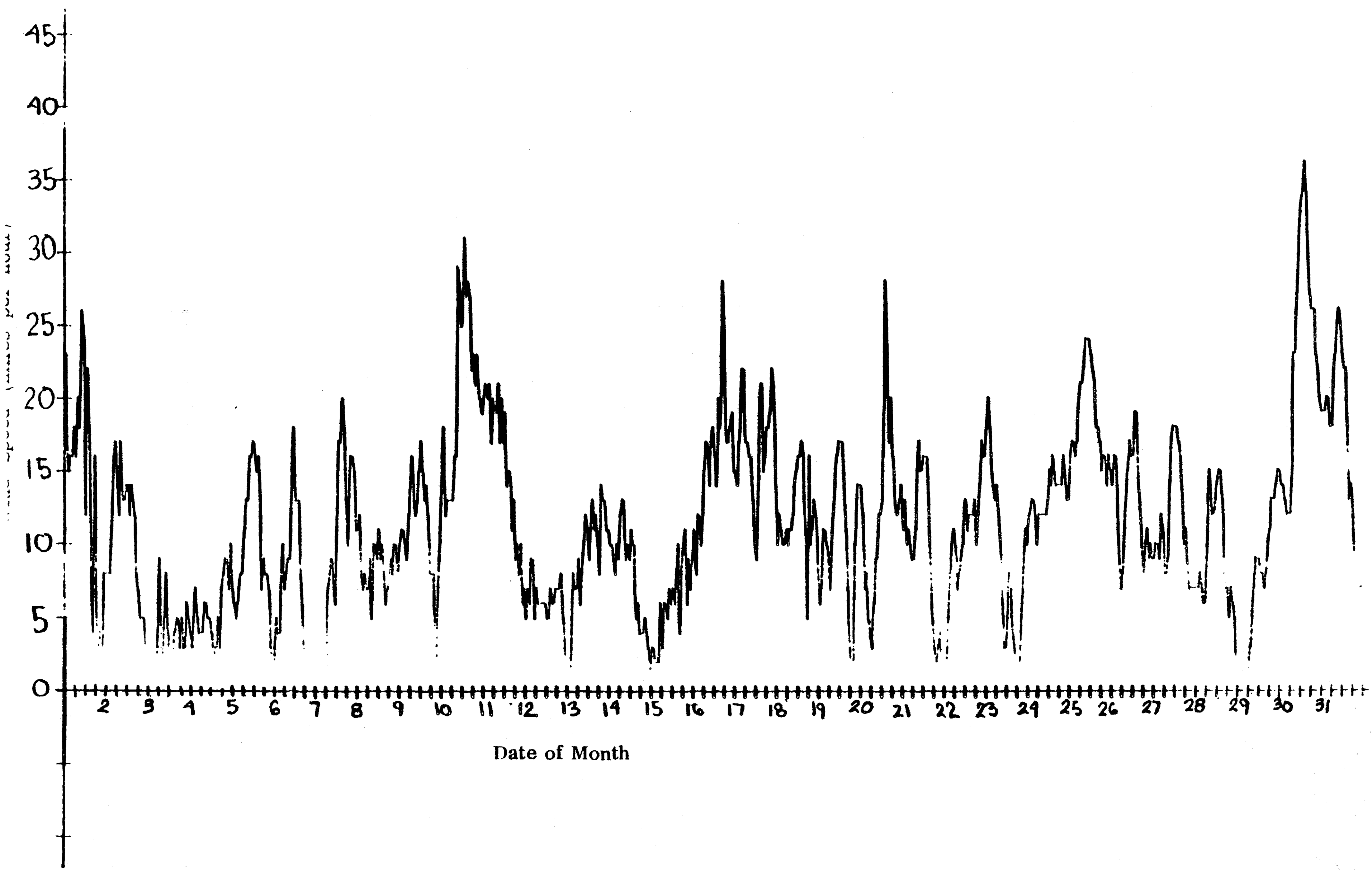
SENSOR LOCATION--WATER TOWER

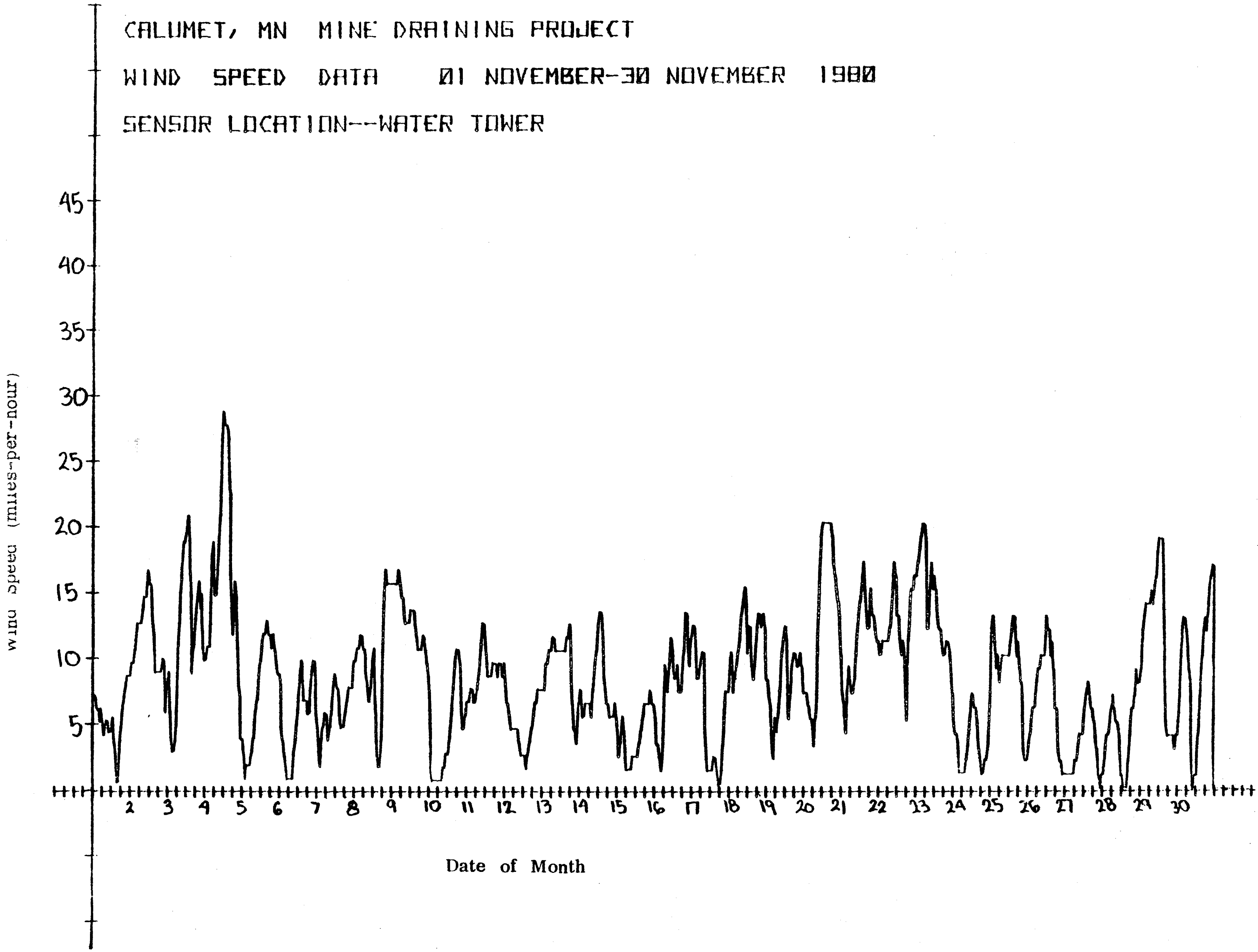


CALUMET, MN MINE DRAINING PROJECT

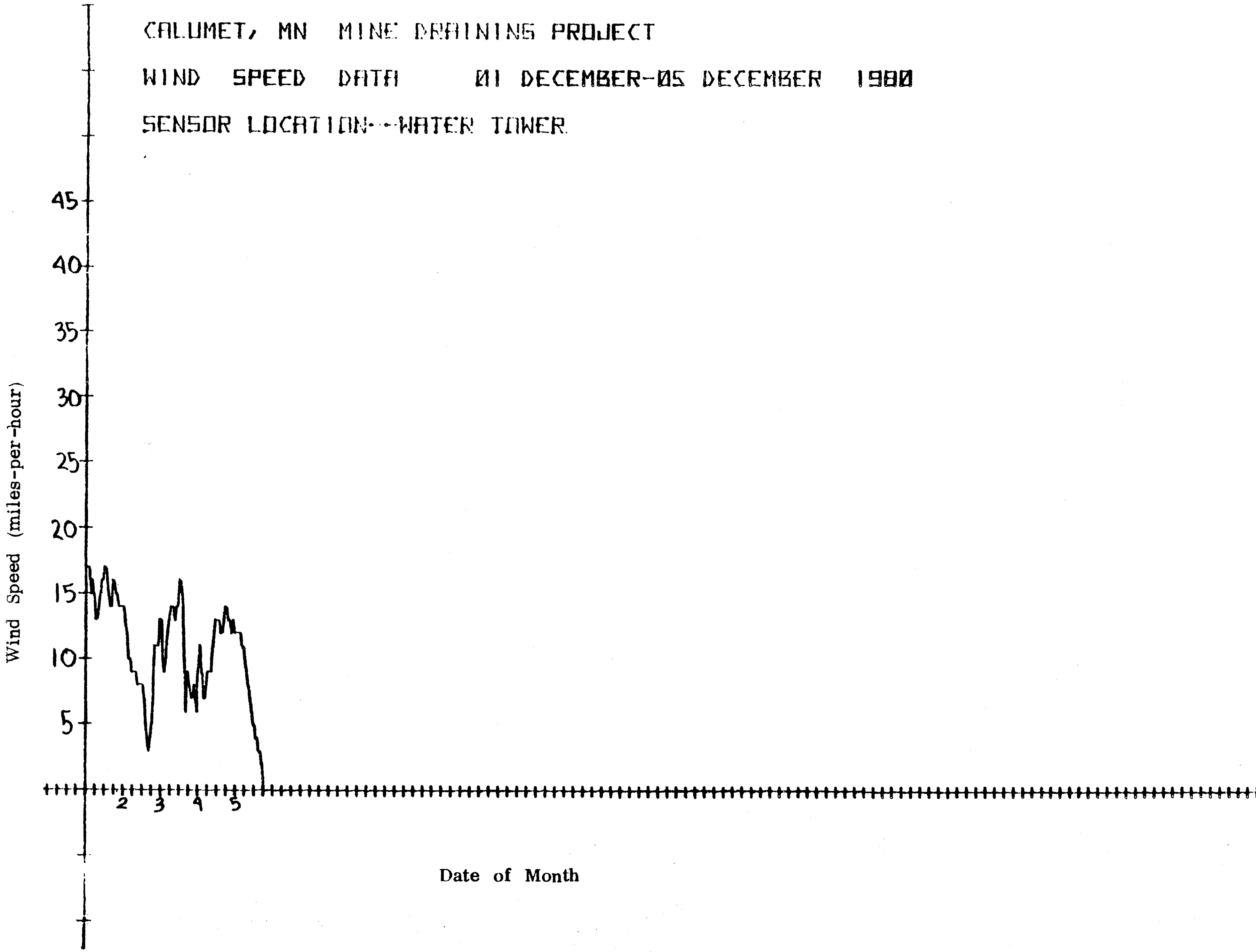
WIND SPEED DATA 01 OCTOBER-31 OCTOBER 1980

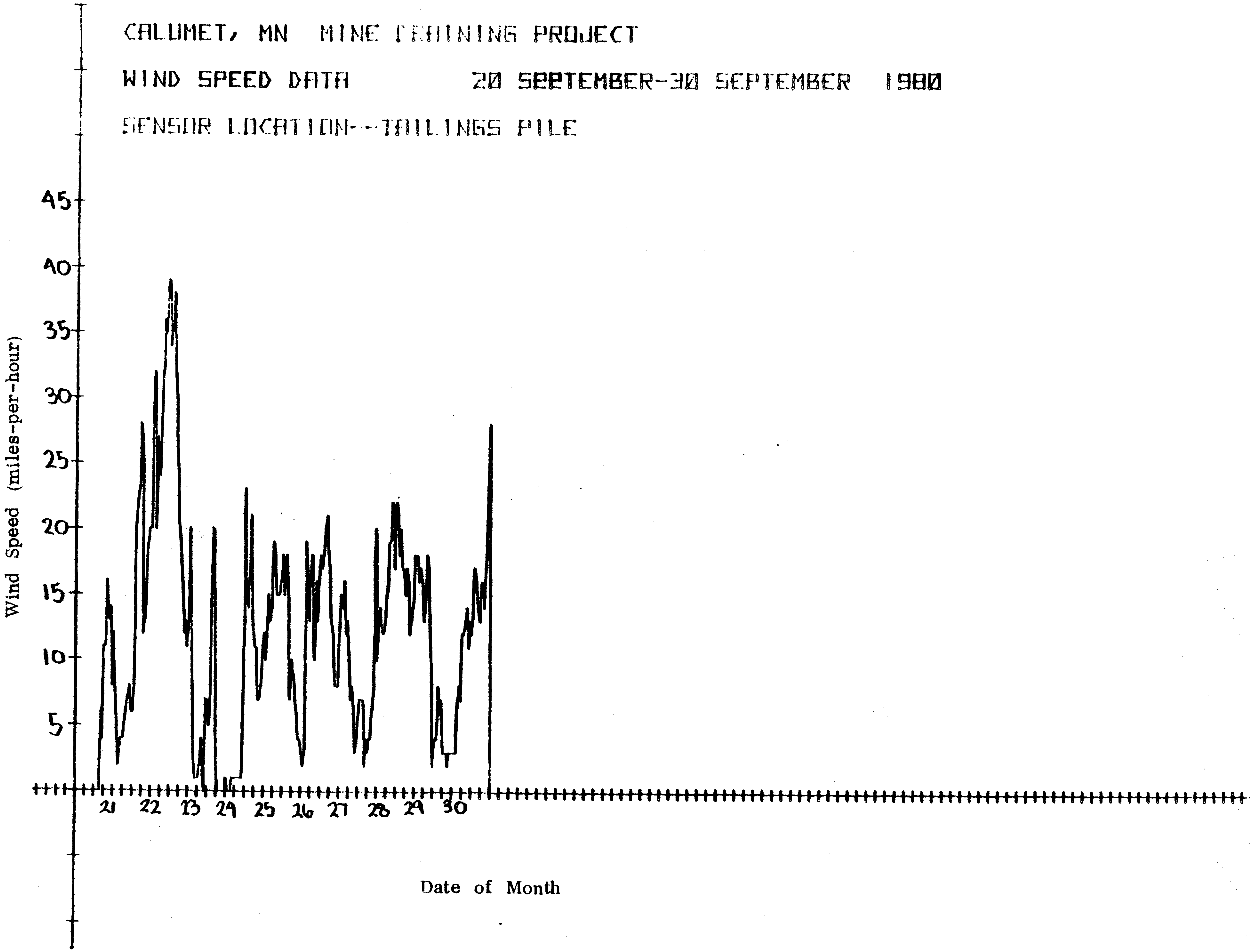
SENSOR LOCATION--WATER TOWER





CALUMET, MN MINE DRAINING PROJECT
WIND SPEED DATA 01 NOVEMBER-30 NOVEMBER 1980
SENSOR LOCATION--WATER TOWER
Wind Speed (miles-per-hour)
45
40
35
30
25
20
15
10
5
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Date of Month

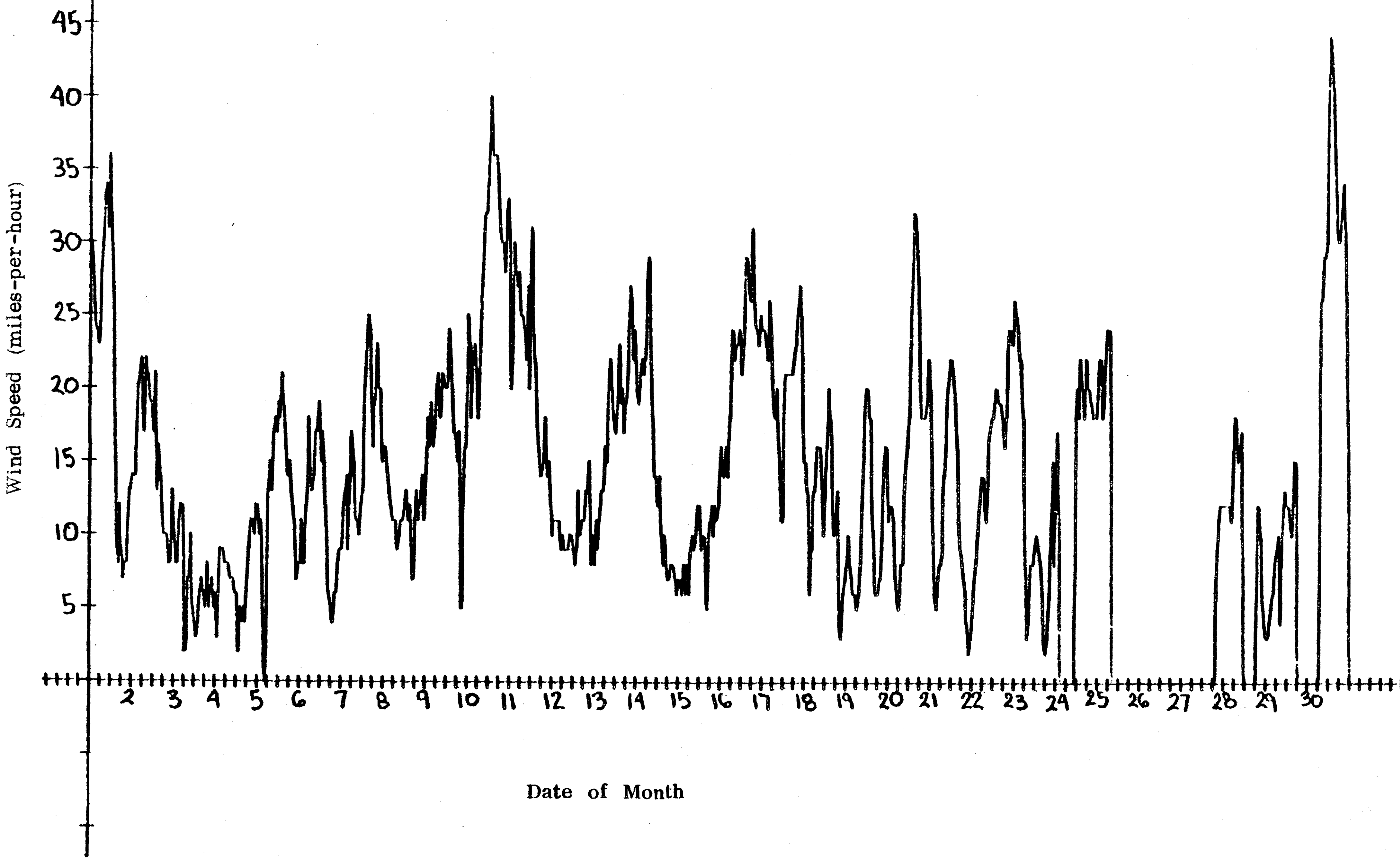

CALUMET, MN MINE DRAINING PROJECT
WIND SPEED DATA 01 DECEMBER-05 DECEMBER 1980
SENSOR LOCATION--WATER TOWER
45
40
35
30
25
20
15
10
5
Wind Speed (miles-per-hour)
2
3
4
5
Date of Month

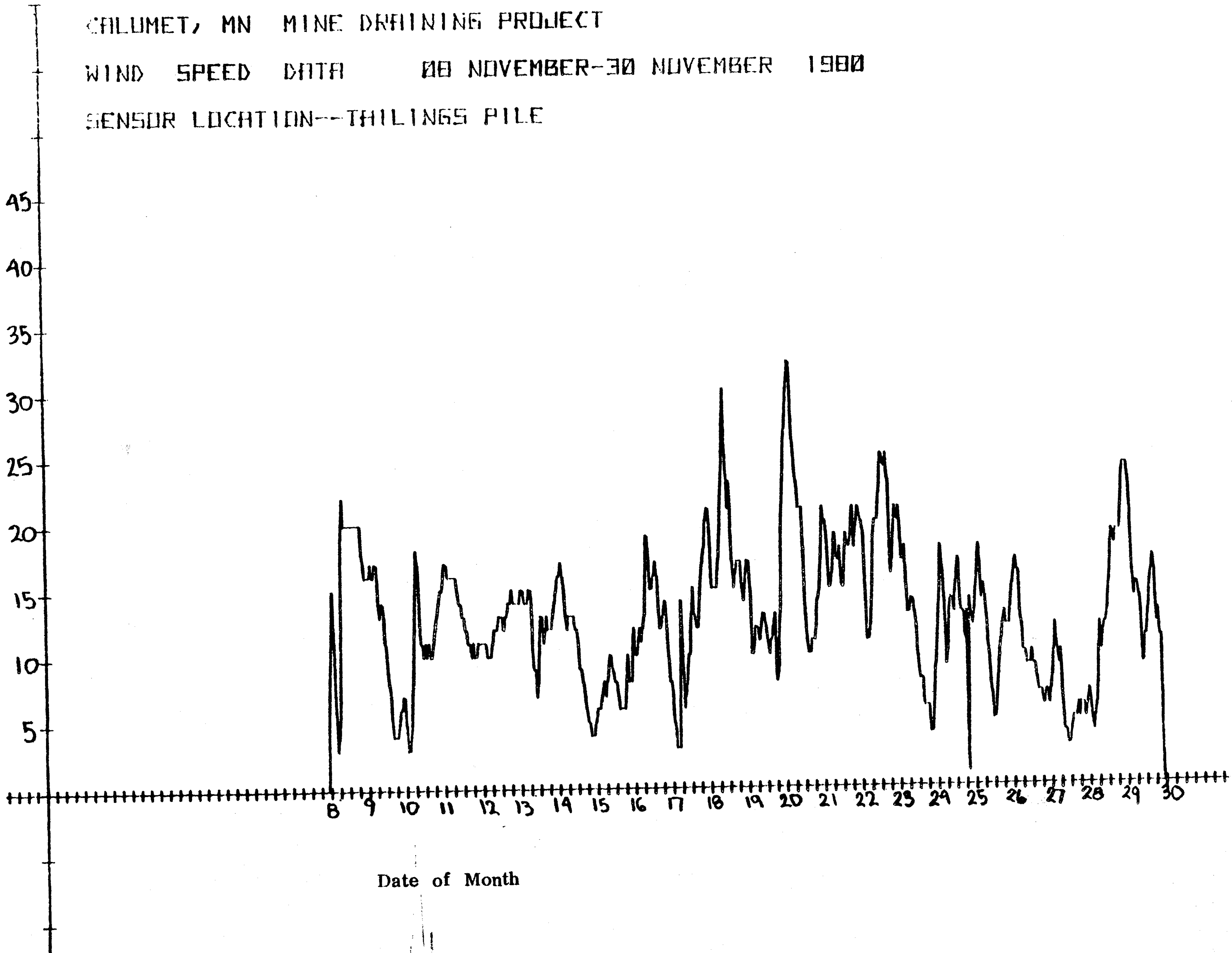

CALUMET, MN MINE TRAINING PROJECT
WIND SPEED DATA 20 SEPTEMBER-30 SEPTEMBER 1980
SENSOR LOCATION--TAILINGS PILE
Wind Speed (miles-per-hour)
45
40
35
30
25
20
15
10
5
21 22 23 24 25 26 27 28 29 30
Date of Month

