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APPLICATION STUDY OF WIND POWER TECHNOLOGY
TO THE CITY OF HART, MICHIGAN

Progress Report

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December 31, 1975

Work Performed Under Contract No. E(11-1)-2603

Division of Engineering Research
Michigan State University
East Lansing, Michigan

MASTER

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Division of Solar Energy

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Progress Report
Energy Research and Development
Administration
Washington, D.C.

APPLICATION STUDY OF WIND POWER TECHNOLOGY TO THE CITY OF HART, MICHIGAN

prepared by

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ABSTRACT

This proposal seeks follow-on funding support for a Year II effort [Year I is under ERDA Grant E(11-1)-2603] concerned with wind energy application to small municipal electric systems and rural electric cooperatives. A microcosmic approach is used as contrasted with the macrocosmic one of the national mission studies. It is proposed to: (1) go on with the study of the wind-hydro combination to achieve base-load or load-following capability, in addition to study of the fuel-saver mode of operation; (2) continue wind data development necessary in support of the effort; and (3) devise economic- and systems-models covering a number of operating modes. Emphasis is on technical feasibility and a systems study to define the economic potential of the various applications for several time-horizons. The information so developed will be generalized in order that it may find application elsewhere.

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1. SUMMARY OF INTERIM REPORT

The city of Hart, a small municipality of approximately 2,500 people, is located in a high wind region eight miles east of Lake Michigan and is situated approximately midway between the two larger cities of Muskegon and Ludington. Hart derives its electric energy from a city owned municipal electric power system. This power system has a peak capacity of 4 MW and depends almost entirely on diesel generation using gas and oil. The diesel plant is supplemented by a 300 kW hydro facility located at the outlet of Hart Lake. There is no spinning reserve. In effect it is supplied by a 5,000 kW interconnection to the Wolverine Electric Cooperative, a generation and transmission (G and T) Rural Electric Cooperative. The Hart Municipal System covers about three square miles surrounded by areas supplied by the system of the Oceana Electric Cooperative, a distribution rural electric cooperative.

The characteristics of (1) location in or near a high wind energy region (wind speeds average between 13 and 14 mph on the lakeshore), (2) diesel generation of electricity, (3) the presence of a hydro facility and (4) a peak generation capacity of only 4 MW all converge to make the city of Hart an interesting and promising application for wind energy conversion systems (WECS). The high wind energy in the Hart region indicates good economic potential for WECS applications. As costs of oil and natural gas continue to rise, the cost of generating electricity from diesel facilities becomes relatively more expensive. The hydro facility, modified and updated, may be utilized for energy storage to offset the intermittency and randomness of wind availability. Since the peak capacity of the Hart system is only 4 MW, a few 500 kW or 1.5 MW wind turbines can make significant impact on the total energy generating system.

The research reviewed in this progress report has as its goal to study the technical and economic feasibility of a WECS for the city of Hart. By conducting this indepth study for Hart, it is felt an approach or methodology will be developed that can be generalized to other rural and small municipal applications. In addition, it is felt that general information important to other applications, i.e., the

generic characteristics for small rural and municipal applications, will emerge from this study. A major question to be answered is: to what degree might it be possible, if at all, for a small municipality, such as Hart, to become energy-self-sufficient with respect to the electric power needs in a cost-effective manner and in what time frame?

The research in this grant is divided into a number of phases.

They are:

Wind Data Collection and Analysis

Assessment of the Hart Power Demand and Consumer Usage

Assessment of: (1) Wind turbine performance in the Hart area

(2) Transmission line assessment

Hydro Assessment

Economics of WECS

Environmental impact of WECS in the Hart region

Development of a Systems Model for the Hart Power System

The progress of each of these project phases is reported in Sections 2-9 which follow. Conclusions of these phases are summarized below.

1.1. Wind Data Collection and Analysis

Initial efforts were directed towards the assembly, editing, and storage of selected historical wind data from the Coast Guard Stations along the Great Lakes shoreline of upper and lower Michigan. Three MSU established, permanent, continuous, field-recording wind stations were located in the Hart area. 1975 wind information was gathered and placed on computer tape from these MSU stations along with the 1975 wind data from the Ludington and Muskegon Coast Guard stations. This data collection phase of the project represented a significant initial effort and the processing of a few additional historical records and the incoming 1975 data continues at a moderate workload level. Since commencing this study, over 400,000 pieces of historical and 1975 wind data have been recorded on assessment forms and over 100,000 of these have received final editing and are available on computer tape. This stored information can be retrieved at will for the computer programs developed to process these wind data.

Software has been written to operate on raw wind data and obtain:

- 1) average annual, monthly, and seasonal energy density;
- 2) wind speed and power distribution curves and velocity frequency curves by month and year;
- 3) wind roses and energy roses by month and year;
- 4) diurnal wind speed variation for month and year;
- 5) height corrected wind speeds.

By comparing 1975 wind data from Muskegon and inland MSU wind stations, an approximate relationship was established for apparent energy between these locations. This relationship was used to derive a 12 month estimate for the 1972 winds at the State Police Tower. It is recognized that the methods employed were only very approximate and that continuous wind monitoring into year II will provide several full years of wind information at inland locations.

Some important preliminary conclusions are:

- 1) The wind power densities along the coastal regions of Michigan correspond to an average annual wind power density of $225-375 \text{ W/m}^2$ at 10 meters. These densities, among the highest within the U.S., demonstrate that the coastal region of Michigan is an excellent area for wind turbine applications.
- 2) At all wind measuring stations, winter months are months of relatively high wind energy while summer months have relatively low wind energy. This fact suggests the possibility of using wind energy to replace oil, natural gas, and bottled gas for heating in the winter.
- 3) The yearly and monthly wind energy behavior along the coast from Ludington to Muskegon appears to be very similar (neglecting any terrain effects). Thus, the historical wind data from Ludington and Muskegon Coast Guard stations can be used with a high degree of confidence to provide historical wind information for the coastal region directly west of the city of Hart.
- 4) At a given height, wind energy is rapidly attenuated as one moves only a few miles inland from the coast. Preliminary estimates indicate that the wind energy in the city of Hart is over 50 % lower than the wind energy along the coast, although Hart is only about eight miles from Lake Michigan.

1.2. Hart Power Demand and Consumer Usage

Twelve months of hour-by-hour total load and power generation by diesel, hydro and Wolverine have been card punched and are

available for developing future load growth and economic predictions.

Attempts were made to break down consumer usage into purpose and time-of-day and season. It was felt that this type of information would be helpful in determining how utilization practices might be adjusted to accommodate the availability of wind power. Few results have been produced to date and it may well take another year to produce tangible information.

1.3. Assessment

1.3.1. Wind Turbine Performance in the Hart Area

Using the historical and 1975 wind information and the G.E. and Kaman 500 kW and 1.5 MW designs, the total energy, average power and down time were calculated for a number of different sites on the shore of the Great Lakes and at inland locations next to or in Hart.