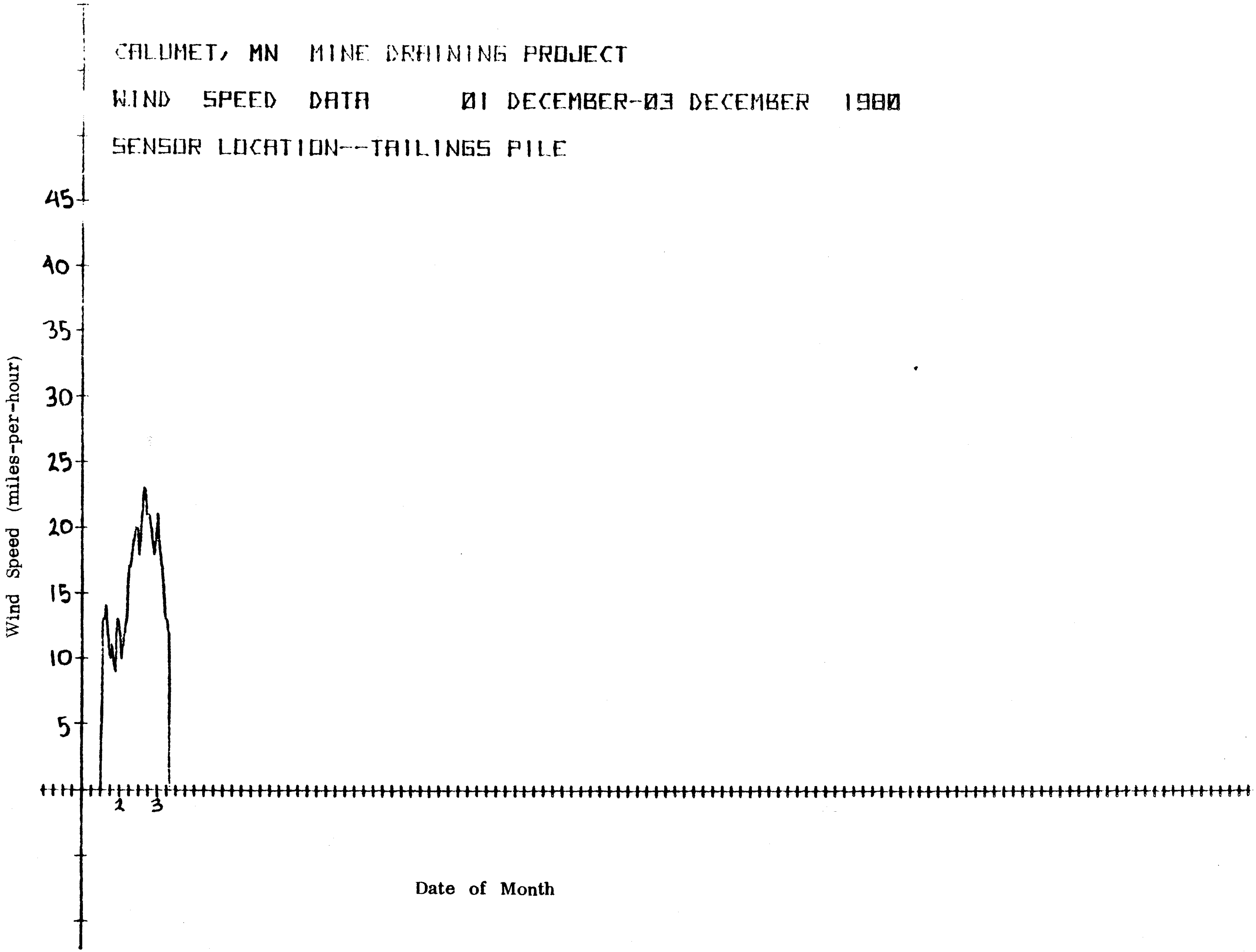
CALUMET, MN MINE DRAINING PROJECT

WIND SPEED DATA 01 OCTOBER-30 OCTOBER 1980

SENSOR LOCATION--TAILINGS PILE



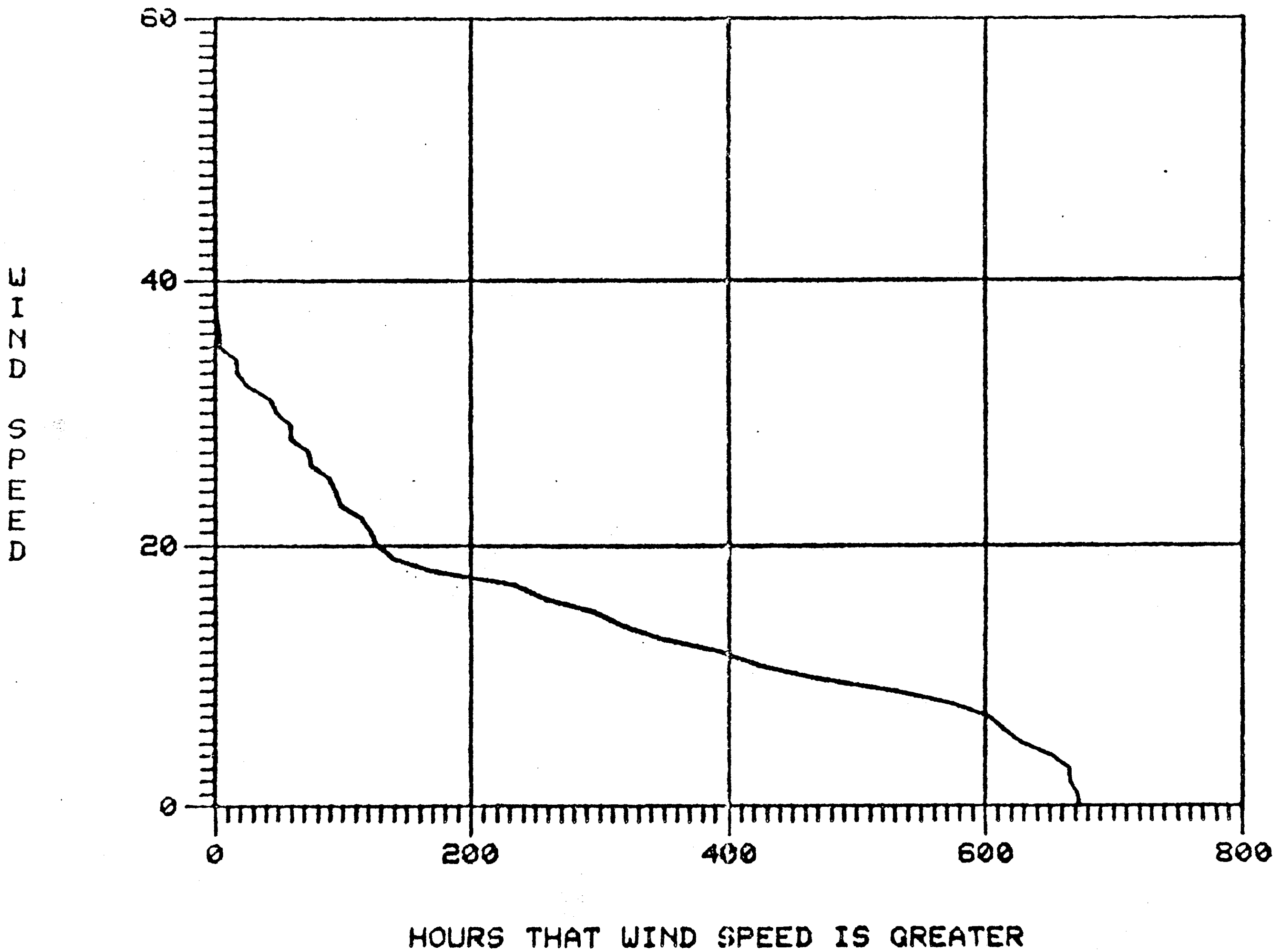

CALUMET, MN MINE DRAINING PROJECT
WIND SPEED DATA 08 NOVEMBER-30 NOVEMBER 1980
SENSOR LOCATION--TAILINGS PILE
Wind Speed (miles-per-hour)
45
40
35
30
25
20
15
10
5
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Date of Month

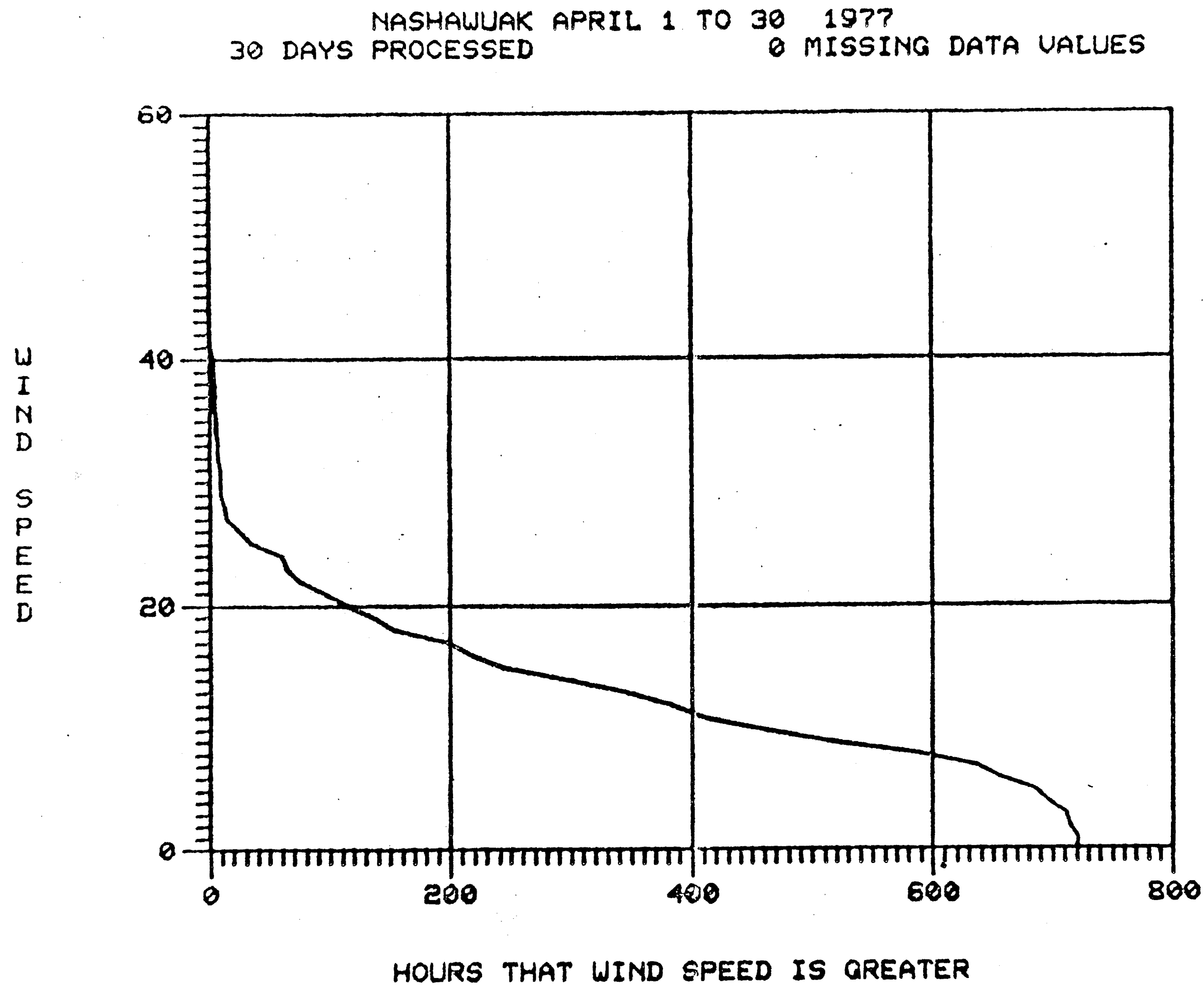

CALUMET, MN MINE DRAINING PROJECT
WIND SPEED DATA 01 DECEMBER-03 DECEMBER 1980
SENSOR LOCATION--TAILINGS PILE
45
40
35
30
25
20
15
10
5
Wind Speed (miles-per-hour)
1
3
Date of Month

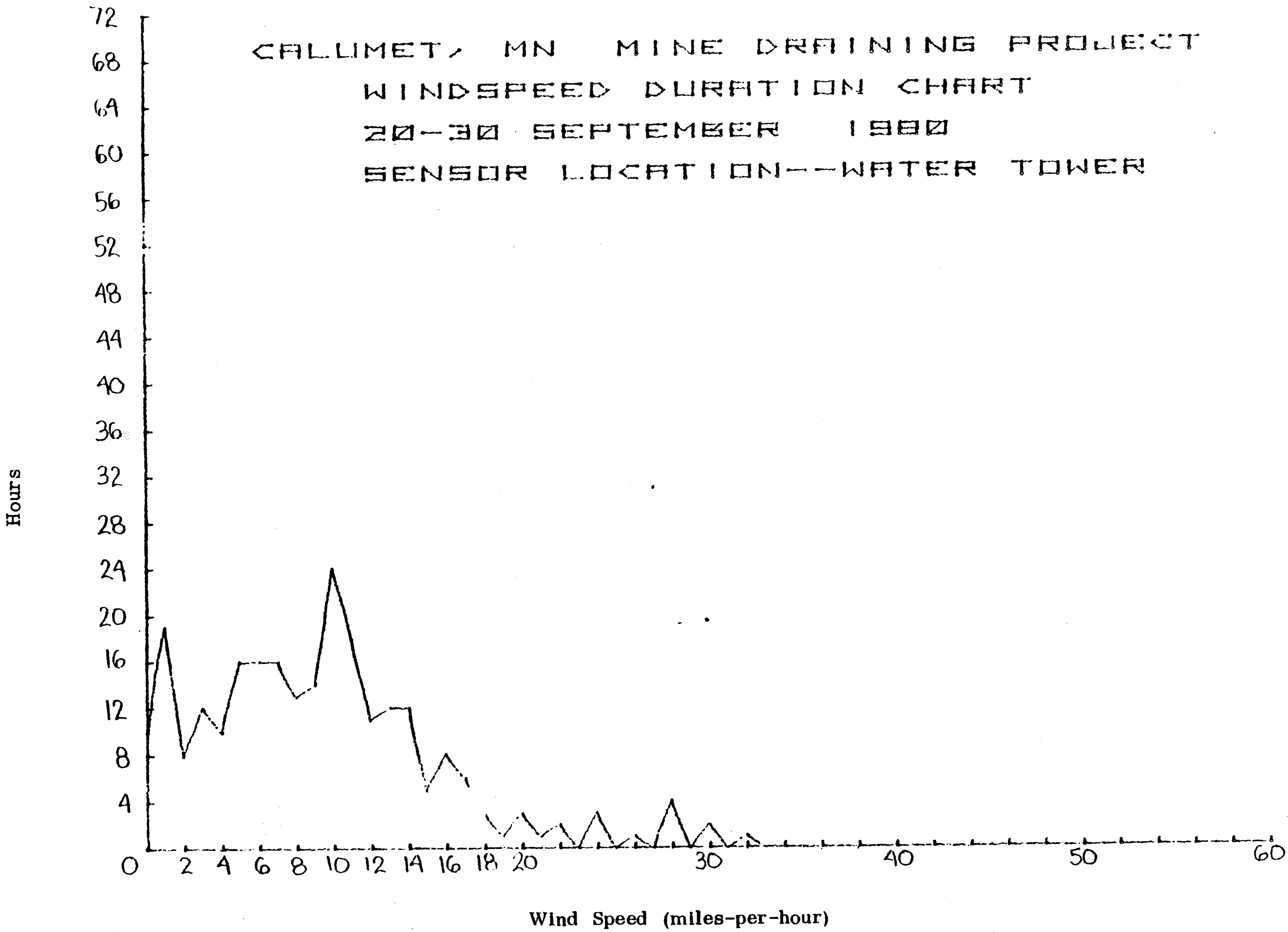
Appendix 7

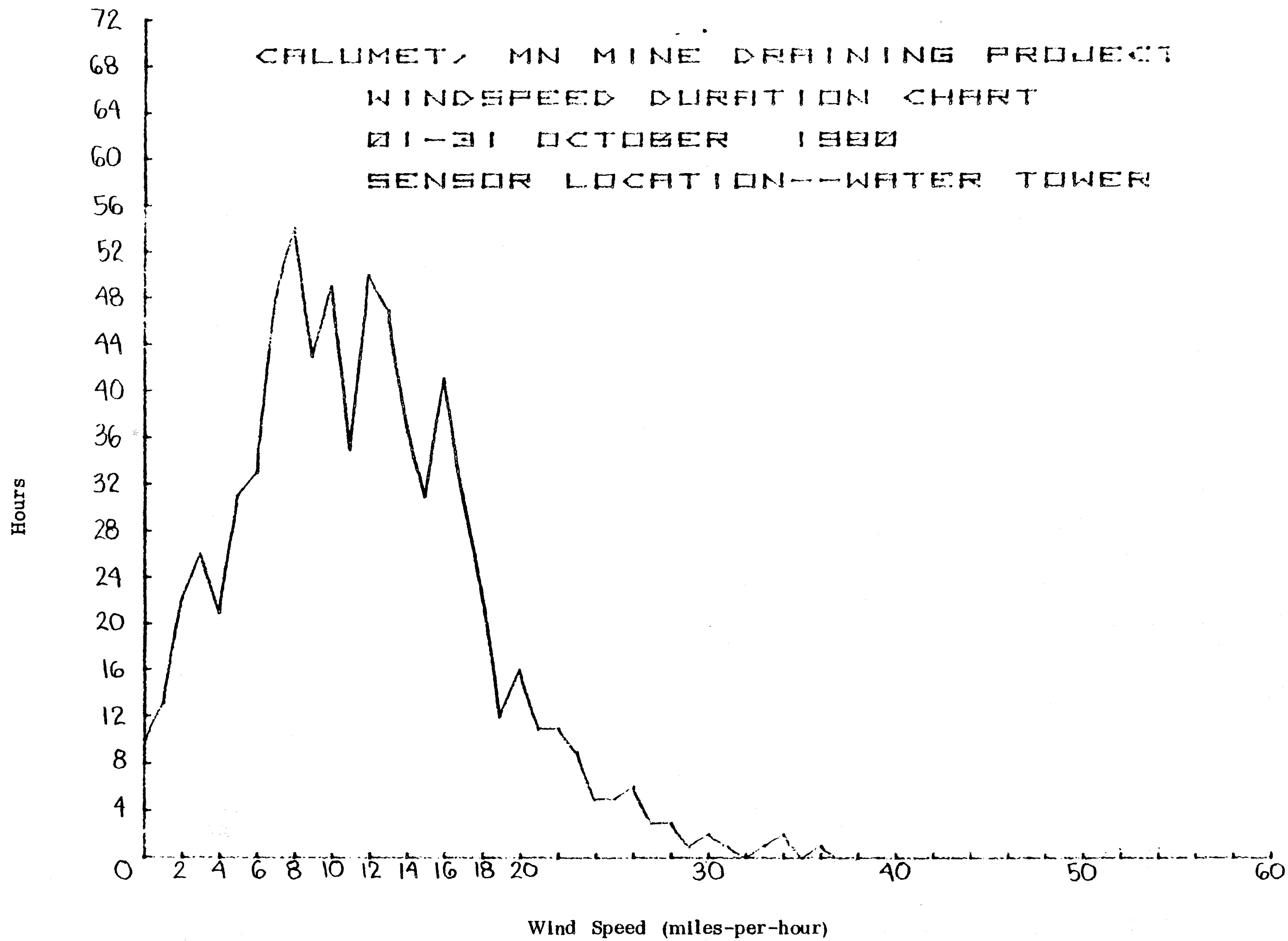
Wind Speed Duration by Site
Per Month

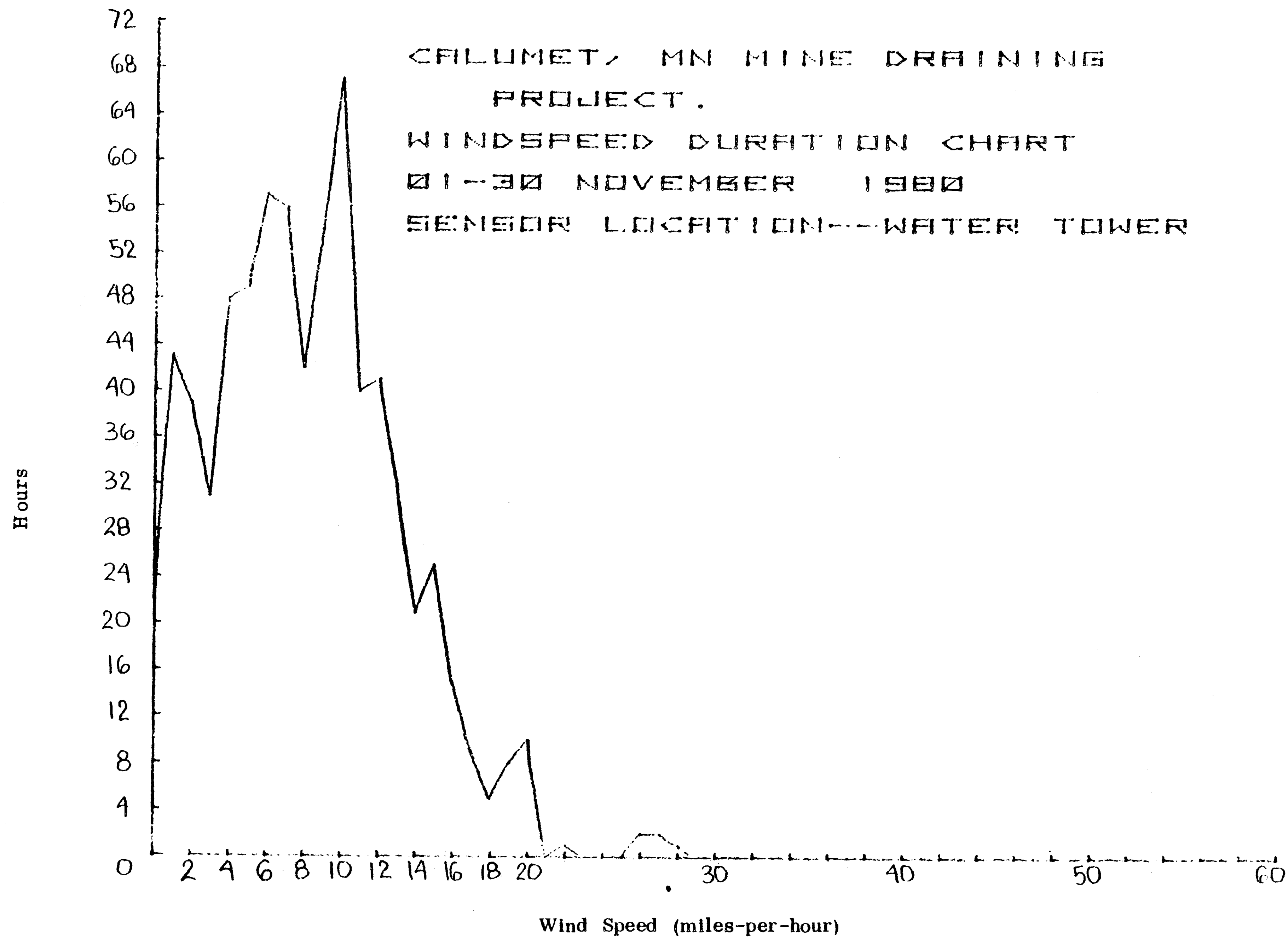
NASHAWAUK MARCH 1 TO 31 1977
31 DAYS PROCESSED 71 MISSING DATA VALUES

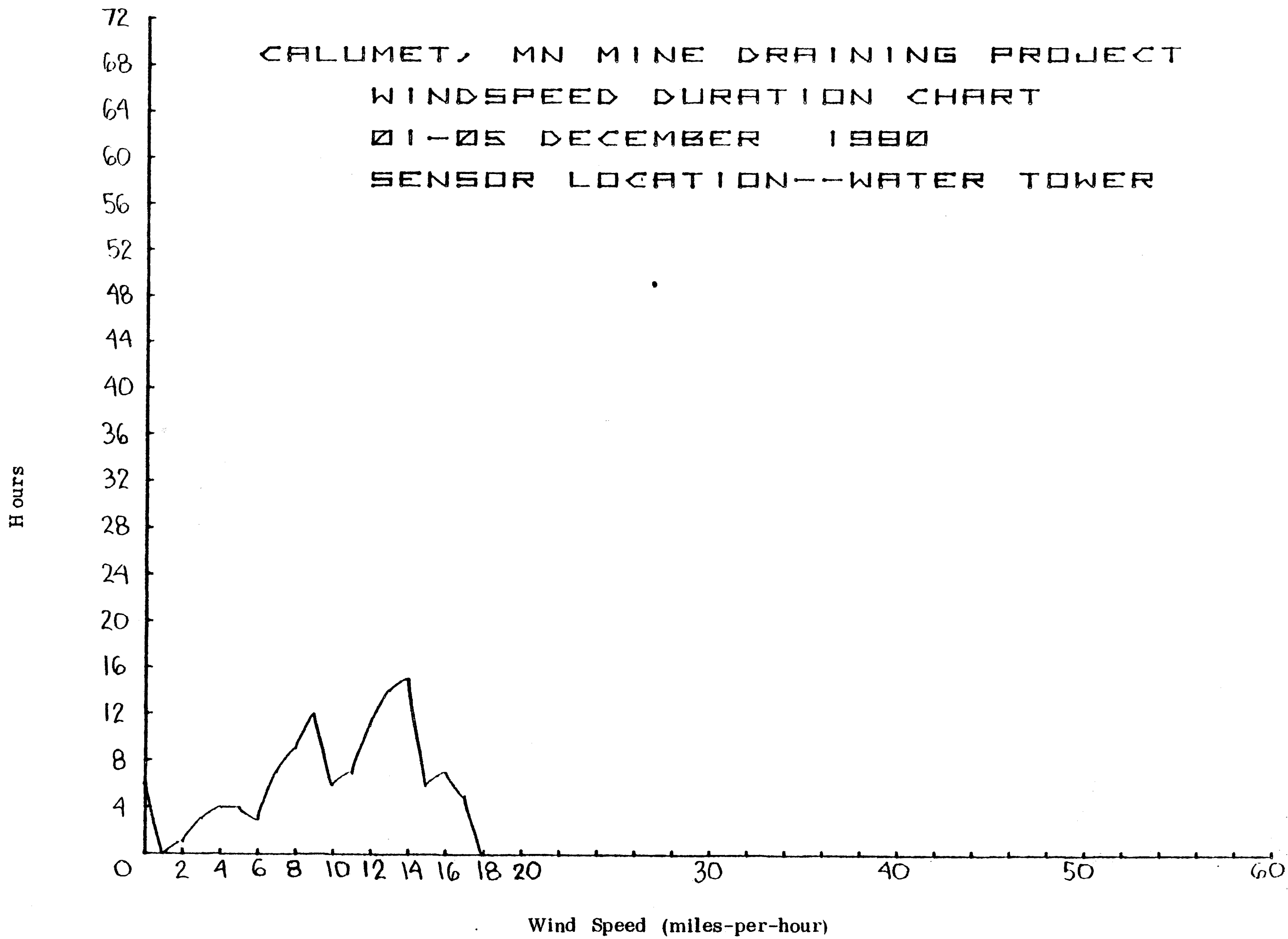


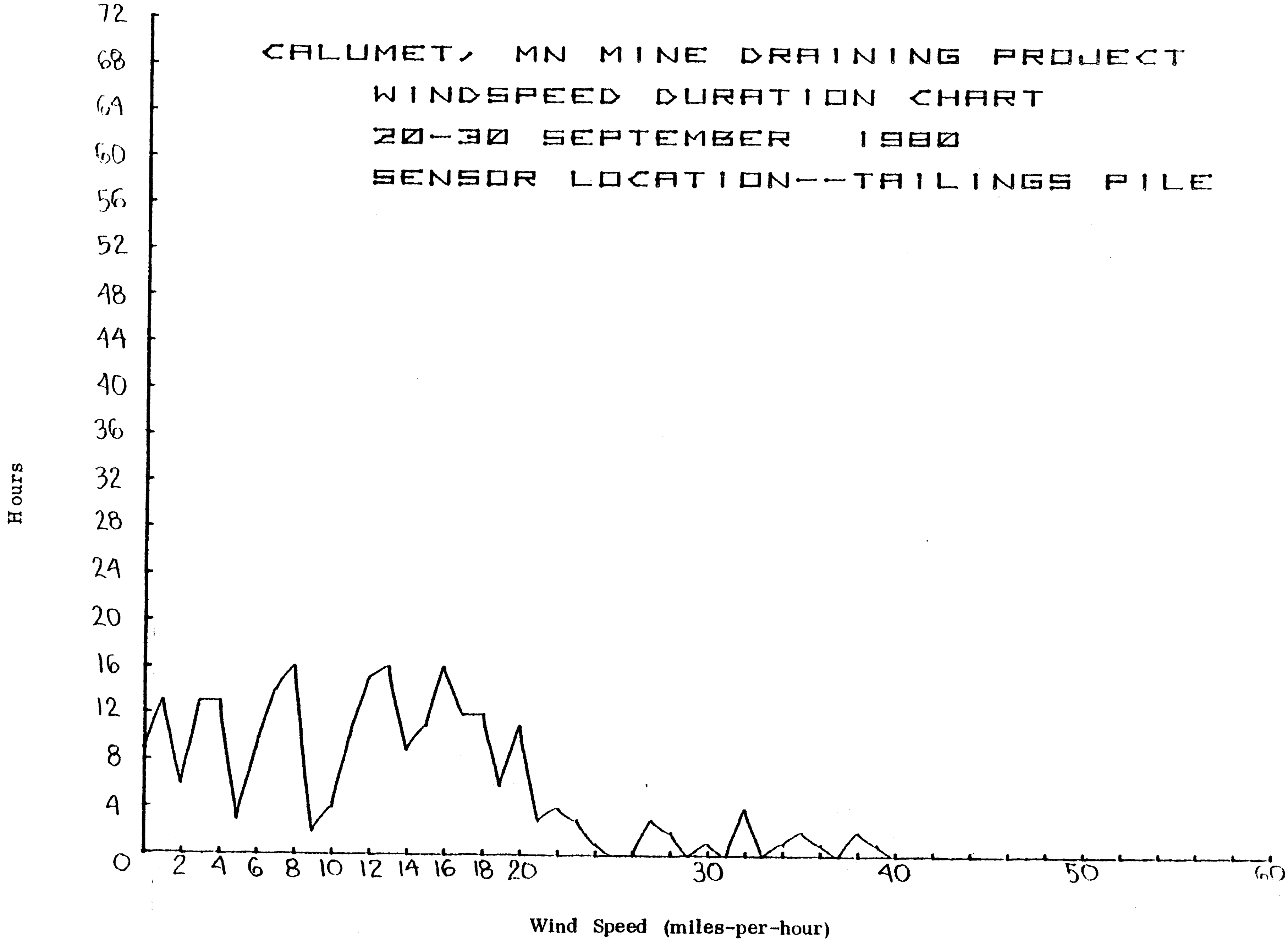

NASHAWUAK APRIL 1 TO 30 1977
30 DAYS PROCESSED
0 MISSING DATA VALUES
WIND SPEED
60
40
20
0
0
200
400
600
800
HOURS THAT WIND SPEED IS GREATER

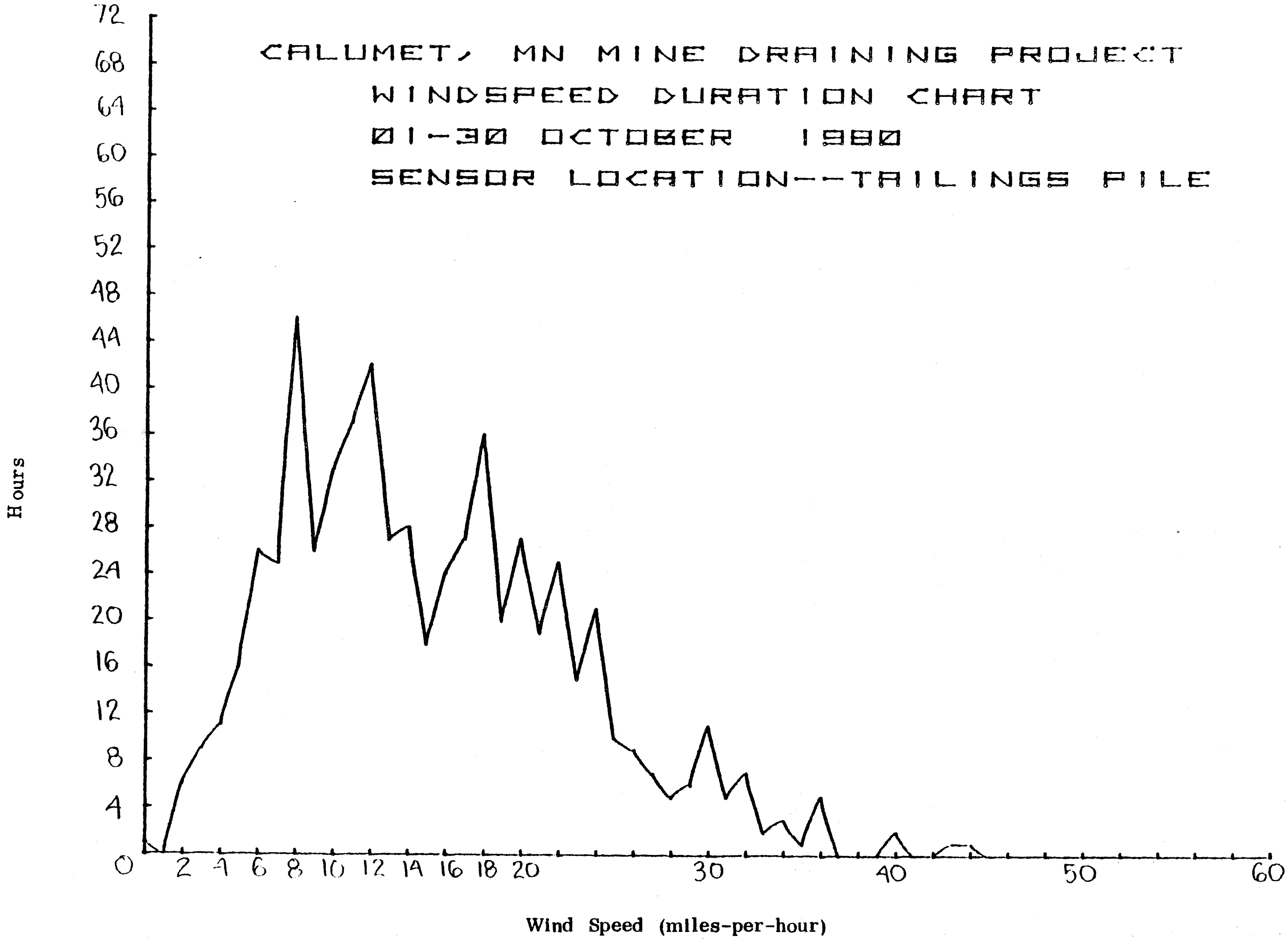

CALUMET, MN MINE DRAINING PROJECT
WINDSPEED DURATION CHART
20-30 SEPTEMBER 1980
SENSOR LOCATION--WATER TOWER
Hours
72
68
64
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
2
4
6
8
10
12
14
16
18
20
30
40
50
60
Wind Speed (miles-per-hour)


CALUMET, MN MINE DRAINING PROJECT
WINDSPEED DURATION CHART
01-31 OCTOBER 1980
SENSOR LOCATION--WATER TOWER
Hours
Wind Speed (miles-per-hour)
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72
2 4 6 8 10 12 14 16 18 20 30 40 50 60

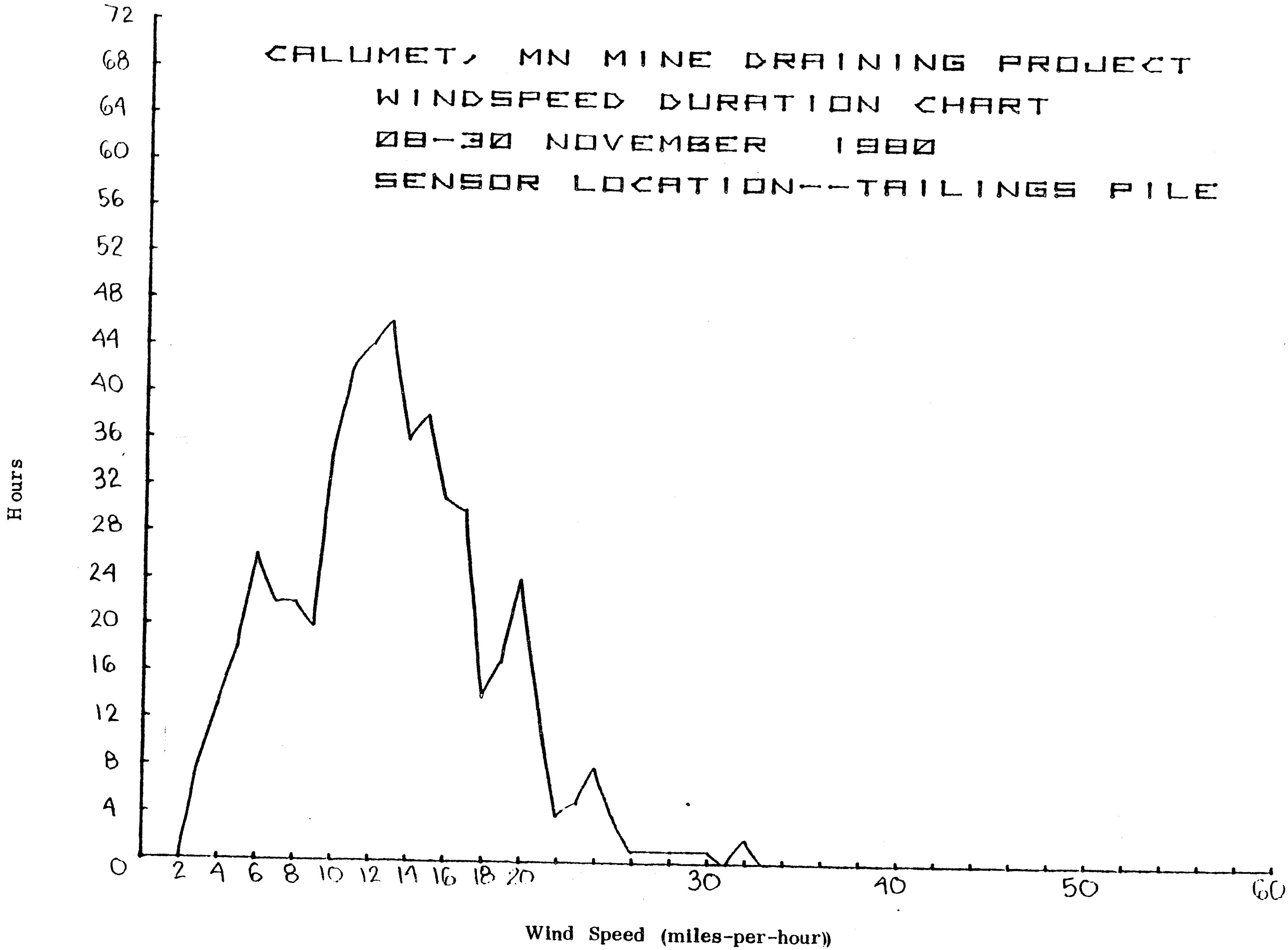

CALUMET, MN MINE DRAINING
PROJECT.
WINDSPEED DURATION CHART
01-30 NOVEMBER 1980
SENSOR LOCATION--WATER TOWER
Hours
72
68
64
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
2 4 6 8 10 12 14 16 18 20 30 40 50 60
Wind Speed (miles-per-hour)

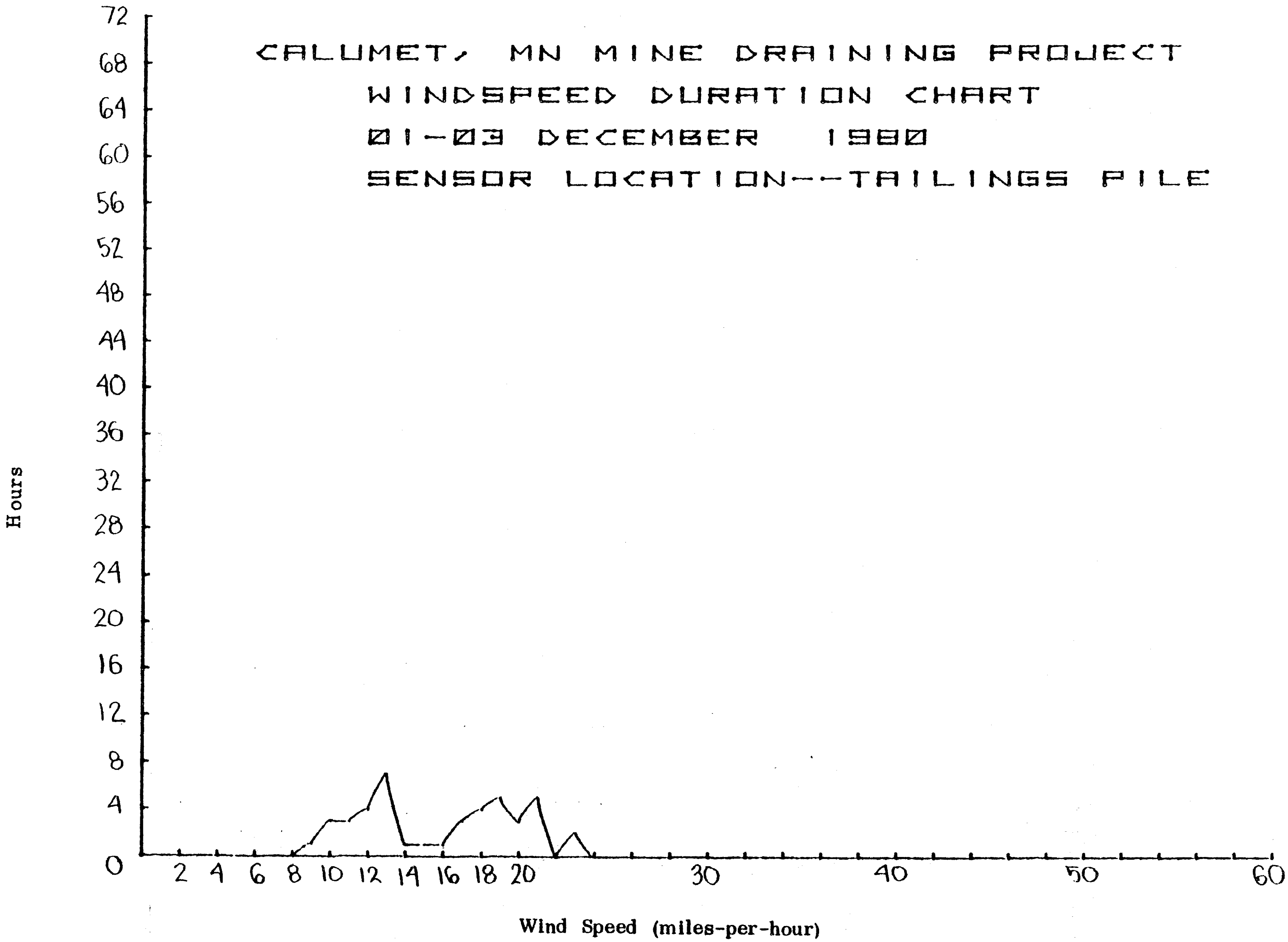

CALUMET, MN MINE DRAINING PROJECT
WINDSPEED DURATION CHART
01-05 DECEMBER 1980
SENSOR LOCATION--WATER TOWER
72
68
64
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
Hours
2 4 6 8 10 12 14 16 18 20 30 40 50 60
Wind Speed (miles-per-hour)