Some preliminary conclusions are:

- 1) The 500 kW machines are superior to the 1.5 MW machines in the Hart region. The 500 kW machines are favored over the 1.5 MW machine in both the fuel saver mode of operation and as part of a baseload with energy storage operation. That is, they have a higher plant factor and lower down time for both inland and coastal sites in the Hart region.
- 2) A large wind turbine of 1 MW or more which is designed for yearly average wind speeds of 14-15 mph appears to be in the region. Applications for this machine would be more numerous than the G.E. and Kaman 1.5 MW designs.
- 3) The annual energy output for each machine next to the city of Hart is over 50% less than the energy output on coastal sites. This conclusion must be verified with more complete inland wind measurements.

1.3.2. Assessment of Existing Transmission Line Grid

The transmission grids of the Wolverine Electric Cooperative and Oceana Electric Cooperative were assessed for their capacity.

The important conclusions are:

- 1) The 69 kW Wolverine network has the capacity to transfer power equal to the entire Hart peak demand. Thus, this network can easily handle energy from both 500 kW and 1.5 MW wind turbines.
- 2) The three phase Oceana distribution network can only handle outputs from the 500 kW and 1.5 MW machines for distances of less than two miles. However, 200 kW machines, e.g., the Plum Brook machine, can be tied directly into the three-phase Oceana grid.

- 3) For most sites 500 kW and 1.5 MW machines would have to be tied directly into the 69 kV Wolverine network.

1.4. Hydro Assessment

The Hart hydro facility was investigated for its potential use as the energy storage reservoir for a wind-hydro baseload electric generating system. This hydro facility is typical of most such generating units in Michigan in that it is operated as a flowthrough system with little or no capacity for storage. Thus, the Hart Lake basin was surveyed to determine the energy storage potential of the lake area. Also, the month by month waterflow in the Pentwater River was estimated and a cost estimate in \$/kW covering the modification and expansion of the hydro facility was established. The conclusions are:

- 1) The height of Hart Lake can be increased 6 feet without encountering any major problems. The energy stored in this water increase would allow a 1,000 kW system to run for at least 38 hours.
- 2) Water discharge estimates indicate that on the average, twice as much water flows in the Pentwater River than is presently used to generate electricity by the Hart Hydro facility.
- 3) The expansion of the hydro facility would cost \$800/kW.

This hydro assessment is presently being generalized in order to develop the generic technical and economic characteristics at such wind-hydro energy delivery systems. Preliminary surveys indicate that, assuming a 50-50 match of wind power and hydro-power, more than 1,000 MW could be derived from wind-hydro combinations in Michigan. This would be all baseload generation, obviously requiring no fossil fuels.

1.5. Preliminary Economics

The economics of WECS as fuel savers or as part of a hydro baseload electric generating facility were investigated. In general, the economics strongly favor lakeshore locations over inland city of Hart locations. These preliminary economics indicate that WECS as fuel savers or as baseload are both competitive now (or will be shortly as fuel prices rise) with the present Hart diesel generating facility.

The energy cost differences (\$/kWh) between the 500 kW and

1.5 MW G.E. and Kaman designs are not substantial. Since the 500 kW machine has the technical advantage of having less down time than the 1.5 MW machine, it appears that a system of 500 kW machines may be the best solution for wind turbines in the Great Lakes region.

Some energy generation alternatives open to Hart were re-viewed. Research continuing into year II will compare these and other energy alternatives open to the city of Hart with the costs of "fuel saver and baseload WECS." The economics will be generalized to a class of small cities similar to Hart.

1.6. The Environmental Impact of Wind Turbines and Their Operation in the Hart Area

Five sites were rated as to the potential environmental impact of wind turbine installations. It is felt that wind turbines will have very few environmental problems. Certain types of impacts such as bird kill and of E-M interference are somewhat speculative and must be investigated by more indepth studies.¹

The major problem with wind turbines may be one of aesthetics or visual pollution. This may be the case with sites along the coast of Michigan. For example, it has been shown in this progress report that wind energy is significantly higher on the lake and coast than even a few miles inland. Because of the low down time and high plant factor the 500kW designs are favored over the 1.5 MW designs in the Lake Michigan area. Thus, even for a small application like the city of Hart, several or more lake sites spread over tens of miles would be desirable. However, the lakeshore is a scenic and a recreation area and to find environmentally acceptable sites accessible to the appropriate transmission lines may prove difficult. Thus, the siting constraints, indicate the need in the Great Lakes Region for a large machine of 1 MW or more with a high plant factor and a low down time.

2. WIND DATA COLLECTION AND ANALYSIS

Measurements to determine wind behavior, particularly as they relate to wind power studies, can be classified according to one or more of the following principal objectives:

- (a) those measurements which provide data so that the

probable annual energy output of a particular wind energy conversion system, located at or near the site of the measuring station, can be predicted;

- (b) those measurements which are required to furnish information on the wind structure under different climatic, topographic, seasonal, and diurnal conditions, at or near the site of interest;
- (c) those measurements which provide raw data that are needed in special studies which permit system designers to develop an optimum wind energy conversion system for the site or region of interest.

Each of these wind measurement objectives is being met for the Great Lakes Region through the wind data collection and analysis portion of the Michigan State University wind research project. Although the MSU project, as a whole, focuses on the small municipal power system in Hart, Michigan, the generic characteristics of the wind in the Great Lakes Region are being emphasized. These generic results then in turn are being applied to the city of Hart's small municipal power system study.

2.1. The Availability and Application of NOAA and U.S. Coast Guard Wind Data

In our consideration of the methods to be used in collecting wind data, we recognized from the outset the fact that much valuable information on wind speeds and directions already exists in records of NOAA and the U.S. Coast Guard. For obvious reasons, wind data obtained by these sources have not been based on the requirements for a wind energy conversion system (WECS). Instead, they are, in the main, related to the general wind regime for districts surrounding observation stations, and thus are not necessarily located at particularly windy sites. Nevertheless, they provide reasonably reliable long-term records. We decided not to neglect them because they provide important benchmark data.

After careful thought, we decided that meteorological data for NOAA and the U.S. Coast Guard Stations in the Great Lakes Region can be put to advantage. Both historical and current wind data from these sources are used for the following:

- (a) As a basis for wind surveys indicating the areas in the

Great Lakes Region where the highest wind speeds are likely to be found;

- (b) As an indication of the direction of the prevailing wind since a knowledge of this is important when selecting wind power sites;
- (c) As a measure of the constancy, or variability, of the annual mean wind speed from year to year;
- (d) As an indication of the annual wind regime derived from the values of monthly mean wind speeds for an area;
- (e) As a measure of the diurnal variations in wind speed to be expected at different seasons of the year;
- (f) As a guide for determining the probability of the occurrence of various maximum wind speeds or calm spells;
- (g) As benchmark data used in correlation studies with data derived from wind recording instruments which are to be placed for short time periods at potential wind power generation sites.