CALUMET, MN MINE DRAINING PROJECT
WINDSPEED DURATION CHART
20-30 SEPTEMBER 1980
SENSOR LOCATION--TAILINGS PILE
Hours
72
68
64
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
2 4 6 8 10 12 14 16 18 20 30 40 50 60
Wind Speed (miles-per-hour)



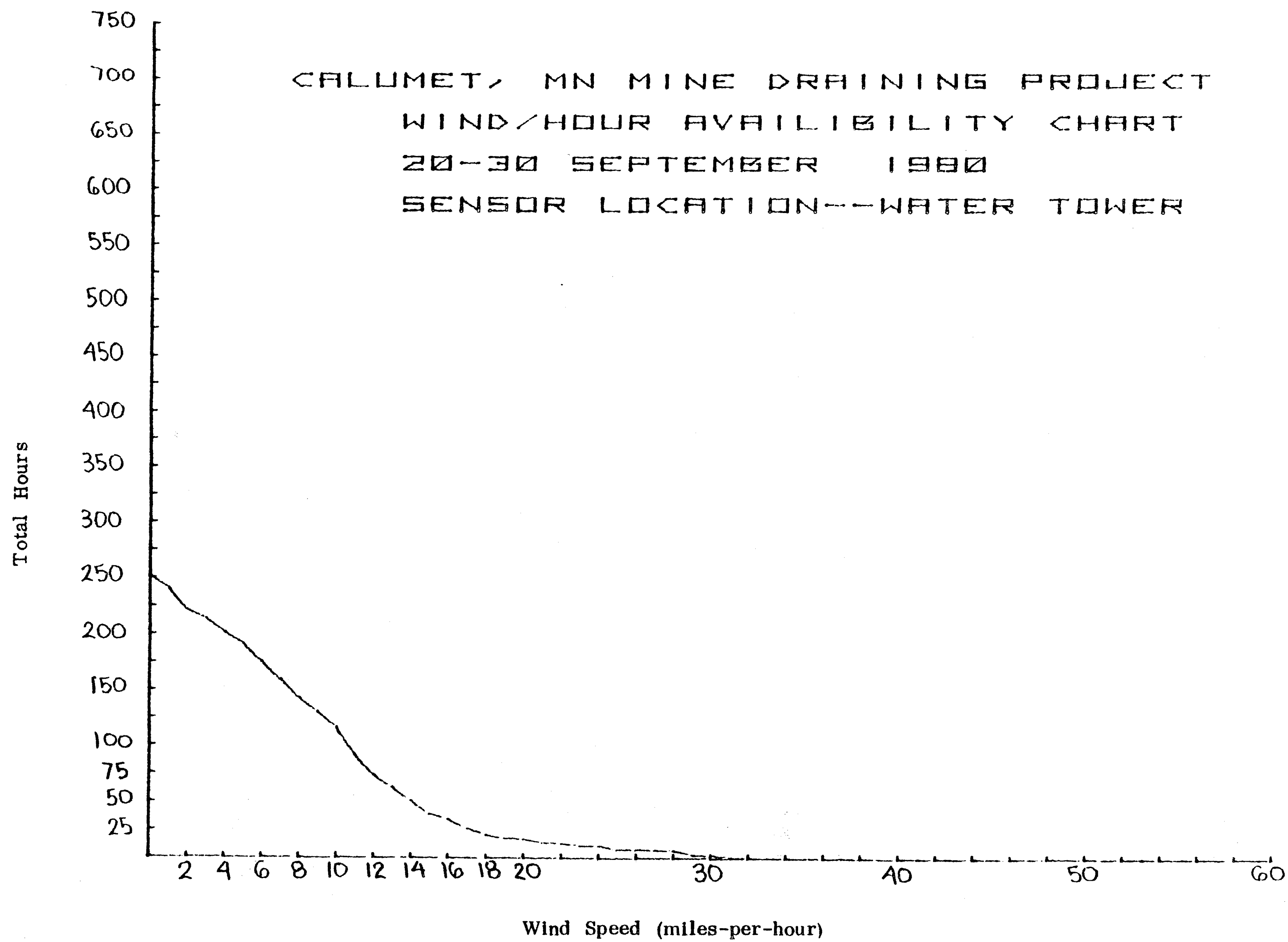
CALUMET, MN MINE DRAINING PROJECT
WINDSPEED DURATION CHART
01-30 OCTOBER 1980
SENSOR LOCATION--TAILINGS PILE
Hours
72
68
64
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
2
4
6
8
10
12
14
16
18
20
30
40
50
60
Wind Speed (miles-per-hour)

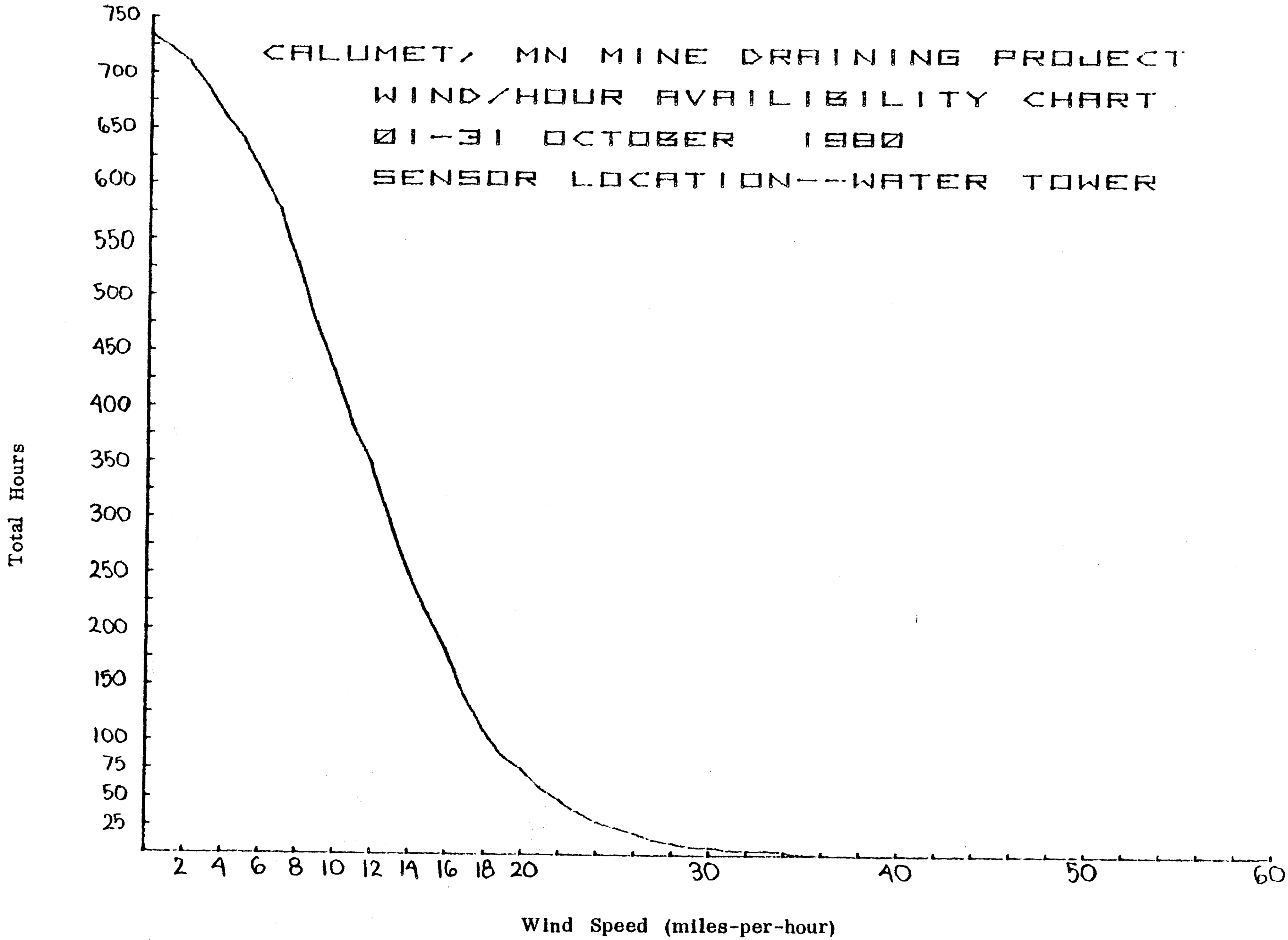

CALUMET, MN MINE DRAINING PROJECT
WINDSPEED DURATION CHART
08-30 NOVEMBER 1980
SENSOR LOCATION--TAILINGS PILE
Hours
72
68
64
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
2 4 6 8 10 12 14 16 18 20 30 40 50 60
Wind Speed (miles-per-hour)

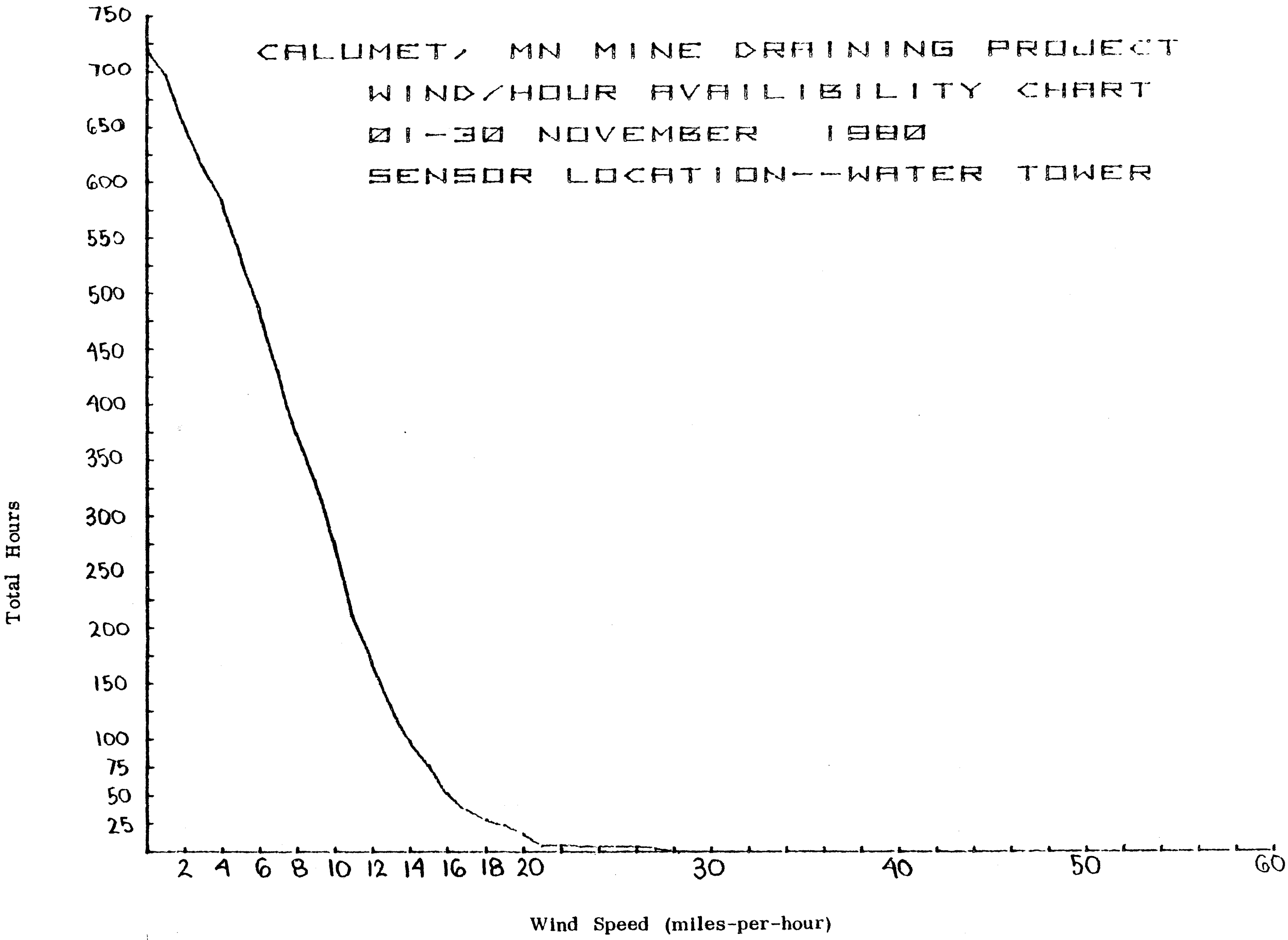

CALUMET, MN MINE DRAINING PROJECT
WINDSPEED DURATION CHART
01-03 DECEMBER 1980
SENSOR LOCATION--TAILINGS PILE
Hours
72
68
64
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
2 4 6 8 10 12 14 16 18 20 30 40 50 60
Wind Speed (miles-per-hour)

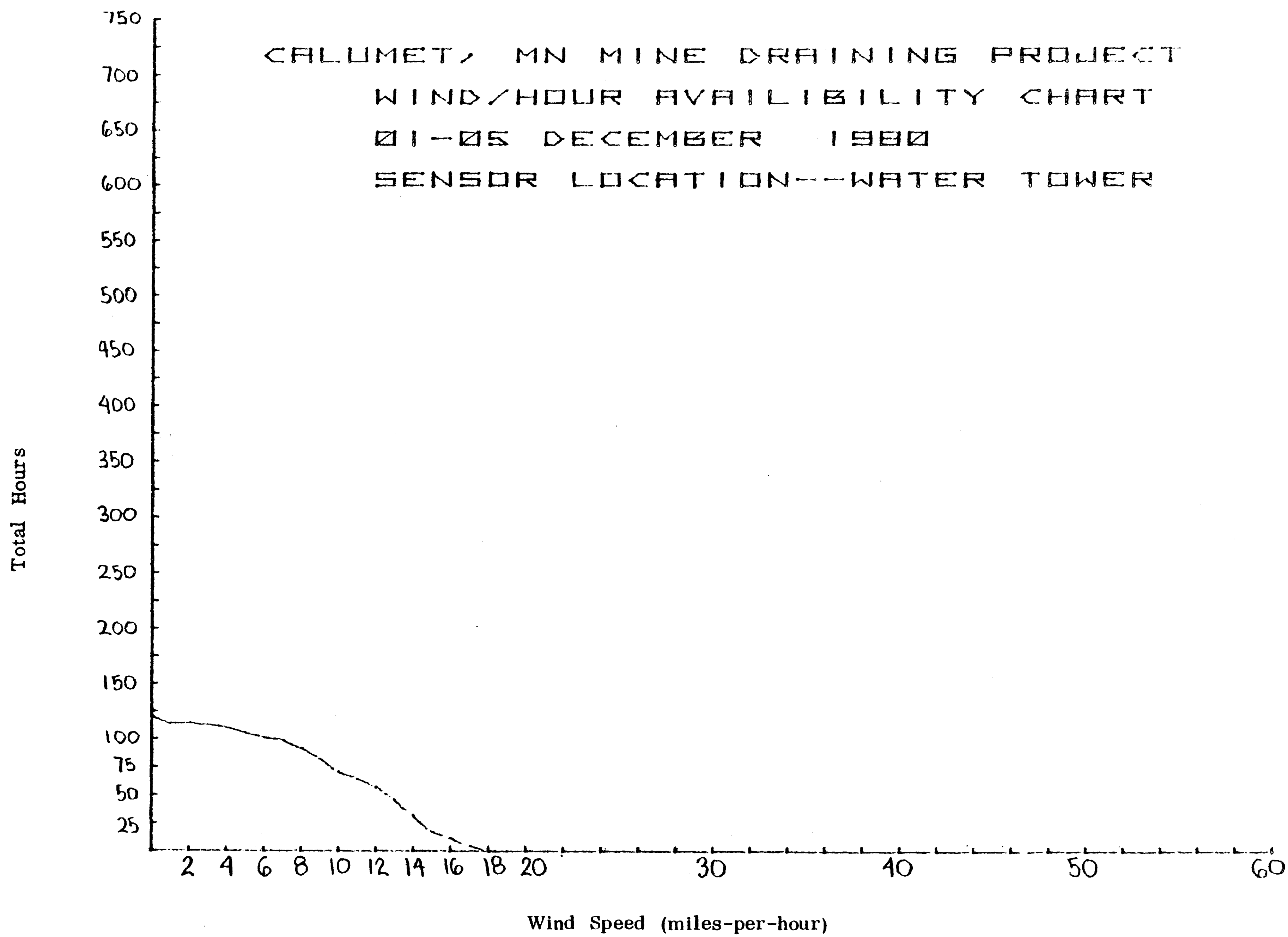
Appendix 8

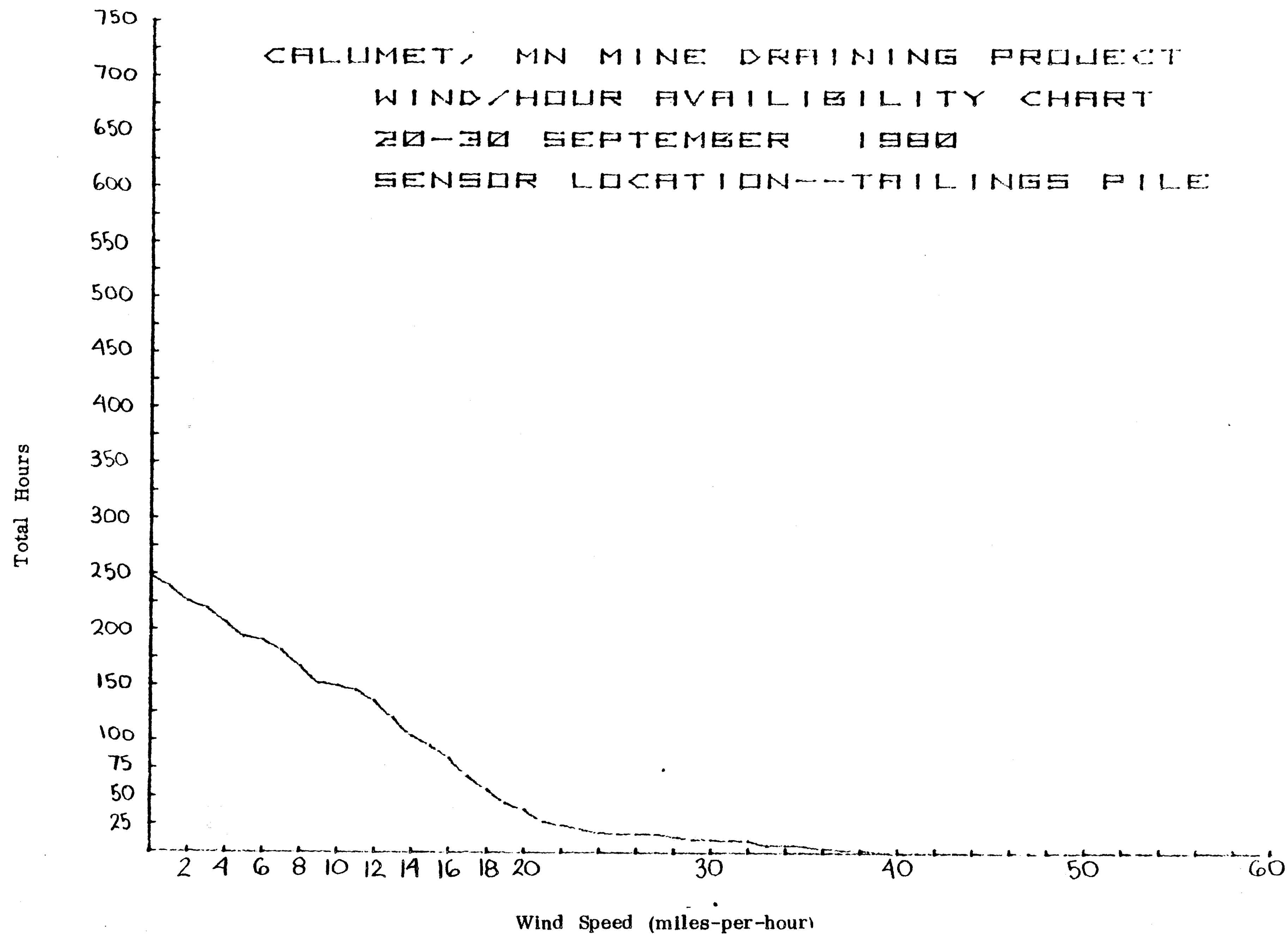
Wind/hour Availability by Sites
Per Month

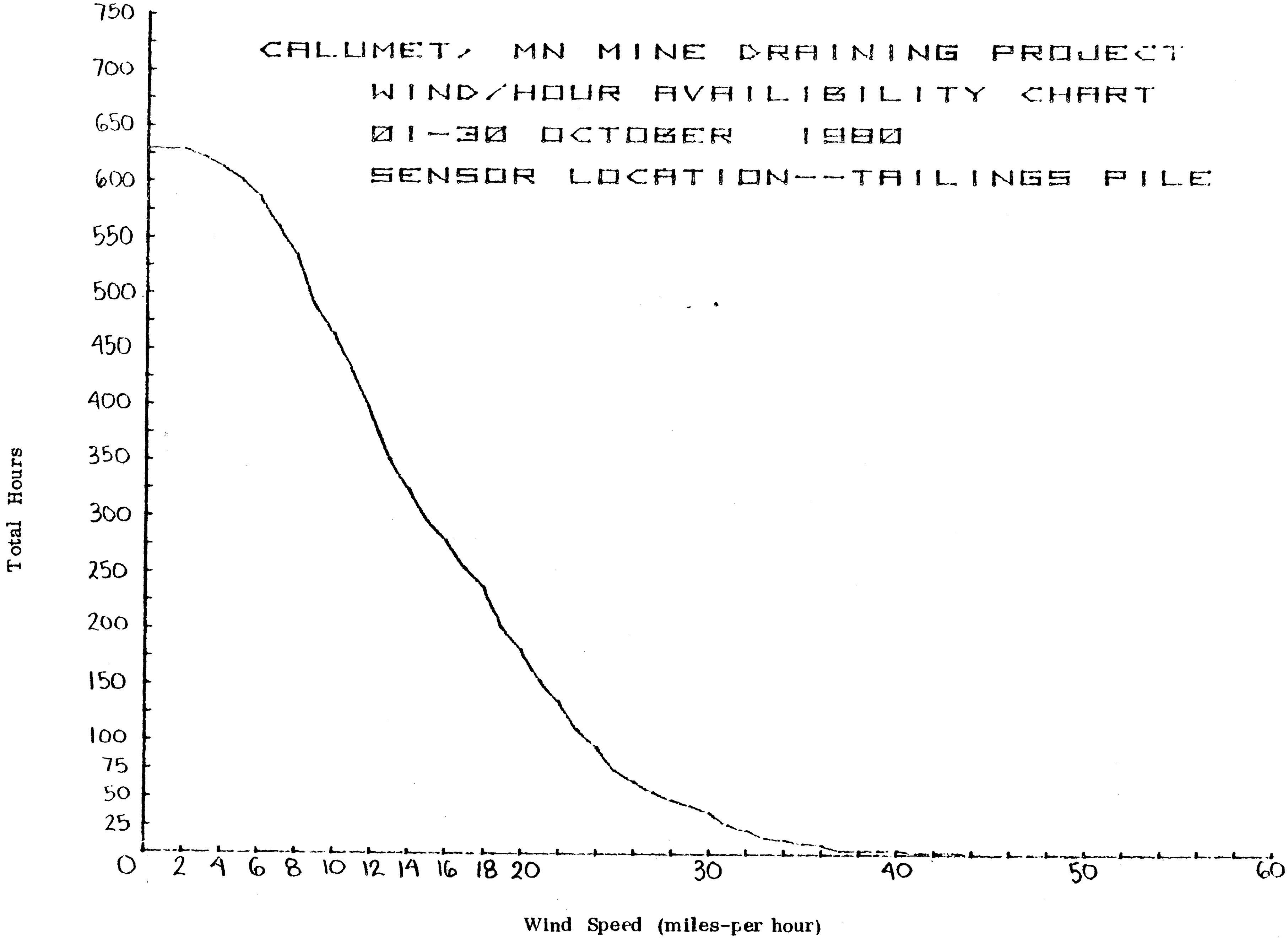

CALUMET, MN MINE DRAINING PROJECT
WIND/HOUR AVAILIBILITY CHART
20-30 SEPTEMBER 1980
SENSOR LOCATION--WATER TOWER
Total Hours
750
700
650
600
550
500
450
400
350
300
250
200
150
100
75
50
25
2 4 6 8 10 12 14 16 18 20 30 40 50 60
Wind Speed (miles-per-hour)


CALUMET, MN MINE DRAINING PROJECT
WIND/HOUR AVAILIBILITY CHART
01-31 OCTOBER 1980
SENSOR LOCATION--WATER TOWER
Total Hours
750
700
650
600
550
500
450
400
350
300
250
200
150
100
75
50
25
2 4 6 8 10 12 14 16 18 20 30 40 50 60
Wind Speed (miles-per-hour)

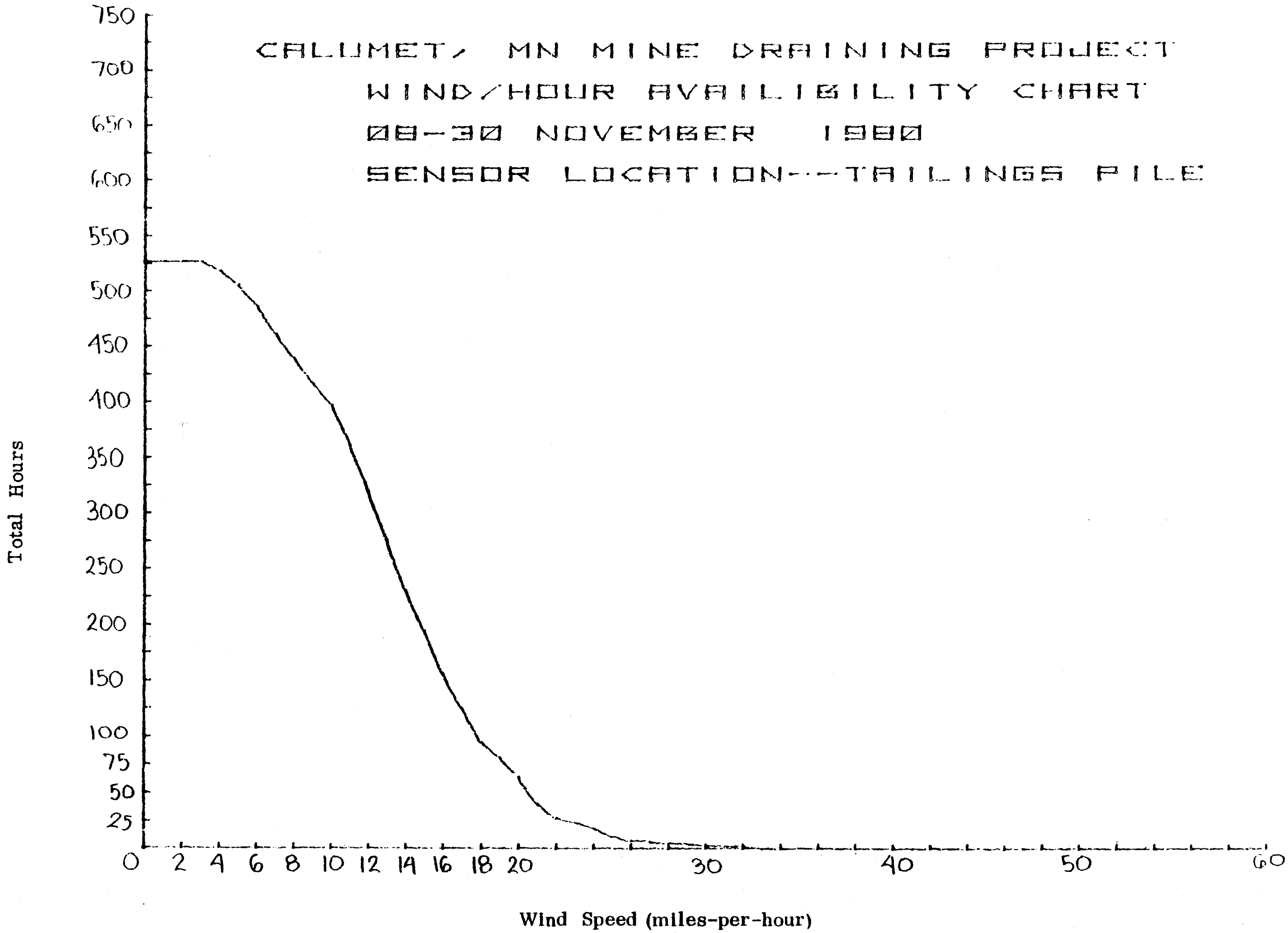

CALUMET, MN MINE DRAINING PROJECT
WIND/HOUR AVAILIBILITY CHART
01-30 NOVEMBER 1980
SENSOR LOCATION--WATER TOWER
Total Hours
750
700
650
600
550
500
450
400
350
300
250
200
150
100
75
50
25
2 4 6 8 10 12 14 16 18 20 30 40 50 60
Wind Speed (miles-per-hour)


CALUMET, MN MINE DRAINING PROJECT
WIND/HOUR AVAILIBILITY CHART
01-05 DECEMBER 1980
SENSOR LOCATION--WATER TOWER
Total Hours
750
700
650
600
550
500
450
400
350
300
250
200
150
100
75
50
25
2 4 6 8 10 12 14 16 18 20 30 40 50 60
Wind Speed (miles-per-hour)

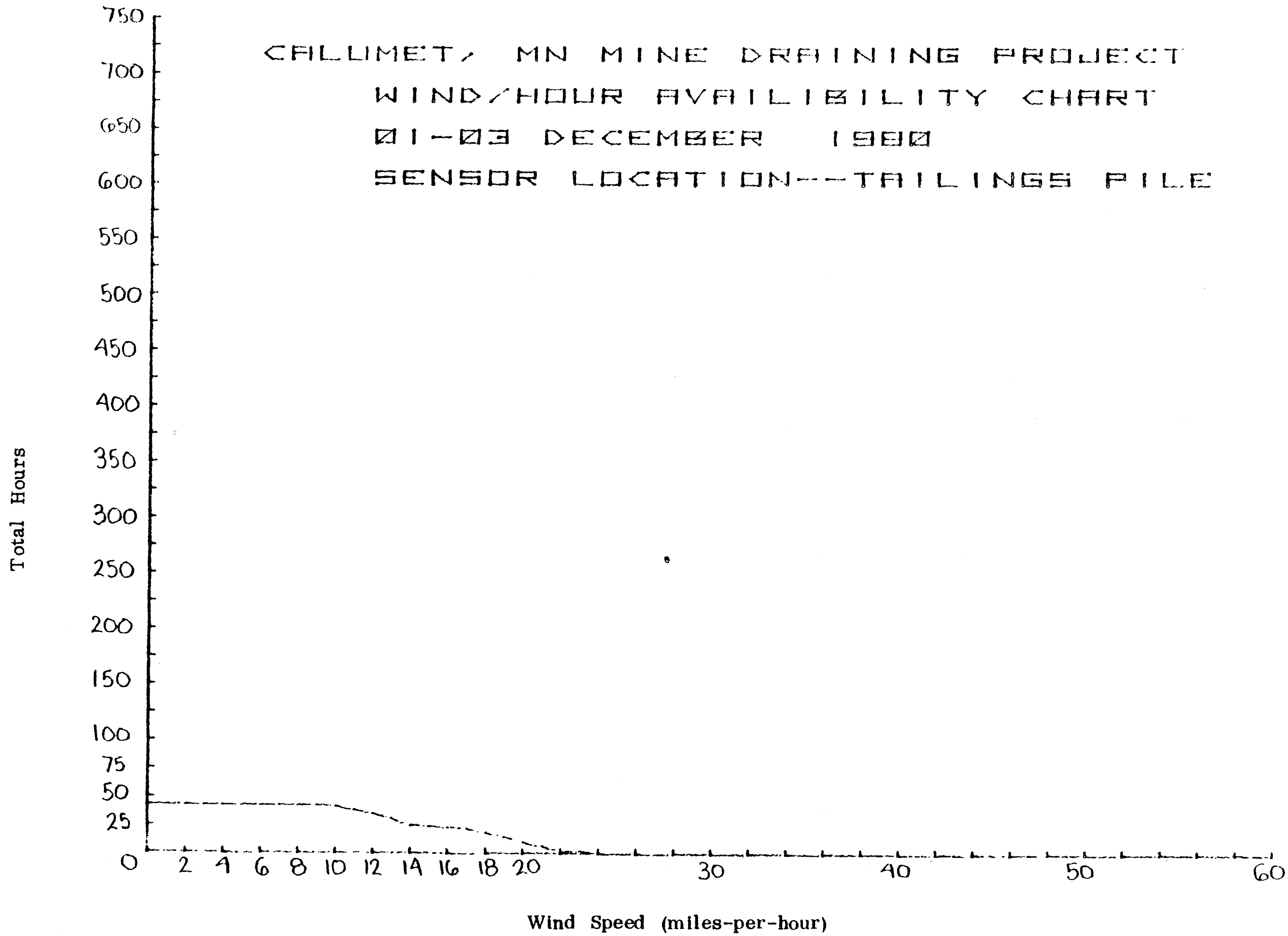

CALUMET, MN MINE DRAINING PROJECT
WIND/HOUR AVAILIBILITY CHART
20-30 SEPTEMBER 1980
SENSOR LOCATION--TAILINGS PILE
Total Hours
750
700
650
600
550
500
450
400
350
300
250
200
150
100
75
50
25
2 4 6 8 10 12 14 16 18 20 30 40 50 60
Wind Speed (miles-per-hour)



CALUMET, MN MINE DRAINING PROJECT
WIND/HOUR AVAILIBILITY CHART
01-30 OCTOBER 1980
SENSOR LOCATION--TAILINGS PILE
Total Hours
750
700
650
600
550
500
450
400
350
300
250
200
150
100
75
50
25
0
2
4
6
8
10
12
14
16
18
20
30
40
50
60
Wind Speed (miles-per hour)



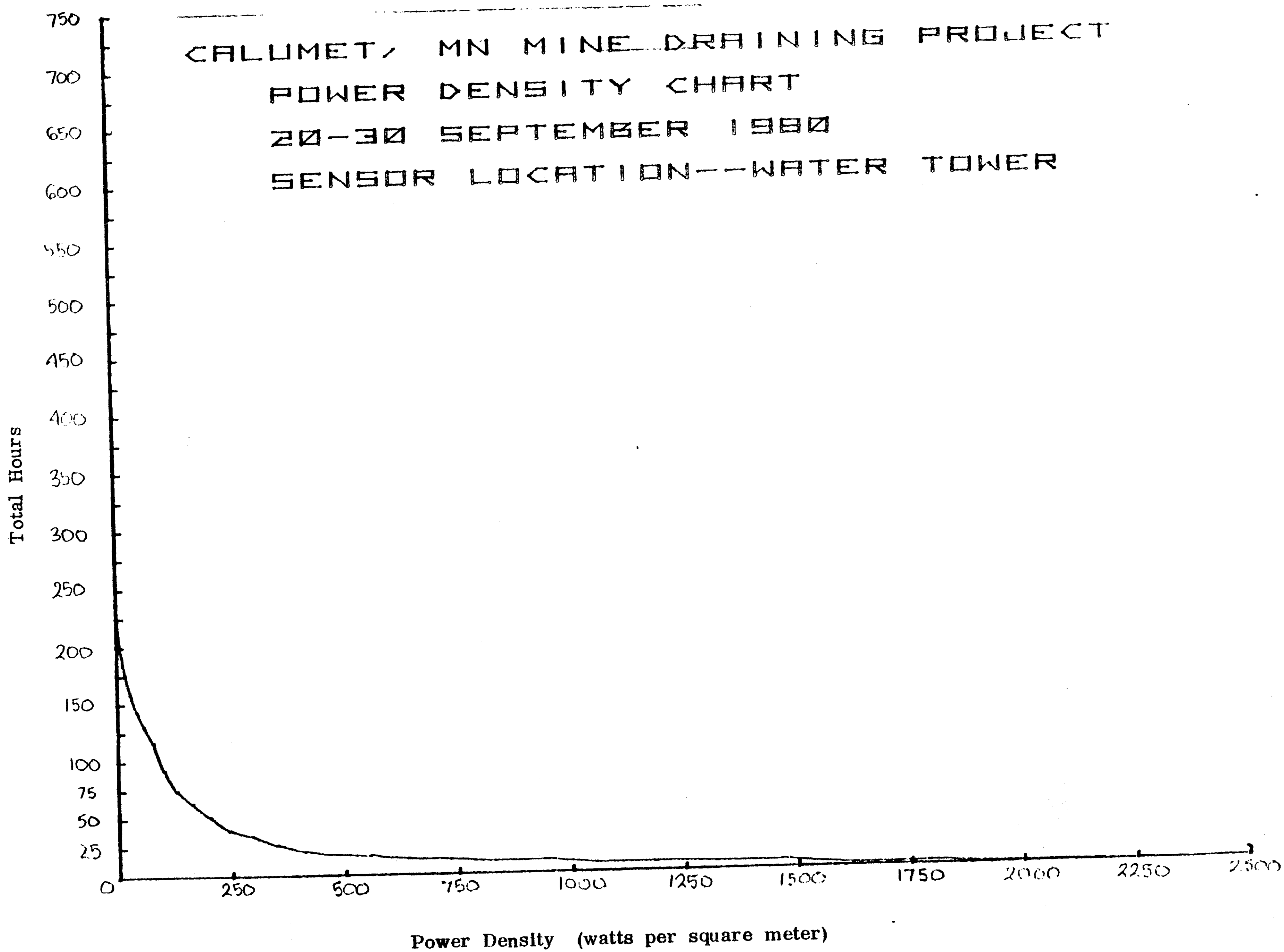
CALUMET, MN MINE DRAINING PROJECT
WIND/HOUR AVAILIBILITY CHART
08-30 NOVEMBER 1980
SENSOR LOCATION--TAILINGS PILE
Total Hours
750
700
650
600
550
500
450
400
350
300
250
200
150
100
75
50
25
0
2
4
6
8
10
12
14
16
18
20
30
40
50
60
Wind Speed (miles-per-hour)

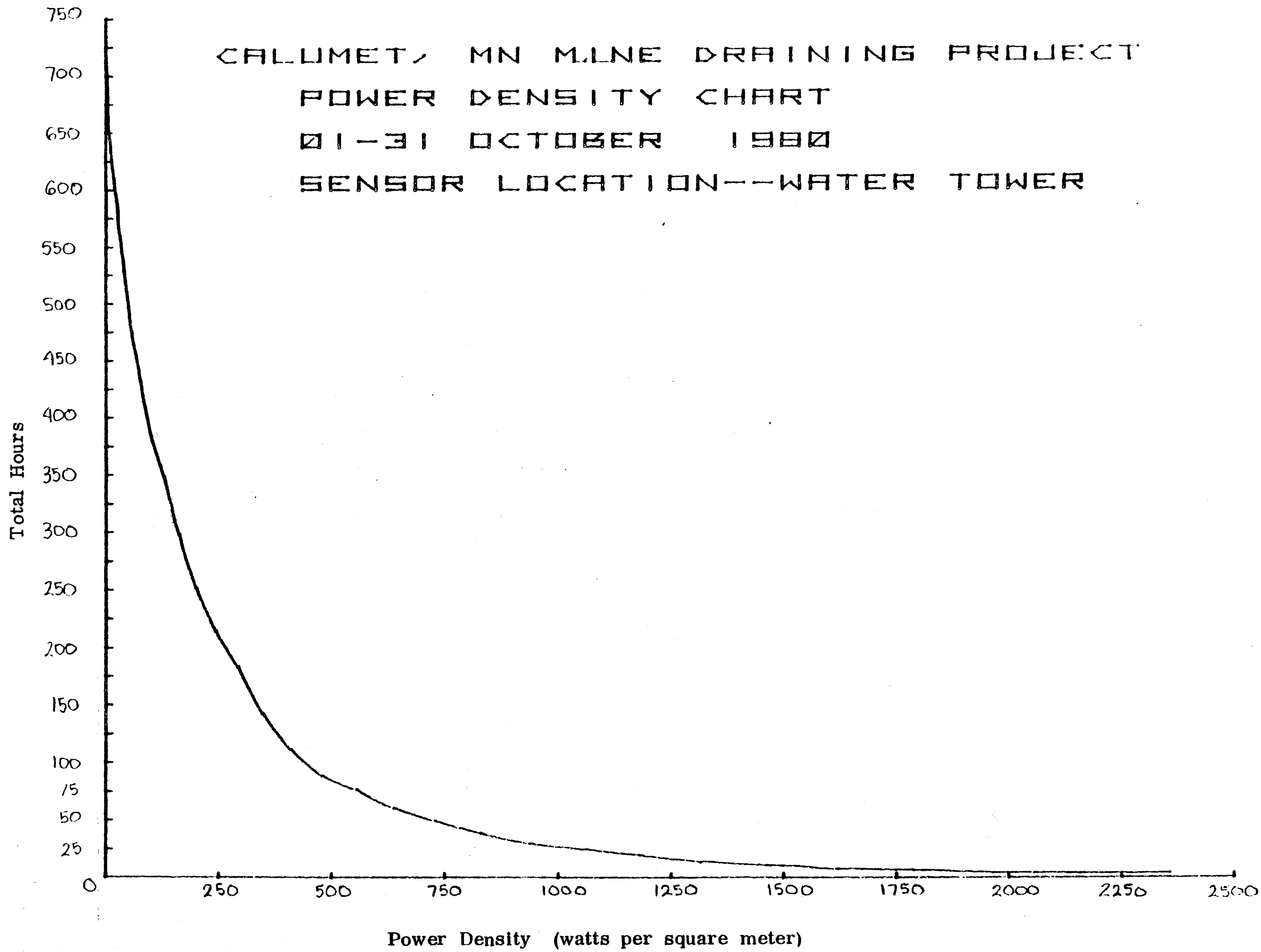


CALUMET, MN MINE DRAINING PROJECT
WIND/HOUR AVAILIBILITY CHART
01-03 DECEMBER 1980
SENSOR LOCATION--TAILINGS PILE
Total Hours
750
700
650
600
550
500
450
400
350
300
250
200
150
100
75
50
25
0
2
4
6
8
10
12
14
16
18
20
30
40
50
60
Wind Speed (miles-per-hour)