Michigan, which has over 3000 miles of shoreline on five of the six Great Lakes, is particularly well situated for being the "laboratory" in which winds in the Great Lakes Region are studied. Furthermore, Michigan has in its favor the fact that there are twenty-nine² NOAA and U.S. Air Force meteorological stations and more than a half dozen U.S. Coast Guard Stations within its boundaries, all which routinely record wind speed and direction information. (See Figure 1).

2.2. The Installation of Dedicated Field-recording Wind Sets

Unfortunately, not all of the wind data required for making an effective evaluation of wind behavior in the Great Lakes Region can be obtained from these NOAA, U.S. Air Force, and U.S. Coast Guards Stations. The deficiencies in the data derived from these stations, particularly as they relate to wind power studies are as follows:

- (a) The recordings are not made continuously but rather typically every one-to-four hours. As a result, the data obtained at these stations is not useful in determining the short-term dynamic characteristics of the wind, e.g., the power spectra of the wind speed and the short-term variations in the wind direction for various wind speeds;
- (b) Two or more wind recording instruments are never placed at the same station for the purpose of understanding how

wind speed and wind direction vary in the short-term or the long-term with height. Also, data for horizontal shear determinations are never collected;

- (c) Many of the permanent wind recording stations are in relatively sheltered areas. Wind records at these locations are often not indicative of the wind energy potential in the area;
- (d) The permanent wind recording stations are not situated in an array that would permit one to determine how the winds are attenuated as they move inland from one of the Great Lakes.

To augment the standard meteorological stations, five sets of field-recording wind sets (R.M. Young Company Model 6404) were purchased and installed. With these instruments, wind speed and direction are continuously and simultaneously recorded on a two-pen, strip-chart recorder.

One wind vane and three-cup anemometer set was placed 110 feet above the coast of Lake Michigan atop the Little Point Sable Lighthouse. This lighthouse is strategically located on the shore of Lake Michigan approximately 20 miles from the Ludington Coast Guard Station, 25 miles from the Muskegon Coast Guard Station, and only seven miles from the city of Hart (see Figures 1 and 2). A second field-recording wind set was mounted at a height of 30 meters on a State Police communication tower just south of the city of Hart (see Figure 2). This tower was chosen because it sits on a promising 320 ft. hill and also is almost straight inland from the Little Point Sable Lighthouse. The third field-recording wind set was placed on the Pro Gas tower at 30 meters, in the city of Hart. The fourth and fifth wind sets either mounted on one of the two towers already mentioned in order to gather spatial gradient information on the winds, or they are mounted on a portable tower. The portable tower is used to determine the attenuation of wind speed with distance as the wind moves in off Lake Michigan. Also, it will be used as a prospecting tool in the search for suitable high-wind locations in the Hart region.

Wind data will be recorded continuously for at least two years, and will be correlated with the Ludington and Muskegon Coast Guard data and will also serve as benchmark wind data for other wind data

Figure 1. Map of Michigan showing the location of the existing NOAA, U. S. Air Force, and U. S. Coast Guard wind recording stations.

Figure 2. Map of the Hart region showing the location of the dedicated field recording wind sets.

collected in the Great Lakes Region and city of Hart region since it will be the first processed continuous wind data known to be available on the entire Lake Michigan shoreline. It is worth noting that the Hart area is very similar topographically to much of the Great Lakes Region; therefore, the results of this wind study should be of general use throughout the Region.

2.3 Data Management and Data Reduction

With a simple calculation, it can be seen that if only hourly data from all of the possible wind data sources within the State of Michigan were collected, there would be over one-half million data items annually. Because of this, data must be carefully selected, collected, organized, maintained, and disseminated; otherwise, inefficiency and chaos will result.

Basically, we obtain raw wind data from tables prepared by the National Weather Service, from tables prepared by the U.S. Coast Guard, and from the strip charts derived from our dedicated field-recording wind sets. A typical table from the Coast Guard and a typical strip-chart recording are shown in Figures 3 and 4, respectively. (Note: The data from the Coast Guard is in knots)

Each wind recording station is given a unique "Station Code." Hourly data are then transferred from the raw tables and charts onto "Wind Energy Assessment Forms" (See Figure 5). The data are now essentially in a card-image format. From the forms, computer cards are punched and the data are entered into the computer-based data management system where it is stored on magnetic tape. Specialized wind data, e.g., data which are derived from the continuous strip charts and relate to short-term wind phenomena, are entered into the computer in a similar manner.

All data is maintained on the computer in such a manner that researchers have easy access to any type of raw-data listing that might be required. Also, the data may be massaged in any number of ways in order to get useful data summaries, or selected portions of the data base might be moved directly into one of the power system models for simulation purposes.

DATE <u>MAY 75</u>		NOAA FORM 75-5A 10-75		U. S. DEPARTMENT OF COMMERCE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION				FORM APPROVED O.M.B. NO. 41-R2734			
STATION NAME <u>STA. LUDINGTON</u>				STATE <u>M</u>		STATION CALL <u>7 C</u>		LOCATION <u>43-57N</u> <u>86-26 W</u>			
(1) DATE	(2) TIME	(3) SKY COND.	(4) PRESENT WEATHER	(5) VISI- BILITY (in mi.)	(6) WIND DIR.	(7) WIND SPEED (in mph)	(8) STATE OF SEA HEIGHT PERIOD (in ft) (in sec)	(9) SEA TEMP °F	(10) AIR TEMP °F	(11) PRESSURE	(12) REMARKS
02	1300	CY	H	09	SSW	05	CALM M	M	54	30.09	WLP
	1500	PC	H	09	SSW	10	CALM M	M	52	30.07	
	1700	PC	H	09	SSW	05	CALM M	M	54	30.05	
	1900	C	H	09	S	05	CALM M	M	51	30.04	
	2100	C		10	SSW	04	UNK M	M	47	30.00	
	2300	C		10	E	10	CALM M	M	54	29.99	
03	0100	C		10	E	06	CALM M	M	48	29.94	
	0300	C		10	S	18	CALM M	M	46	29.92	
	0500	C		10	S	20	UNK M	M	48	29.88	
	0700	CY		07	N	03	CALM M	M	48	29.90	
	0900	CY	H	07	ENE	06	CALM M	M	53	29.89	
	1100	CY	H	10	E	07	CALM M	M	60	29.83	
	1300	CY	H	10	SSW	13	CALM M	M	57	29.73	
	1500	CY	F	08	SSW	09	01 M	M	47	29.76	
	1700	CY	F	05	NE	02	CALM M	M	48	29.74	
	1900	CY	F R	01	NE	05	CALM M	M	48	29.69	
	2100	CY	F R	01	NNE	05	UNK M	M	50	29.69	
	2300	CY	F R	01	N	05	UNK M	M	50	29.68	

NOAA FORM 75-5A (10-75) SUPERSEDES PREVIOUS EDITION.