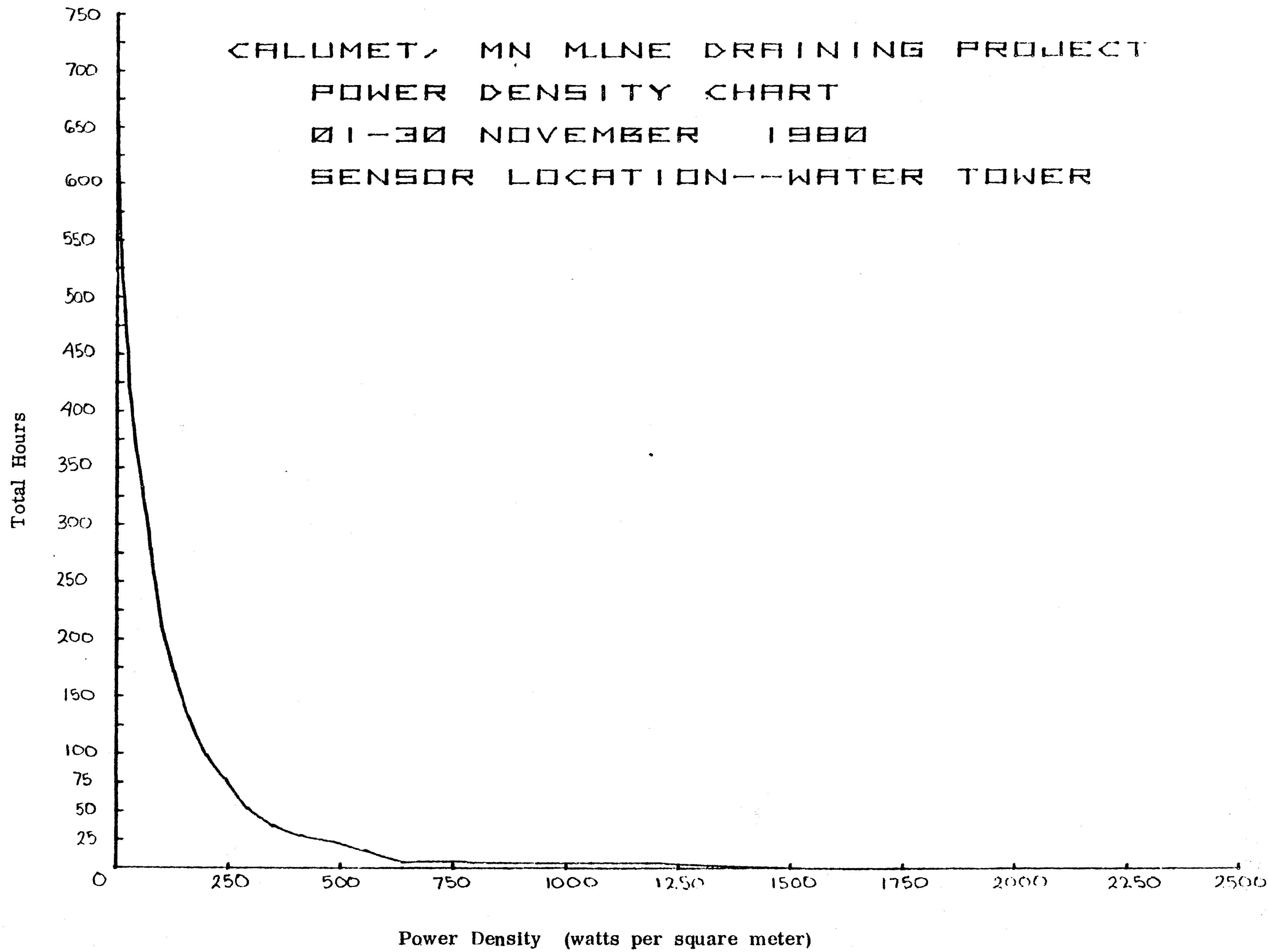
Appendix 9

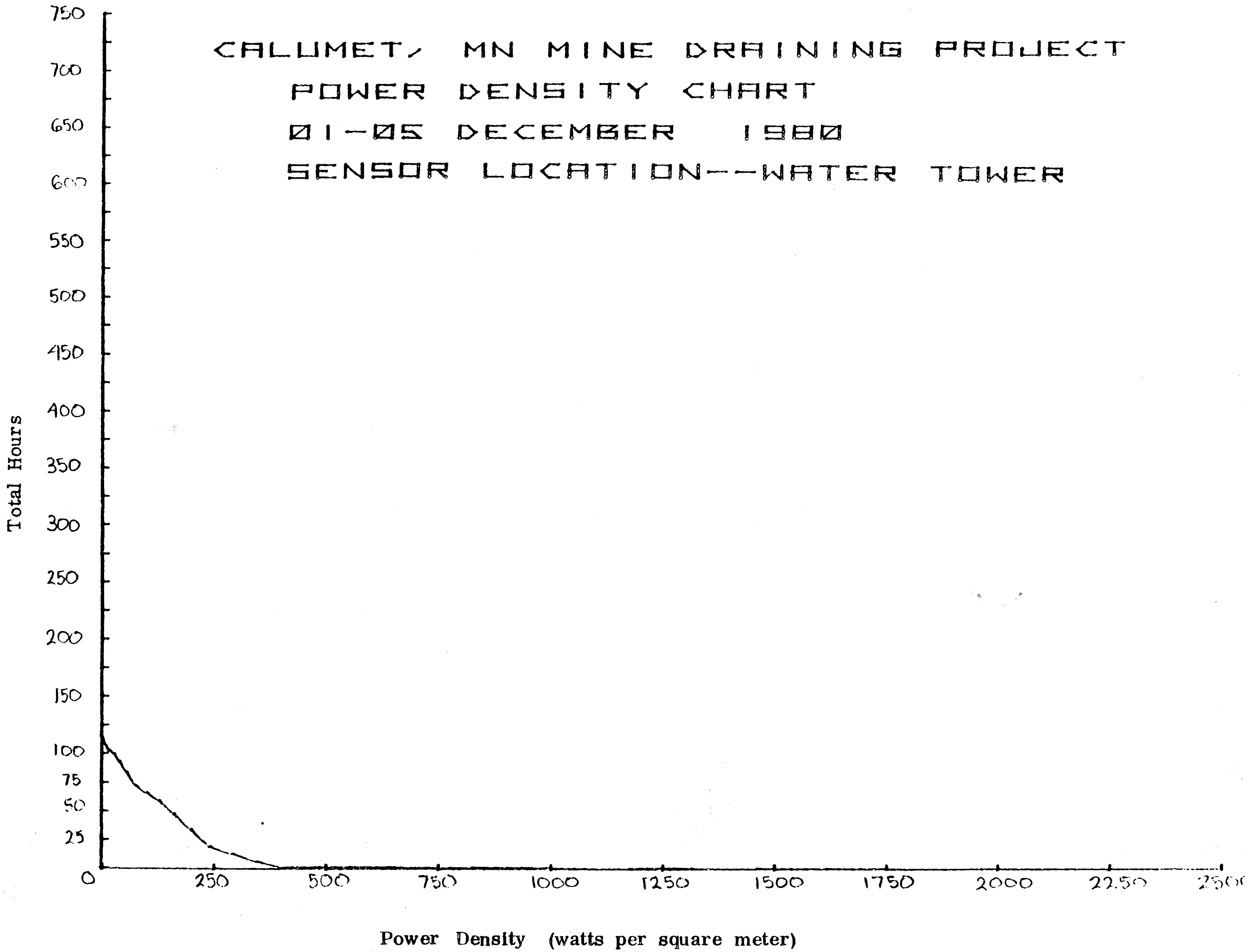
Power Density Charts

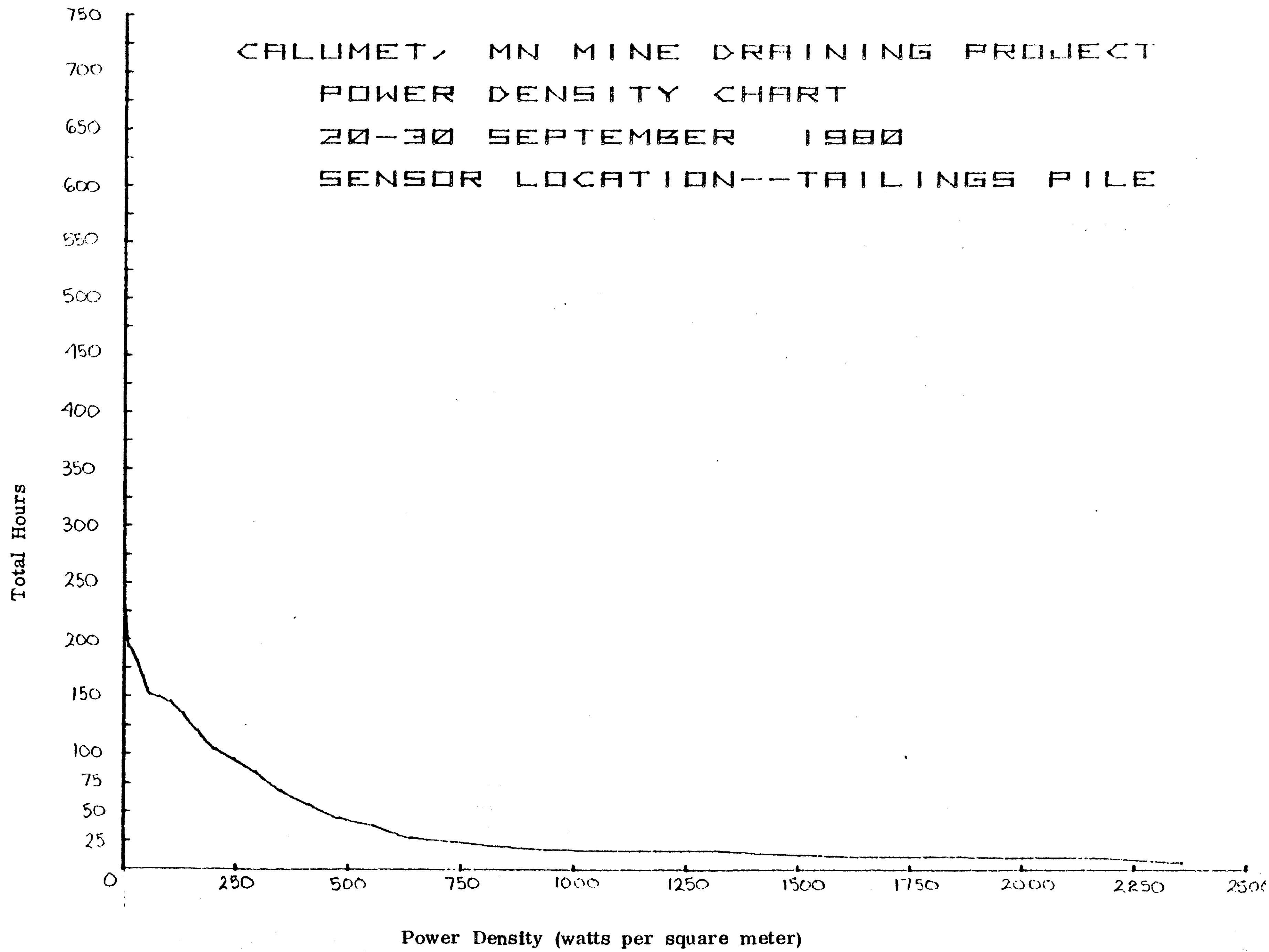

CALUMET/ MN MINE DRAINING PROJECT
POWER DENSITY CHART
20-30 SEPTEMBER 1980
SENSOR LOCATION--WATER TOWER
Total Hours
750
700
650
600
550
500
450
400
350
300
250
200
150
100
75
50
25
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Power Density (watts per square meter)

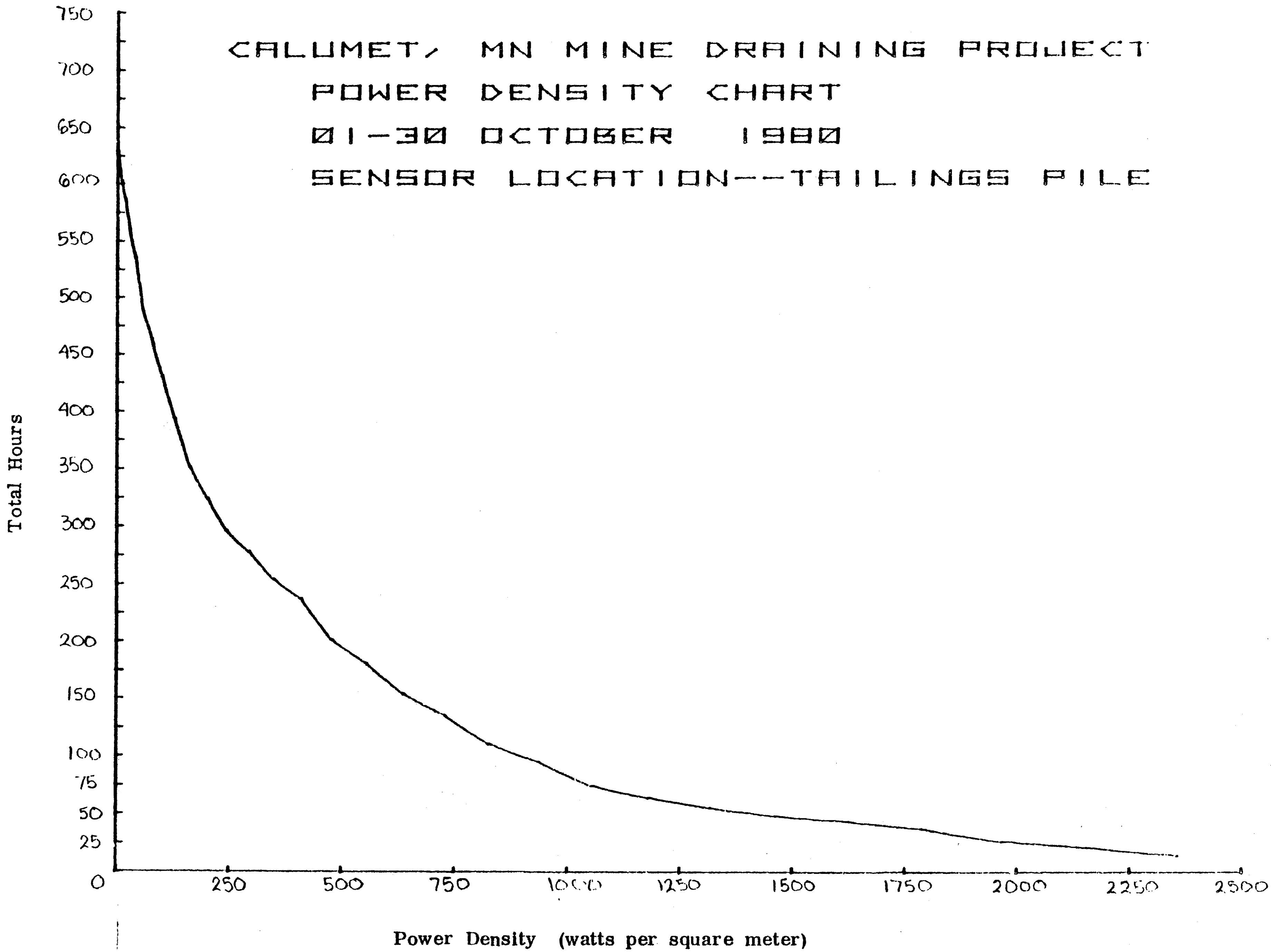


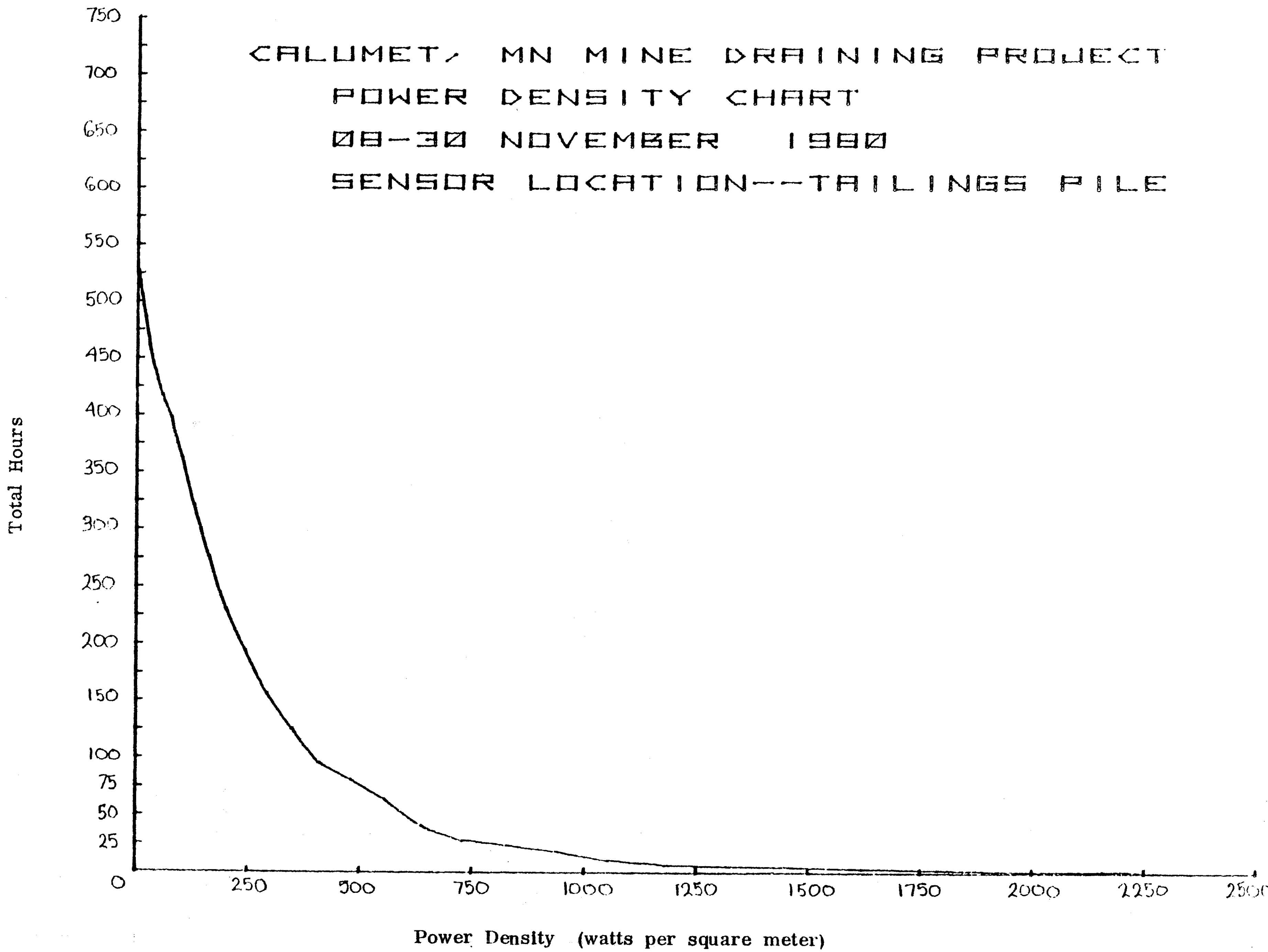
CALUMET, MN MINE DRAINING PROJECT
POWER DENSITY CHART
01-31 OCTOBER 1980
SENSOR LOCATION--WATER TOWER
Total Hours
750
700
650
600
550
500
450
400
350
300
250
200
150
100
75
50
25
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Power Density (watts per square meter)

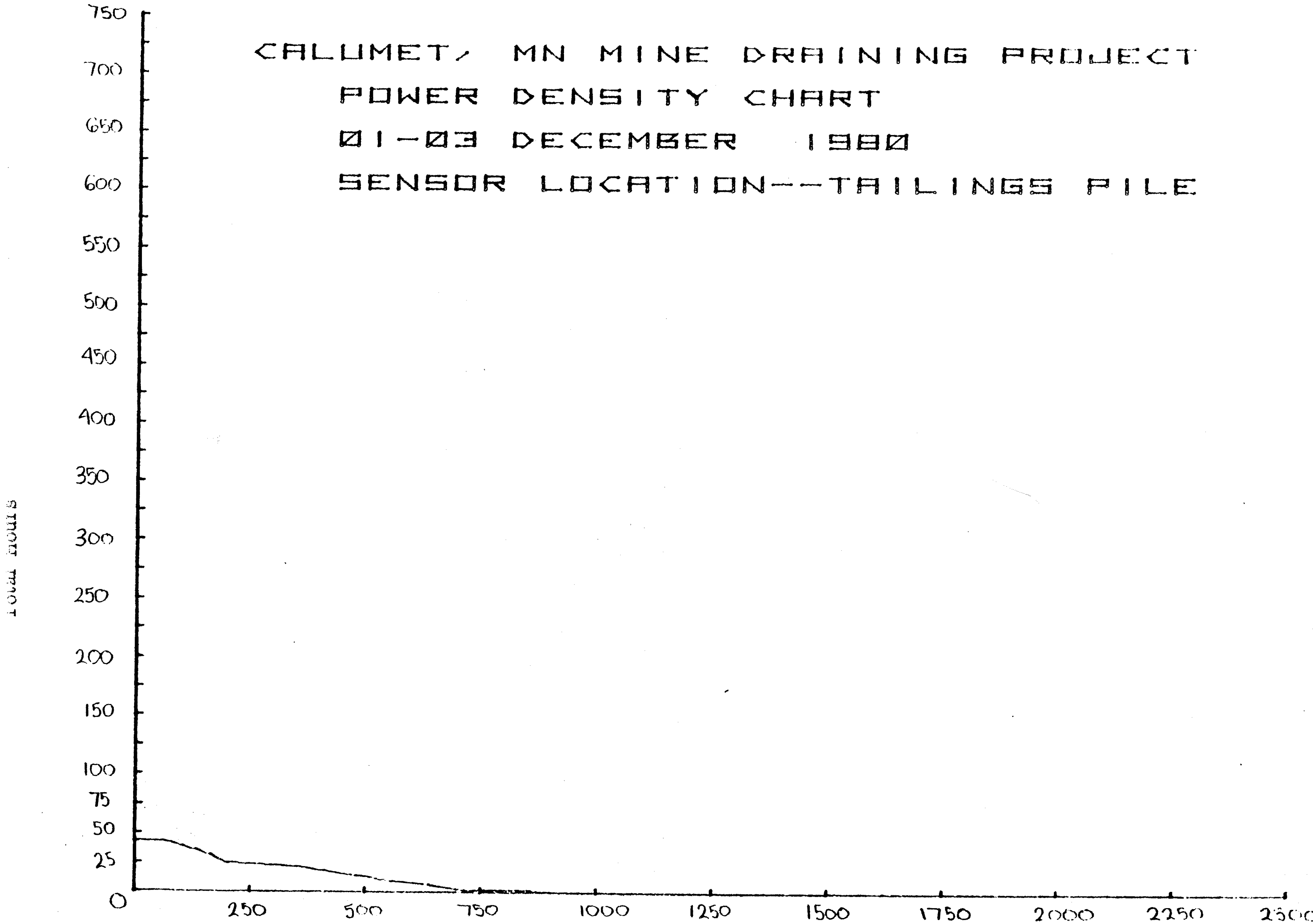

CALUMET, MN MINE DRAINING PROJECT
POWER DENSITY CHART
01-30 NOVEMBER 1980
SENSOR LOCATION--WATER TOWER
Total Hours
750
700
650
600
550
500
450
400
350
300
250
200
150
100
75
50
25
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Power Density (watts per square meter)


CALUMET, MN MINE DRAINING PROJECT
POWER DENSITY CHART
01-05 DECEMBER 1980
SENSOR LOCATION--WATER TOWER
Total Hours
750
700
650
600
550
500
450
400
350
300
250
200
150
100
75
50
25
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Power Density (watts per square meter)


CALUMET, MN MINE DRAINING PROJECT
POWER DENSITY CHART
20-30 SEPTEMBER 1980
SENSOR LOCATION--TAILINGS PILE
Total Hours
750
700
650
600
550
500
450
400
350
300
250
200
150
100
75
50
25
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Power Density (watts per square meter)


CALUMET, MN MINE DRAINING PROJECT
POWER DENSITY CHART
01-30 OCTOBER 1980
SENSOR LOCATION--TAILINGS PILE
Total Hours
750
700
650
600
550
500
450
400
350
300
250
200
150
100
75
50
25
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Power Density (watts per square meter)

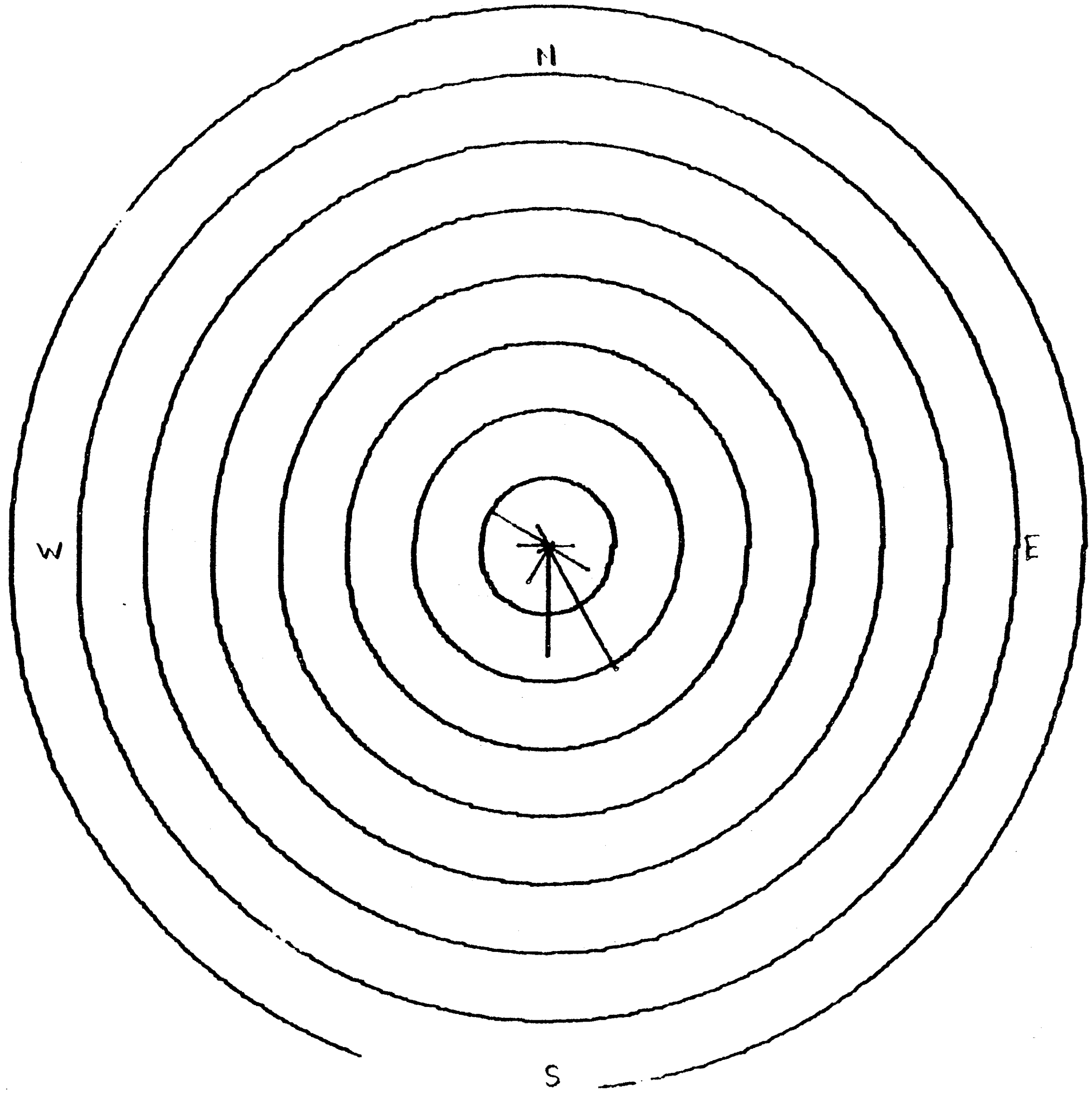

CALUMET, MN MINE DRAINING PROJECT
POWER DENSITY CHART
08-30 NOVEMBER 1980
SENSOR LOCATION--TAILINGS PILE
Total Hours
750
700
650
600
550
500
450
400
350
300
250
200
150
100
75
50
25
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Power Density (watts per square meter)



Power Density (watts per square meter)

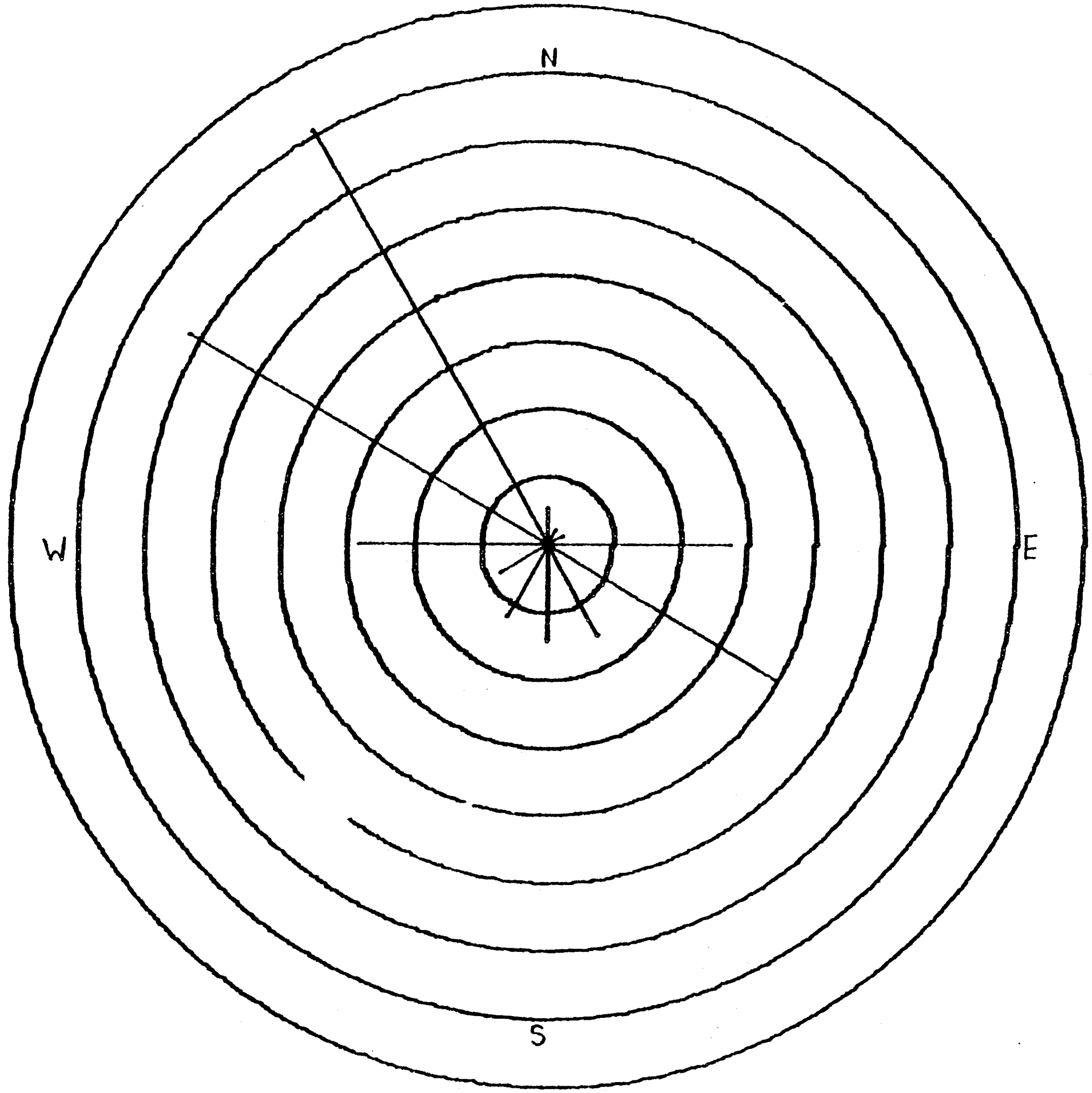
Wind Rose Data for Calumet

Wind Rose Data For Calumet, Minnesota 20-30 September, 1980
Sensor Location--Water Tower



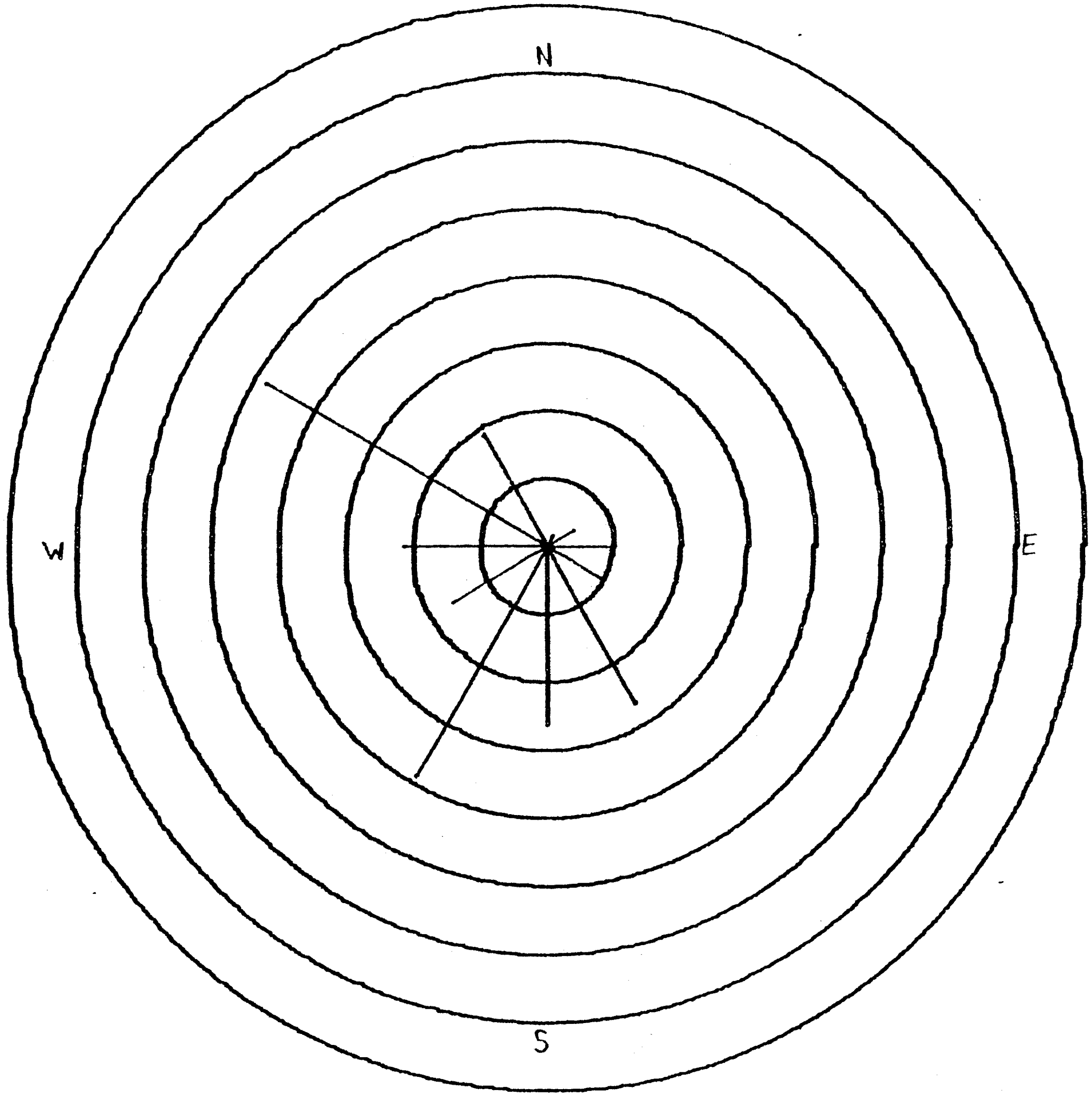
(Each circle represents 25 hours)

Wind Rose Data for Calumet, Minnesota 01-31 October, 1980
Sensor Location--Water Tower



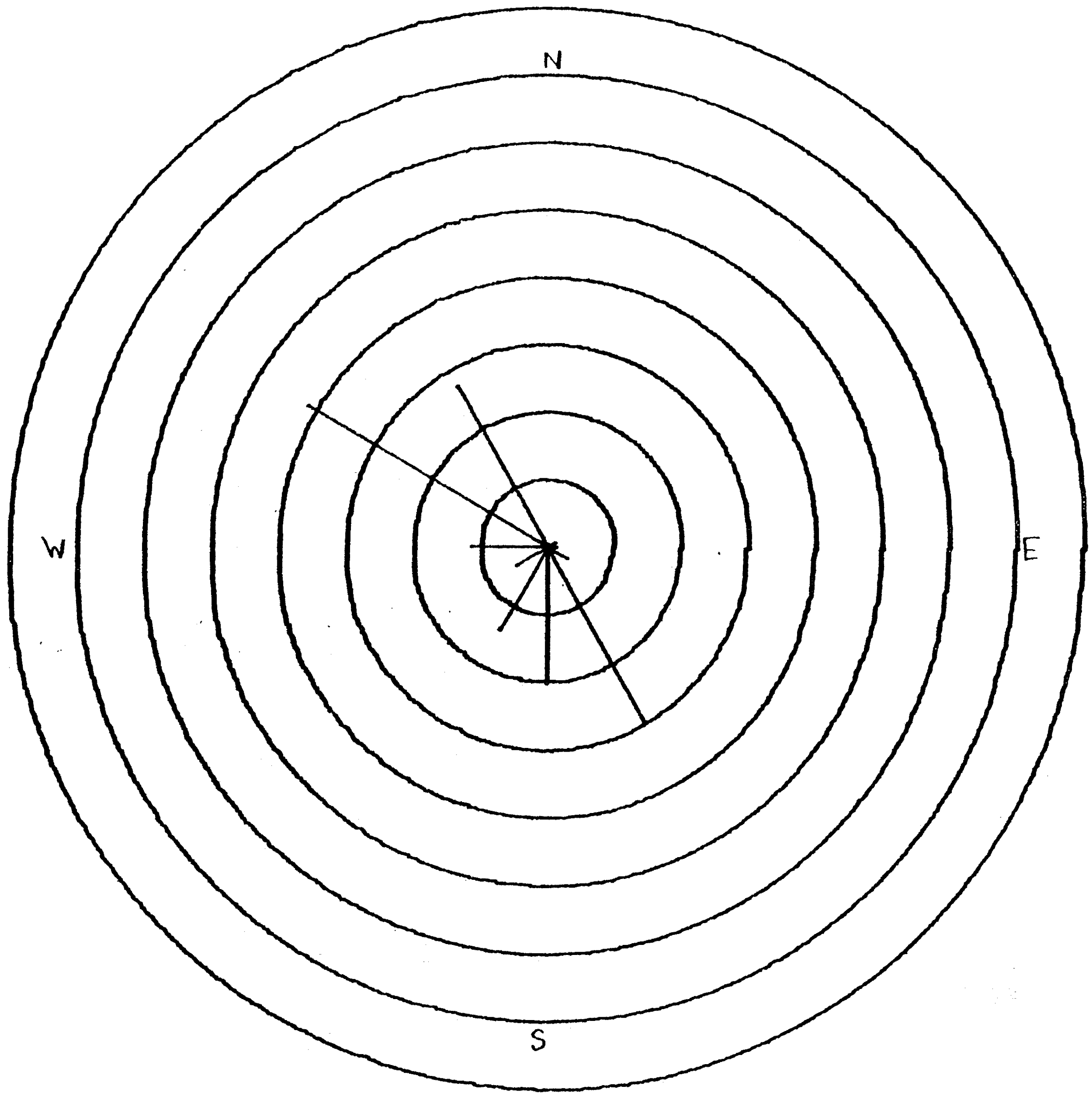
(Each circle represents 25 hours)

Wind Rose Data for Calumet, Minnesota 01-30 november, 1980
Sensor Location--Water Tower



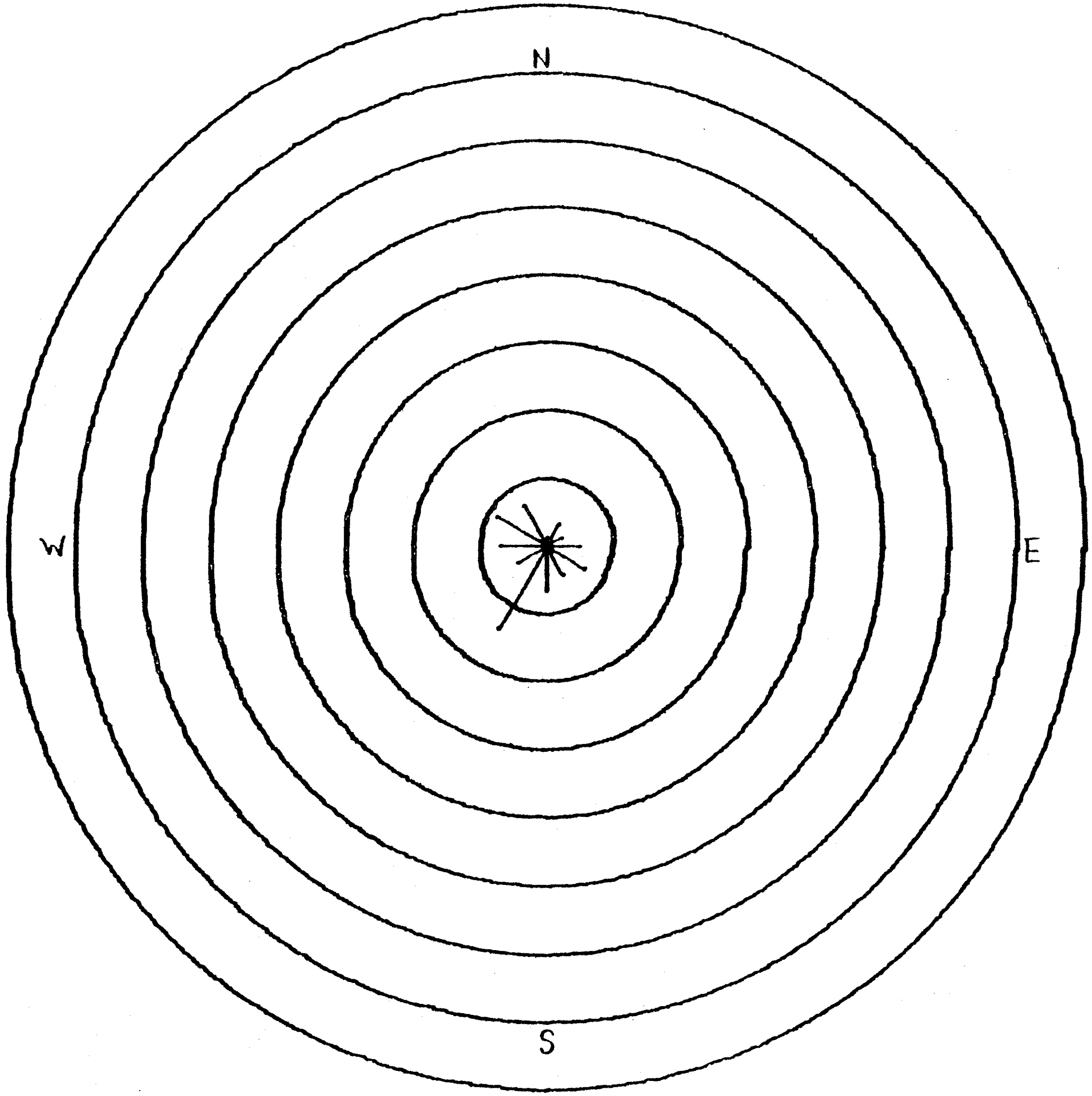
(Each circle represents 25 hours)