Figure 3. Typical meteorological chart completed by the U. S. Coast Guard.

Figure 4. Typical output from one of the dedicated field-recording wind sets.

WIND ENERGY ASSESSMENT FORM (WE- 2)
MICHIGAN STATE UNIVERSITY

DATE 3/19/75 STATION NO. HTSP01 STATION LOCATION STATE POLICE

TIME OF DAY	WIND SPEED (MPH)			DIRECTION ($\div 15^\circ$)	COMMENTS
	AVG	MAX	MIN		
1:00	5	6	4	6	
2:00	3	5	2	6	
3:00	2	4	0	0	
4:00	3	4	2	0	
5:00	5	8	2	20	
6:00	9	12	6	18	
7:00	6	8	5	19	
8:00	7	10	5	18	
9:00	8	12	4	19	
10:00	7	10	4	19	
11:00	7	10	5	18	
12:00	10	14	6	19	
13:00	8	12	5	19	
14:00	12	16	7	19	
15:00	12	17	7	19	
16:00	7	12	3	19	
17:00	7	11	3	18	
18:00	8	12	4	18	
19:00	10	14	7	18	
20:00	8	11	5	19	
21:00	8	13	3	20	
22:00	8	12	3	2	
23:00	5	10	0	14	
24:00	7	10	3	14	

DAILY AVERAGE (MPH) 7

Name: Betty Shanahan Date: 21 April 1975

Figure 5. Example of a completed "Wind Energy Assessment Form."

2.4. Preliminary Results of the Wind Assessment Study

Immediately upon receiving notification that we were awarded the Grant (February 1975), three of the field-recording wind sets were purchased. These were installed at the three permanent wind recording sites by April 1, 1975. The fourth wind set and the portable tower were put in the field around August 1, 1975. The fifth wind set was obtained from an existing MSU weather station on Beaver Island. Several minor problems were encountered with the wind recording instruments; namely, the strip-chart paper bound several times in the recorders with approximately a 10 % loss of data resulting. At the time of this report, all useful data through October 1, 1975, has been extracted from the strip charts and put on the computer. Also, immediately upon receiving notification of the Grant, we asked for and received permission from the District Commander of the U.S. Coast Guard to have Ludington and Muskegon Coast Guard Station personnel send us copies of their wind data logs at the end of each month. This information is now on the computer up to October 1, 1975. In addition to these wind data sources, we initiated a project to incorporate selected wind data contained on National Weather Service magnetic tapes into our Great Lakes Region wind power study. This data is currently being entered on our computer and analyzed.

Table 1 summarizes both the 1975 and historical wind data by year and station that has been gathered to date by this project. As indicated in Table 1, six years of historical data have been processed and have been given final editing and stored on magnetic tape. Six months (March-October) of 1975 wind data from five (Ludington, Muskegon, Little Sable, State Police, and Pro Gas) wind measuring stations in the Hart region has also been processed, edited and placed on computer tape. Also included are nine more years of wind data that have been key punched on computer cards and an additional eleven years of historical wind data which has been recorded only on assessment forms. It is expected that these 20 years of wind data will be edited and placed on computer tape by the end of the first year of this project.

Software packages have been written which enable a researcher to obtain for each station monthly and yearly average velocities,

TABLE 1

Historical Wind Data

STATION	Recorded on Assessment Forms					Computer File					File Edited				
	68	69	70	71	72	68	69	70	71	72	68	69	70	71	72
Muskegon	X	X	X	X	X			X	X	X					X
Ludington		X	X	X	X			X	X	X					X
Point Betsie			X	X	X			X	X	X					X
Grand Marais			X	X	X				X	X					X
Lansing Shoals				X	X					X					X
St. Joseph			X	X	X			X	X	X					
Eagle Harbor 1971			X												
Hancock Portage 1971			X												
Manitou 1971			X												
Marquette 1971			X												
Passage Isle 1971			X												
Rock of Ages 1971			X												
1975 Wind Data															
Muskegon 3/75-10/75			X			X					X				
Ludington 3/75-10/75			X				X					X			
Pro Gas 3/18/75-10/21/75			X				X					X			
State Police 3/18/75 - 10/2/75			X				X					X			
Lighthouse 3/18/75-10/2/75			X				X					X			

velocity-frequency curves, speed and power duration curves by month and year, monthly, seasonal, or annual energy density and/or power density, and wind rose and energy rose curves by month and year. An additional computer program automatically corrects wind speed for any height using the appropriate vertical wind profile correction formula.² Figures 6 through 14 display the outputs of these software packages for Muskegon 1972 wind data. Each year of final edited wind data indicated in Table 1 can be processed yielding the appropriate duration curves, wind roses, etc. The yearly average wind speeds indicated in Figure 15 are examples of these computer calculations. When the data collection and analysis phase of the wind power study reach the appropriate point in time, a technical report will be issued. This report will summarize all of our wind data from each station as well as all of the conclusions which can be drawn from the data.

Despite the fact that much of the data is very preliminary, we are using it as a data base to provide key information needed to predict the probable energy output and economics of known and planned wind energy conversion systems. Also, from the preliminary data, we are now able to draw several very general conclusions concerning Great Lakes wind power climatology. In the next section, we will present these conclusions and also provide a sampling of 1975 wind data which has been collected and analyzed to date.

2.5. Wind Power Climatology of the Great Lakes Region: a Preliminary Assessment

The Great Lakes appear to have a profound effect on the winds in the region. At inland locations and sheltered meteorological stations along the coastlines, average annual wind speeds are in the 8-to-11 MPH range.⁴ This corresponds to an average annual wind power density of 100-150 W/m² at 10 meters. Since most of the meteorological stations are either inland or sheltered, any national wind power survey would rate the Great Lakes Region as only "moderate" as far as wind power is concerned. This is in fact the exact conclusion drawn by J.W. Reed⁵ in his study entitled "Wind Power Climatology of the United States".

As shown in Figure 15 wind data from U.S. Coast Guard

VELOCITY FREQUENCY DATA FOR MUSKEGON 1972

VELOCITIES IN KNOTS

HEIGHT CORRECTED FROM 21.3 M TO 10.0 M (HEIGHT CORRECTION EXP= .16)

VEL	TOTAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	VEL**3
0	150	6	12	36	30	24	36	0	6	0	0	0	0	0
1	12	0	0	0	0	0	0	6	6	0	0	0	0	1
2	252	18	18	24	0	6	18	54	42	39	24	9	0	8
3	183	12	0	12	12	24	24	12	24	27	21	12	3	27
4	1251	42	120	72	84	114	120	156	168	117	108	87	63	64
5	504	42	78	36	72	54	30	42	30	30	33	36	21	125
6	336	12	24	18	18	66	30	36	42	24	12	24	30	216
7	723	24	72	96	84	72	54	42	60	54	60	57	48	343
8	258	12	36	12	18	60	18	18	6	24	27	15	12	512
9	1257	42	84	120	126	96	102	96	96	93	93	141	168	729
10	222	24	12	18	12	24	30	6	12	24	6	33	21	1000
11	645	66	30	66	42	54	60	66	60	54	45	48	54	1331
12	330	24	12	36	48	42	12	24	30	39	18	21	24	1728
13	576	48	24	54	42	54	66	60	60	54	36	23	45	2197
14	87	12	12	0	12	0	6	12	0	12	9	12	0	2744
15	117	18	24	0	24	0	6	6	6	3	15	9	6	3375
16	336	30	30	12	48	6	12	24	48	21	42	33	30	4096
17	48	0	0	6	6	0	12	0	0	12	0	12	0	4913
18	540	66	54	36	12	12	66	42	30	57	48	39	78	5832
19	201	54	12	18	6	6	6	0	6	9	33	27	24	6859
20	72	24	0	6	6	6	0	0	0	0	6	12	12	8000
21	32	6	0	0	6	0	0	0	0	3	12	6	0	9261
22	153	48	12	18	6	0	0	0	0	9	45	6	9	10648
23	27	0	0	6	0	0	0	0	0	3	3	3	6	12167
24	15	0	0	0	0	0	0	0	0	0	6	0	3	13824
25	81	24	6	12	0	0	0	0	0	0	18	15	6	15625
26	123	36	18	18	0	0	0	0	0	0	33	15	0	17576
27	24	0	0	6	0	0	0	0	0	3	12	15	21	19683
28	12	0	0	0	0	0	0	0	0	0	0	0	0	21952
29	12	0	0	6	0	0	0	0	0	0	0	0	0	24389
30	12	0	0	0	0	0	0	0	0	0	0	0	3	27000
31	48	24	6	0	0	0	0	0	0	0	0	0	18	29791
32	0	0	0	0	0	0	0	0	0	0	0	0	0	32768
33	0	0	0	0	0	0	0	0	0	3	0	0	6	35937
34	0	6	0	0	0	0	0	0	0	0	0	0	0	39304
35	15	6	0	0	0	0	0	0	0	0	0	0	9	42875
36	0	0	0	0	0	0	0	0	0	0	0	0	0	46656
37	0	0	0	0	0	0	0	0	0	0	0	0	0	50653
38	0	0	0	0	0	0	0	0	0	0	0	0	0	54872
39	0	0	0	0	0	0	0	0	0	0	0	0	0	59319
40	0	0	0	0	0	0	0	0	0	0	0	0	0	64000
41	0	0	0	0	0	0	0	0	0	0	0	0	3	68921
42	0	0	0	0	0	0	0	0	0	0	0	0	0	74088
43	0	0	0	0	0	0	0	0	0	0	0	0	0	79507
44	0	0	0	0	0	0	0	0	0	0	0	0	0	85184
45	0	0	0	0	0	0	0	0	0	0	0	0	0	91125
46	0	0	0	0	0	0	0	0	0	0	0	0	0	97336
47	0	0	0	0	0	0	0	0	0	0	0	0	0	103823
48	0	0	0	0	0	0	0	0	0	0	0	0	0	110592
49	0	0	0	0	0	0	0	0	0	0	0	0	0	117649
50	0	0	0	0	0	0	0	0	0	0	0	0	0	125000
ND	125	0	0	0	6	24	12	42	12	6	6	9	12	

Figure 6. Velocity frequency data for Muskegon 1972.

VELOCITY DURATION DATA FOR MUSKEGON 1972

VELOCITIES IN KNOTS

HEIGHT CORRECTED FROM 21.3 M TO 10.0 M (HEIGHT CORRECTION EXP= .16)

VEL	TOTAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	VEL**3
0	8655	744	696	744	714	720	708	702	732	714	738	711	732	0
1	8503	738	684	708	684	696	672	696	726	714	738	711	732	1
2	8241	720	666	684	672	650	654	642	678	675	714	702	732	8
3	8057	666	666	672	684	630	630	630	654	648	693	690	732	27
4	8007	666	666	672	684	630	630	630	654	648	693	690	732	64
5	7967	666	666	672	684	630	630	630	654	648	693	690	732	125
6	7967	666	666	672	684	630	630	630	654	648	693	690	732	341
7	7967	666	666	672	684	630	630	630	654	648	693	690	732	512
8	7967	666	666	672	684	630	630	630	654	648	693	690	732	125
9	7967	666	666	672	684	630	630	630	654	648	693	690	732	341
10	7967	666	666	672	684	630	630	630	654	648	693	690	732	512
11	7967	666	666	672	684	630	630	630	654	648	693	690	732	125
12	7967	666	666	672	684	630	630	630	654	648	693	690	732	341
13	7967	666	666	672	684	630	630	630	654	648	693	690	732	512
14	7967	666	666	672	684	630	630	630	654	648	693	690	732	125
15	7967	666	666	672	684	630	630	630	654	648	693	690	732	341
16	7967	666	666	672	684	630	630	630	654	648	693	690	732	512
17	7967	666	666	672	684	630	630	630	654	648	693	690	732	125
18	7967	666	666	672	684	630	630	630	654	648	693	690	732	341
19	7967	666	666	672	684	630	630	630	654	648	693	690	732	512
20	7967	666	666	672	684	630	630	630	654	648	693	690	732	125
21	7967	666	666	672	684	630	630	630	654	648	693	690	732	341
22	7967	666	666	672	684	630	630	630	654	648	693	690	732	512
23	7967	666	666	672	684	630	630	630	654	648	693	690	732	125
24	7967	666	666	672	684	630	630	630	654	648	693	690	732	341
25	7967	666	666	672	684	630	630	630	654	648	693	690	732	512
26	7967	666	666	672	684	630	630	630	654	648	693	690	732	125
27	7967	666	666	672	684	630	630	630	654	648	693	690	732	341
28	7967	666	666	672	684	630	630	630	654	648	693	690	732	512
29	7967	666	666	672	684	630	630	630	654	648	693	690	732	125
30	7967	666	666	672	684	630	630	630	654	648	693	690	732	341
31	7967	666	666	672	684	630	630	630	654	648	693	690	732	512
32	7967	666	666	672	684	630	630	630	654	648	693	690	732	125
33	7967	666	666	672	684	630	630	630	654	648	693	690	732	341
34	7967	666	666	672	684	630	630	630	654	648	693	690	732	512
35	7967	666	666	672	684	630	630	630	654	648	693	690	732	125
36	7967	666	666	672	684	630	630	630	654	648	693	690	732	341
37	7967	666	666	672	684	630	630	630	654	648	693	690	732	512
38	7967	666	666	672	684	630	630	630	654	648	693	690	732	125
39	7967	666	666	672	684	630	630	630	654	648	693	690	732	341
40	7967	666	666	672	684	630	630	630	654	648	693	690	732	512
41	7967	666	666	672	684	630	630	630	654	648	693	690	732	125
42	7967	666	666	672	684	630	630	630	654	648	693	690	732	341
43	7967	666	666	672	684	630	630	630	654	648	693	690	732	512
44	7967	666	666	672	684	630	630	630	654	648	693	690	732	125
45	7967	666	666	672	684	630	630	630	654	648	693	690	732	341
46	7967	666	666	672	684	630	630	630	654	648	693	690	732	512
47	7967	666	666	672	684	630	630	630	654	648	693	690	732	125
48	7967	666	666	672	684	630	630	630	654	648	693	690	732	341
49	7967	666	666	672	684	630	630	630	654	648	693	690	732	512
50	7967	666	666	672	684	630	630	630	654	648	693	690	732	125
ND	125	0	0	0	0	24	12	42	12	6	6	9	12	125000
AVES	11.7	17.0	11.2	11.8	10.5	9.0	10.1	9.4	9.4	10.9	13.3	12.6	14.9	IN MPH
AVES	10.2	14.8	9.8	10.2	9.1	7.8	8.7	8.2	8.2	9.5	11.5	11.0	13.0	IN KNOTS