Wind Rose Data for Calumet, Minnesota   01-22 December, 1980
Sensor Location--Water Tower



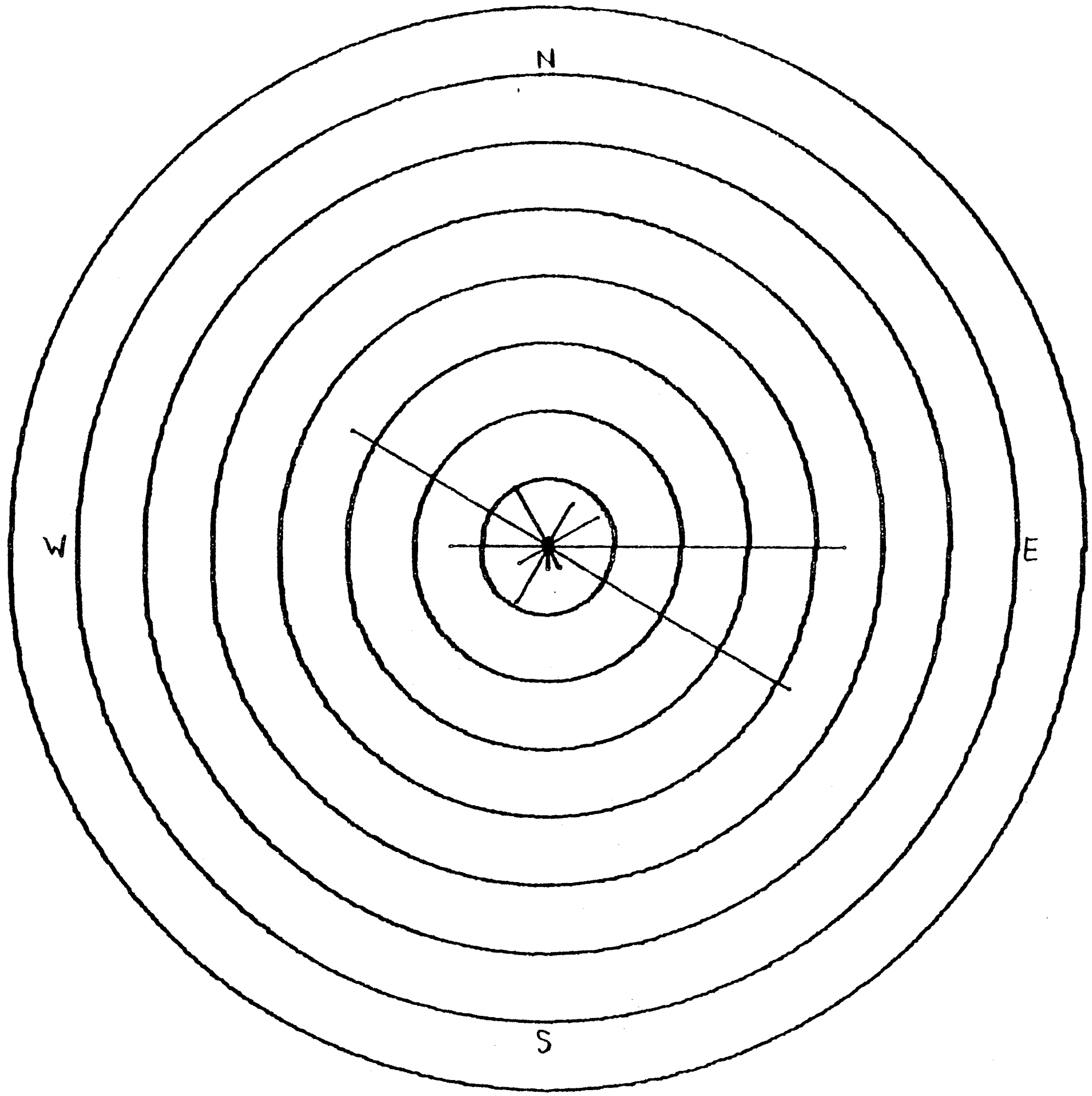
(Each circle represents 25 hours)

Wind Rose Data for Calumet, Minnesota 20–30 September, 1980
Sensor Location--Tailings Pile



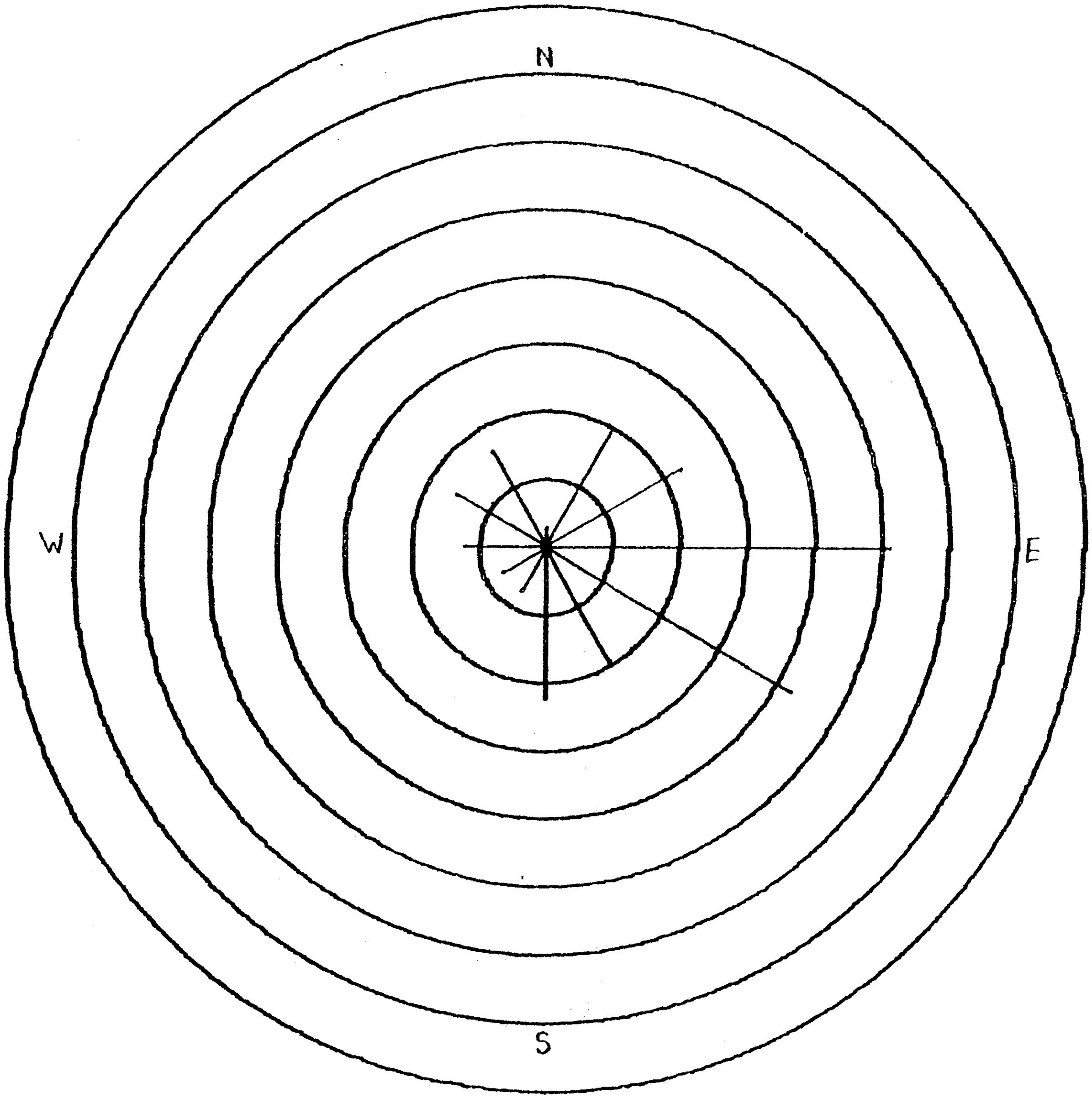
(Each circle represents 25 hours)

Wind Rose Data for Calumet, Minnesota 01-31 October, 1980
Sensor Location--Tailings Pile



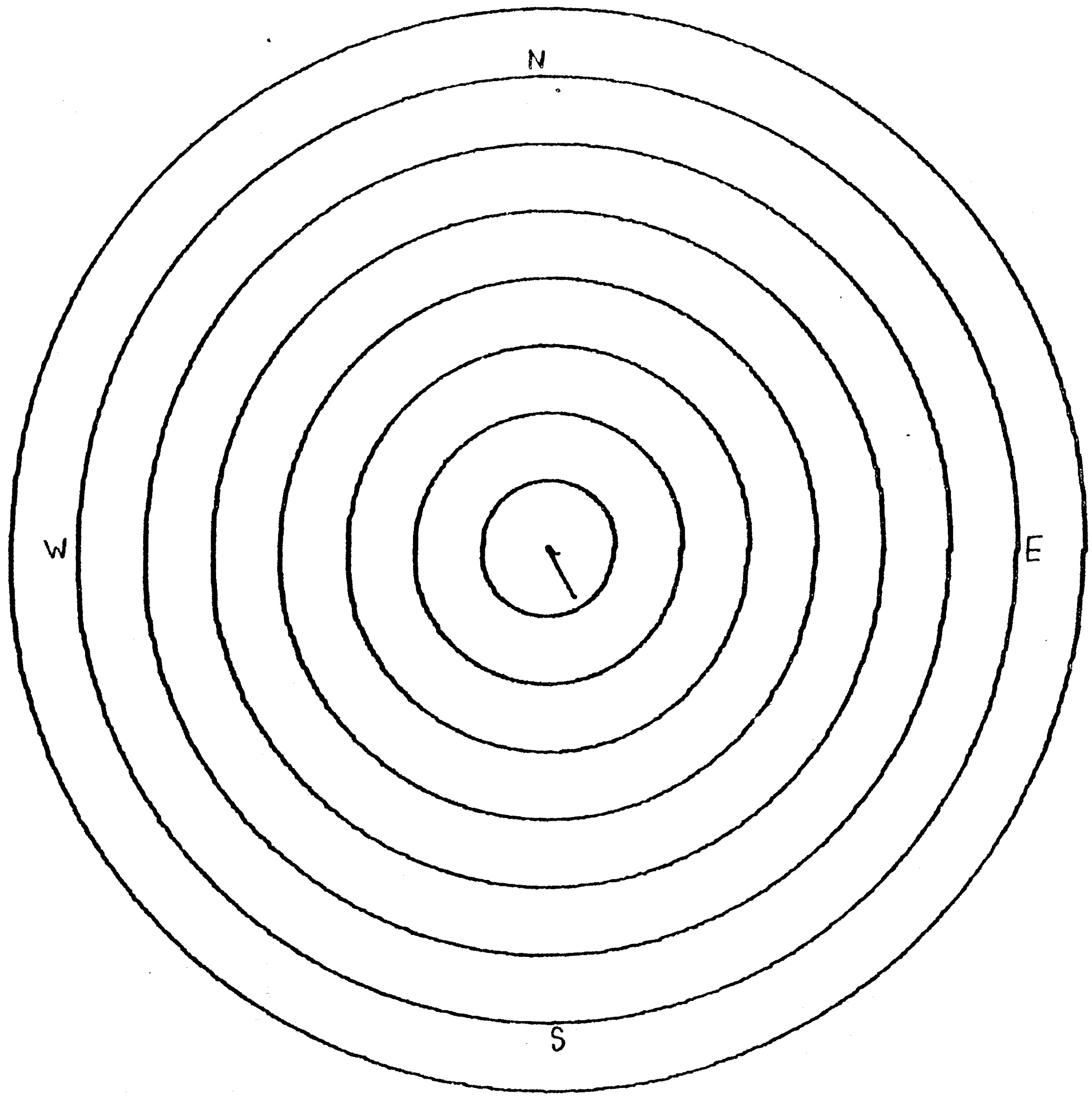
(Each circle represents 25 hours)

Wind Rose Data for Calumet, Minnesota 01-30 November, 1980
Sensor Location--Tailings Pile



(Each circle represents 25 hours)

Wind Rose Data for Calumet, Minnesota 01-02 December 1980
Sensor Location--Tailings Pile



(Each circle represents 25 hours)

Revised 1/81

MANUFACTURING LIST

Wind Energy Systems:

SOURCE	MODEL #	ROTOR SIZE (Dia. in ft.)	RATED POWER (Kilowatts)
Acorn Machine & Design P.O. Box 324 Mesquite, TX 75149 (214) 348-8225			
Aero Power Systems, Inc. 2398 - 4th Street Berkeley, CA 94710 (415) 848-2710	"SL 1500"	12.0	1.43
Aerospace Systems, Inc. 121 Middlesex Turnpike Burlington, MA 01803 (617) 272-7517	Systems		
Aerowatt, S. A. (see Automatic Power, Inc.)			
Aidco Maine Corp. Orr's Island, ME 04066 (207) 833-6700	Systems		
Alcoa Technical Center Aluminum Co. of America Alcoa Center, PA 15069 (412) 339-6651 OR 1501 Alcoa Building Pittsburgh, PA 15219 (412) 553-3185	*	N/A	N/A
Altos-The Alternate Current Box 905 Boulder, CO 80302 (303) 442-0885	"BWP-12B"	11.5	2.0
American Wind Turbine, Inc. 1016 E. Airport Road Stillwater, OK 74074 (405) 377-5333	"16 ft." "12 ft." Water Pumpers	15.3 11.5	2.0 1.0

This is TECHNICAL PAPER No. 911 List of Wind Systems Manufacturers, January, 1981.
Additional copies of this paper can be obtained for $4.00 each from:

ALTERNATIVE SOURCES OF ENERGY MAGAZINE
107 S. Central Ave.
Milaca, MN. 56353

SOURCE	MODEL #	ROTOR SIZE (Dia. in ft.)	RATED POWER (Kilowatts)
Astral Wilcon P.O. Box 291 127 W. Main St. Milbury, MA 01527 (617) 865-9412	"AW10-B"	26.0	N/A
Automatic Power, Inc. (Aerowatt, S.A.) 213 Hutcheson Street Houston, TX 77023 (713) 228-5208	Systems		
Bendix Wind Power Products Co. P.O. Box 151 Sedro Woolley, WA 98284 (206) 855-1141, Ext. 246	Systems		
Bergey Wind Power Co. 2001 Priestly Avenue Norman, OK 73069 (405) 364-4212	Systems		
Bertoia Studios 644 Main Street Bally, PA 19503 (215) 845-7096	"A.P.S."	18.0	2.0
Boeing Engineering & Const. Co. Wind Energy and Environment Div. P.O. Box 3707 Seattle, WA 98124 (206) 575-5922	Systems		
Bowjon 2829 Burton Avenue Burbank, CA 91504 (213) 846-2620	Systems Water Pumpers		
Jay Carter Enterprises P.O. Box 684 Burkburnett, TX 76354 (817) 569-2238	Systems		
Chalk Wind Systems P.O. Box 446 St. Cloud, FL 32769 (305) 892-7338	Systems		

SOURCE	MODEL #	ROTOR SIZE (Dia. in ft.)	RATED POWER (Kilowatts)
Coulson Wind Electric RFD 1, Box 225 Polk City, IA 50226	"Model-A"	23.0	8.0
Dempster Industries 711 South 6th Street Box 848 Beatrice, NE 68310 (402) 223-4026	Water Pumpers		
Dominion Aluminum Fabricating Ltd. 3570 Hawkestone Rd. Toronto, Ontario CANADA	"25 x 55" * "20 x 30" *	36.7 20.0	37.0 14.0
Dragonfly Wind Electric 33810 Navarro Ridge Road Albion, CA 95410 (707) 937-4710	Systems		
Dunlite Electrical Prod. Co. c/o Enertech Box 420 Norwich, VT 05055 (802) 649-1145	"2000"	13.5	2.0
Dyna Technology, Inc. (see Winco)			
Dynergy Corp. Box 428 1269 Union Ave. Laconia, NH 03246 (603) 524-8313	"5 Meter" * Water Pumpers	15.0	3.2
Elektro GmbH Winterthur Schqeiz St. Gallerstrasse 27 SWITZERLAND	"Elektro" numerous models		
Enertech Corporation Box 420 Norwich, VT 05055 (802) 649-1145	"1500" & Water Pumpers	13.2	1.5

SOURCE	MODEL #	ROTOR SIZE (Dia. in ft.)	RATED POWER (Kilowatts)
Environmental Energies, Inc. Front Street Copemish, MI 49625 (616) 882-5095	Systems		
Gale Company, The P.O. Box 27 Lake Geneva, WI 53147 (414) 248-6672	Systems		
General Electric Co. Space Division P.O. Box 13601 Philadelphia, PA 19101 (215) 962-2112	Systems		
Grumman Energy Systems, Inc. 4175 Veterans Memorial Hwy. Ronkonkoma, NY 11779 (516) 575-7291	Systems		
Hamilton Standard Windsor Locks, CT 06906 (203) 623-1612	Systems		
Heller-Aller Co., The 900 Oakwood Avenue Napoleon, OH 43545 (419) 592-1856	Water Pumpers		
Hinton Research & Dev. Corp. 417 Kensington Salt Lake City, UT 84115 (801) 487-3896	Systems		
Independent Energy System 113 East 13th St. Erie, PA 16503 (814) 454-1543	"Skyhawk IV"	15.0	4.0
Jacobs Wind Electric Co., Inc. 2720 Fernbrook Lane Minneapolis, MN 55441 (612) 559-9361	"8KVA"	N/A	8.0

SOURCE	MODEL #	ROTOR SIZE (Dia. in ft.)	RATED POWER (Kilowatts)
Kaman Aerospace Corp. Old Windsor Road Bloomfield, CT 06002 (203) 242-4461	*	N/A	N/A
Kedco Inc. 9016 Aviation Blvd. Inglewood, CA 90301 (213) 776-6636	"1620"	16.0	3.0
McDonnell Aircraft Co. Department 342 Building 80 P.O. Box 516 St. Louis, MO 63166 (314) 232-9888; 232-3575	Systems		
Megatech Corporation 29 Cook Street Billerica, MA 01866 (617) 273-1900	"WIP-A1"	6.0	0.4
Mehrkam Energy Dev. Co. Box 179-E, R.D. 2 Hamburg, PA 19526 (215) 562-8856	Systems		
Millville Windmills & Solar Equipment Co. Box 32, 10335 Old 44 Drive Millville, CA 96062 (916) 547-4302	"10-3-IND"	25.0	10.0
North Wind Power Co., Inc. Box 315 Warren, VT 05674 (802) 496-2955	"HR2"	16.4	2.0
Pinson Energy Corp. Box 7 Marstons Mills, MA 02648 (617) 428-8535; 477-2913	"Cycloturbine" C-2E3	16.0	5.0

SOURCE	MODEL #	ROTOR SIZE (Dia. in ft.)	RATED POWER (Kilowatts)
Power Group International 13315 Stuebner-Airline Road Suite 106 Houston, TX 77014 (713) 444-5000	"Humming-Bird"	14.0	4.0
Product Development Institute 4445 Talmadge Road Toledo, OH 43623	"Wind Jennie" "4500"	20.0	4.0
Sencenbaugh Wind Electric Box 11174 Palo Alto, CA 94306 (415) 964-1593	"1000" "500"	12.0 6.0	1.0 0.5
TWR Enterprises Sun-Wind-Home Concepts 72 W. Meadow Lane Sandy, UT 84070	"Wind Titan" N/A	 N/A	 N/A
Tumac Industries, Inc. 650 Fort Street Colorado Springs, CO 80915 (303) 596-4400	Systems		
United Technologies Research Center Silver Lane East Hartford, CT 06108 (203) 727-7536	Systems		
Valley Industries Aeromotor Division Industrial Park Conway, AR 72032 (501) 329-9811	Water Pumpers		
OR			
Valley Industries Wind Energy Division 1427 Hanley Industrial Court St. Louis, MO 63144 (314) 231-2160	Giromill		

SOURCE	MODEL #	ROTOR SIZE (Dia. in ft.)	RATED POWER (Kilowatts)
WTG Energy Systems, Inc. 251 Elm Street Buffalo, NY 14203 (716) 856-1620	Systems		
Wadler Manufacturing Co. Route 2, Box 76 Galena, KS 66739 (316) 783-1355	* Water Pumpers		
Westinghouse Elec. Corp. Advanced Energy Systems Div. P.O. Box 10864 Pittsburgh, PA 15236 (412) 892-5600	Systems		
WhirlWind Power Company Box 18530 2458 W. 29th Ave. Denver, CO 80211 (303) 477-6436	"Model-A"	10.0	2.0
Winco-Division of Dyna Technology, Inc. 225 S. Cordova St. Le Center, MN 56057 (612) 357-6821	"1222H" Wincharger	6.0	0.2
Wind Engineering Corp. Box 5936 Lubbock, TX 79417	"25S-110"	38.0	25.0
Wind Power Systems, Inc. Box 17323 San Diego, CA 92117 (714) 452-7040	"Storm-master 10"	32.8	6.0
Windworks, Inc. RR 3, Box 44-A Mukwonago, WI 53149 (414) 363-4088	Systems		
Winflo Power Ltd. 90 Esna Drive, Unit 15 Markham, Ontario L3R 2R7 CANADA	Systems		

SOURCE	MODEL #	ROTOR SIZE (Dia. in ft.)	RATED POWER (Kilowatts)
Zephyr Wind Dynamo Co. P.O. Box 241 21 Stamwood St. Brunswick, ME 04011 (207) 725-6534	Systems		

Addition:

Aerotherm Corp.
40 West Main
Macungie, PA. 18062
(215) 966-2468

N/A means information not available from our files -- write manufacturer directly.

* means vertical axis type rotor, all others are horizontal axis or propellor type.