Figure 7. Velocity duration for Muskegon 1972.

Figure 8.

Yearly and Monthly Average Wind Speeds at 10 Meters for Muskegon, 1972.

Figure 9. Wind Speed Duration for Muskegon, 1972

Figure 10. Diurnal Variations at 10 Meters for Muskegon, 1972

WIND ROSE

STATION: Muskegon

DATES: Total - 1972

() = AVERAGE VELOCITY IN MPH
HEIGHT CORRECTED TO 30 METERS

% CALM = 1.7%
HOURS OF CALM = 150
MISSING DATA = 144 hrs.
WIND ROSE BASED ON 8,634 hrs. of data

Figure 11. Muskegon 1972 annual wind rose.

ENERGY ROSE

STATION: Muskegon

DATES: Total - 1972

Figure 12. Muskegon 1972 annual energy rose.

WIND ROSE

STATION: Muskegon

DATES: September 1975

() = AVERAGE VELOCITY IN MPH
HEIGHT CORRECTED TO 30 METERS

% CALM = 0.0
HOURS OF CALM = 0
MISSING DATA = 0
WIND ROSE BASED ON 720 hrs. of data

Figure 13. Muskegon September 1975 wind rose.

ENERGY ROSE

STATION: Muskegon

DATES: September 1975

Figure 14. Muskegon September 1975 energy rose.

Figure 15. Wind energy potential in Michigan. Shaded areas indicate regions which have best potential for wind energy systems. Wind speeds indicated are yearly averages at Coast Guard Stations.

stations indicates that average annual wind speeds of between 13 and 18 MPH are the norm at or near the Great Lakes shoreline. These winds correspond to an average annual wind power density of 225-375 W/m^2 at 10 meters. These wind power densities rank amongst the highest within the U.S.⁶ and demonstrate that the coastal region of Michigan is an excellent area for wind turbine applications.

The monthly average wind speeds shown in Figure 8 clearly show that the winter months, October through March are months of high wind energy while the summer months of June through August have low wind energy. Each wind measuring station in the Great Lakes region has a similar seasonal wind pattern. This fact suggests the possibility of using wind energy to replace oil, natural gas, and bottled gas for heating in the winter.

Prevailing winds in the region are westerly. During the summer months, winds are predominantly southwesterly as the "Bermuda High Pressure Center" pushes into the Southeastern United States. During the winter months, the prevailing winds are West to Northwest, but change quite frequently for short periods into the other directions. These changes are due to the interaction of maritime-polar or continental polar air with maritime-tropical air.

The Great Lakes Region, particularly the western and upper portions of the region, resides on the fringe of the Midwest tornado belt. The lower frequency of tornadoes occurring in this region is due to the colder water of the Great Lakes during the spring months, a prime period for tornado activity. Since 1900, for example, only two tornadoes are known to have touched down in Oceana County, the county in which the city of Hart, Michigan is located.⁴

Examples of computer processed 1975 wind data are shown in Table 2 and Figures 16 and 17. Several conclusions are apparent from this information. A comparison of the monthly wind speed averages in Table 2 for Ludington, Muskegon and Little Point Sable Lighthouse and a comparison of their diurnal variations in Figure 16 shows that, although these three stations are separated by 50 miles along the coast of Lake Michigan, they consistently show very similar wind energy behavior. Thus, if the wind energy is well known by month and

TABLE 2
1975 WIND DATA
Average Velocity in MPH at 30 m.

	March	April	May	June	July	August	Sept.	Yearly Average
Muskegon Average Velocity	14.0	13.4	10.9	12.7	11.7	11.3	12.6	12.37
Ludington Average Velocity	15.3	13.7	10.8	12.6	11.7	11.7	12.9	12.61
Light House Average Velocity		13.3	10.9	*	*	*	12.4	
²⁹ State Police Average Velocity		11.1	*	10.1	8.8	7.7	7.1	9.65
Pro Gas Average Velocity		*	8.5	10.1	8.1	9.0	*	

* Not sufficient data for one month average.

Figure 16. Diurnal variations for Ludington, Muskegon and the Little Point Sable lighthouse.

Figure 17. Diurnal variations for Little Point Sable lighthouse, State Police tower and Pro Gas tower.

year at a particular position on the coast, it can be assumed to be known with a high degree of accuracy (neglecting local topographic effects that would be caused by hills and dunes adjacent to the coast) anywhere along this 50 mile coastal region. Furthermore, this implies that the historical wind data from both the Ludington and Muskegon Coast Guard Stations can be used to provide historical wind information for the coastal region west of the city of Hart.

Figure 17 displays the diurnal wind variations for Little Point Sable Lighthouse, State Police Tower and Pro Gas wind stations. The attenuation of wind energy due to the characteristics of the terrain is clearly indicated by the 13.4 mph average wind speed at Little Point Sable Lighthouse vs. the 11.1 and 9.1 averages for the State Police and Pro Gas wind measuring stations respectively. Thus, even though the State Police wind station is 320 feet above the lake level, the attenuation of wind energy is significant. This difference between shoreline wind speeds and wind speeds at inland locations is consistent with the results from the historical wind data. An important question is raised by this fact and must be answered by our study: How rapidly is the wind attenuated as it moves inland off of the Great Lakes?

3. HART POWER DEMAND AND CONSUMER USAGE

3.1 Characterization of Hart Power and Energy Demand

Since the goal of the project is to determine the feasibility of future implementation of wind power in the Hart area, it is necessary to predict the total load as it grows over the prediction time horizon. The total load at any time includes the sum of losses in transmission and distribution as well as consumer load. As indicated in the next section, the features of the load demanded by consumers will be analyzed separately from the total load so that predictions can be corrected for anticipated changes in consumer load behavior and substitution effects between natural gas and electricity. Nevertheless, one input to any feasibility evaluation of wind power is total load predicted on an hourly basis. Since this total load is equal to the sum of power generated by diesel and hydro alternators in Hart, plus that

supplied by Wolverine, operating logs with this data can be used as an historical base. Twelve months of such data has now been card-punched and a typical graph of this total load (called total indicated kilowatts) is shown in Figures 18 and 19. Notice the consistent nightly minimum of about 1100 kW and the daily peaks ranging from 2300 to 3000 kW. This data is typical of most weeks except during the peak season of the local canneries in June, August and September. This historical data will be used to find a probabilistic demand model for the future with a load increase averaging about 7% per year--a value predicted by the Hart management which is lower than the short-term historical data indicates. Corrections to this load growth estimate will be made from the consumer usage study and the corrected estimates used as input to the economic evaluation model discussed in Sections 7 and 9 of this report.

3.2. Utilization and Consumption

The energy shortage is dominantly a shortage of gas and oil. These are the fuels heavily relied upon by Hart, directly and indirectly. To solve the problem, a shift to other energy sources is indicated. One such source is presumed to be wind power. How to apply it cost-effectively, thereby reducing the consumption of precious gas and oil, is, of course, the subject of the present study.

Application of wind power to small electric systems, and the utilization of wind power otherwise, can take several directions:

(1) utilization of wind energy as a fuel saver, (2) wind energy combined with an energy storage system forming a base load operation, (3) changes in consumer utilization practices, i.e. demand, to accommodate, at least in part, variations in wind availability. Option (3) might include energy storage at the consumer level. It might also include a switch in space and water heating fuels from oil and gas to wind-generated electricity.

Options (1) and (2) assume that the market demand for electricity will be met by the supplier, when and if such demand arises. Option (3) would require societal and/or institutional changes related to living habits and life styles, economic and human values, commercial and industrial processes, and a host of other characteristics of a community. In order to determine how such change might be brought

Figure 18. Typical Hart Load Profile (Week of January 6-12, 1974).

Figure 19. Typical Hart Load Profile (Week of October 6-12, 1974).

about, that is, changes which would accommodate the nature of wind power, requires information. Unfortunately, there is little such information readily available.

Ideally, the information needed is time-continuous wind-power data, and individual time-continuous consumption data with time intervals on the order of minutes. The wind data situation is dealt with in Section 2 of this work. Utility-energy consumption data is available only in a macro sense. With respect to the Hart system, there is information on hourly electricity send-out, daily, monthly, and yearly aggregates. Similar information is available for natural gas. Monthly billings tell one about monthly consumption by individual users, and these users can be categorized. The following tables serve to illustrate the type of information available.

August 10, 1975 to September 10, 1975

Table 3, Hart Electric System, Deliveries by Category

(Fruit) Industry	32.9 %
Commercial	4.8
Offices	2.6
Light Industry and Farming	1.7
Residential	21.2
Utilities, Water and Sewage	14.4
Grocery Markets	6.9
Other Retail Stores	2.0
Restaurants	1.3
Bars	.8
Motels	.7
Gas Stations	.3
Schools	2.1
Medical Care	5.3
Public Grounds	1.1
Miscellaneous	<u>1.9</u>
	100.0 %

Total delivery for the period = 1,573,478 kWh.

Source: Billings for the period

TABLE 4

Michigan Consolidated Gas Company
Natural Gas Deliveries by Categories
October 1, 1974 to September 30, 1975

Type of Customer

Residential (a)	.3%
Residential Heating (b)	31.0
Commercial (c)	2.6
Commercial Heating (d)	31.2
Industrial (e)	2.0
Interruptible (f)	32.9
	<hr/> 100.0%

Total deliveries for the period = 292,842 million Btu

- (a) - generally cooking and water-heating
- (b) - generally cooking, water-heating, and heating. Heating is generally 75% of the consumption
- (c) - generally commercial cooking, laundromats, and non-heating commercial uses
- (d) - generally commercial and industrial heating, including residential apartment buildings
- (e) - industrial processing without stand-by (other fuels) capability
- (f) - industrial processing with stand-by capabilities (City of Hart electric plant)

Source: Michigan Consolidated Gas Company

Of note is that natural gas consumption is roughly the equivalent of five times the energy value of the consumption of electric energy.

As already indicated, this type of information is inadequate for determining how wind power availability might be related to total demand, or how utilization practices might be adjusted to accommodate the availability of wind power, adjusted in a reasonably cost-effective and socially acceptable manner. The literature was reviewed to determine whether any past consumption studies could be used to construct the needed detailed consumption profiles. The outcome was negative. Admittedly, a more intensive search might alter this judgement.

The problem centers on the indeterminate nature of the demand variations which are illustrated by Table 5, Baseload, Peakload, and Ratio, Hart Electric System 1974, and Figure 19, Daily Demand Variations, Hart Electric System, week of October 6-12, 1975.

Table 5
Baseload, Peakload, and Ratio
Hart Electric System 1974

Month	Baseload	Peakload	Ratio (Peak/Base)
January	768	3,050	4.0
February	920 highest	2,490	2.7 minimum
March	820	2,450	3.0
April	770	2,260 lowest	2.9
May	800	2,390	3.0
June	820	2,290	2.8
July	730	3,410	4.7
August	820	3,350	4.1
September	580	3,280	5.7 maximum
October	860	3,550 highest	4.1
November	700	2,980	4.3
December	530 lowest	2,940	5.5

Source: Hart Electric Plant Daily Log Sheets for 1974.

The information presented in Table 5, and Figure 19, explains the difficulties one encounters in attempting to match wind power availability with the actual utilization of the kind of energy wind power could supply. It is of note that the peak/base ratio of the Hart system must be considered abnormally high.

The ideal way to approach the problem would be to instrument and continuously meter representative samples of actual consumption.

However, it was felt that this was too costly and time-consuming, without knowing whether the return on the effort could be sufficiently productive and worthwhile. Further analysis is to verify this assumption.

A two-part decision was made to (1) survey the residential sector by means of a user questionnaire included with one mailing of the monthly electric bills, and (2) to obtain information from the other sectors by means of personal interviews to collect pertinent information. A sample of the residential user survey questionnaire can be found in the appendix.

About 60 % of the residential questionnaires have been returned and are yet to be processed. Some random sample interview data of commercial users has also been collected, but has yet to be analyzed and suitably organized.

In summary, because of the unknowns and complexities involved in the questions raised, it may well take another year to produce tangible information useful in terms of the particular objective, that is, to spell out how consumption might be accommodated to the availability of wind energy. It all depends on whether the information can be developed at all without too costly methods and tools.

4. ASSESSMENT

4.1. Wind Turbine Performance in the Hart Area

In order to effectively use wind energy, two different types of modes of operation are available for WECS: (1) WECS as fuel savers and (2) WECS as part of base load of electric system operation. The first of these requires that wind systems be tied directly into existing electric power grids. In general, energy delivered in this manner requires conventional spinning reserve capacity and would be worth the cost of fuel saved in a conventional plant and must compete with any other "dump" energy such as excess energy from a plant which normally is not fully utilized around the clock. Wind systems operating as part of a base load require an adequate energy storage system to be available on demand whenever a wind lull period is present. If energy storage is present, then the energy generated by wind power can be used on demand and the same reserve requirements would exist as for conventional power plants.

For the purpose of WECS design and economics, it is necessary to calculate energy output and average power output per month and year for different wind turbine designs and wind turbine sites. It is also necessary to determine the frequency of occurrence and the length of time of periods when the wind turbines are not in operation. Each of these calculations is dependent on the region's wind characteristics and on individual wind turbine characteristics. Example calculations of energy, average power and down period duration for the G.E. and Kaman Wind turbine designs are presented in this section. Historical wind data from the Muskegon and Ludington Coast Guard Stations (Note the conclusion in section 2.5 that the winds along the Lake Michigan shore west of Hart are very similar to the winds at Muskegon and Ludington) and the 1975 wind data gathered by the MSU wind stations in the Hart region is used as the input wind information.

Tables 6 through 9 show example calculations of the total energy and average power for the 500kW and 1.5 MW G.E. and Kaman machines located at a number of different sites on the shore of Lake Michigan and at inland locations in the vicinity of Hart. These calculations were carried out by numerically integrating actual power duration curves or velocity frequency curves using the best wind turbine information available from the final G.E. and Kaman presentations.

Historical wind information was employed in all the calculations except for those shown in Table 7 for the State Police tower south of the city of Hart. Since a full year of wind information was not available yet from the ongoing MSU wind measurements, the velocity frequency curve for a full year had to be estimated. An approximated velocity-frequency curve was found by using the April - Sept. 1970 wind information to provide a relationship between the energy at Muskegon and the State Police tower. For example, it was found that the energy at the State Police tower was less than one-half of the energy on the Lake Michigan shore. Using this information, the 1972 Muskegon velocity frequency curve was modified, i.e., "shifted" to the State Police tower.

Two wind turbine models were employed. Whenever actual machine characteristics vs. wind speed were available, they were numerically integrated together with the power duration/frequency speed curves. When detailed machine models were not supplied, the

machine efficiently was assumed to be independent of wind speed for wind speeds between "cut-in" and "rated." While cut-in, rated, average, etc. wind speeds are referenced at 30 ft., when making energy and power calculations, the wind speeds could be corrected for height, (h), over the diameter of the wind turbine blade. A height variation of (h) 0.16 was used for lake and lakeshore regions while a height variation of (h) 0.28 was assumed for the wind variation for sites located several miles or more from the lakeshore.

If wind machines are to be used as part of a base-load operation, energy must be available to users on demand. In order to determine the energy storage requirements of a WECS with energy storage, it is necessary to know the frequency at which a wind turbine is closed down and the length of time for each of these down periods. In this report the turning off or closing down of a wind machine is called "down time" and the length of time of such an occurrence is called "down period." The down time and down period include the time when the winds are equal to or above the machine cut-off wind speed as well as when the wind conditions are below the cut-in wind speed. That is, a down period equals the number of consecutive hours the wind speed is less than cut-in or greater than or equal to the cut-off velocity. Thus, the down period is a function of site wind characteristics and the characteristics of the wind turbine configuration selected.

A software package was developed to compute the frequency down period duration curve from the wind turbine and the wind characteristics. Figure 20 shows the frequency of the down period durations for the G.E. 500kW and 1500kW machines using Ludington 1972 wind data. The 500 kW machine is down a total of 1972 hours for the year and has only one down period in excess of 36 hours (actually this down period is in excess of 50 hours). In comparison, the larger 1500 kW machine is down a total of 3640 hours for the year and has 27 down periods in excess of 36 hours (8 of these are in excess of 50 hours). Thus, if the larger machine is part of a base load system, it would require a significantly larger energy storage system than an equivalent system of smaller widely separated wind turbines.

More specifically, one 1.5 MW machine on the lakeshore will produce on the average 400 kW/hr over a year. (See Table 6) Two

TABLE 6.

AVERAGE POWER OUTPUT AND ANNUAL
ENERGY OUTPUT FOR G.E. AND KAMAN WIND TURBINES

Wind Data - Muskegon 1972 - Average velocity = 11.7 mph at 30 feet

Machine	Annual Energy Output	Average Power Output	Plant Factor
G.E. 500 kW	2.04×10^6 kWh	235 kW	0.47
G.E. 1.5 MW	3.41×10^6 kWh	394 kW	0.26
Kaman 500 kW	1.30×10^6 kWh	150 kW	0.30
Kaman 1.5 MW	2.59×10^6 kWh	300 kW	0.20

TABLE 7.
 AVERAGE POWER OUTPUT AND ANNUAL
 ENERGY OUTPUT FOR G.E. AND KAMAN WIND TURBINES
 WIND DATA-STATE POLICE TOWER (1972 estimate)

Machine	Annual Energy Output	Average Power Output	Plant Factor
G.E. 500 kW	1.00×10^6 kWh	114 kW	0.23
G.E. 1.5 MW	1.14×10^6 kWh	130 kW	0.09
Kaman 500 kW	$.55 \times 10^6$ kWh	63 kW	0.126
Kaman 1.5 MW	$.70 \times 10^6$ kWh	80 kW	0.05

TABLE 8.
AVERAGE POWER OUTPUT AND ANNUAL ENERGY
OUTPUT FOR G.E. WIND TURBINES
ALONG THE COAST OF LOWER MICHIGAN

Wind data - 1972 Historical Coast Guard Data

Location	500 kW G. E.		1.5 MW G. E.	
	Annual Energy kW-Hr	Average Power kW	Annual Energy kW-Hr	Average Power kW
Muskegon	2.0×10^6 kWh	235 kW	3.41×10^6 kWh	394 kW
44 Ludington	2.2×10^6 kWh	253 kW	3.46×10^6 kWh	396 kW
Lansing Shoals	2.9×10^6 kWh	334 kW	5.5×10^6 kWh	632 kW

TABLE 9.
AVERAGE POWER OUTPUT FOR 1.5 MW
G.E. Wind Turbine Machine

Wind Data: Muskegon 1972
Diameter = 190 feet

Cut in Velocity = 11.4 mph
Rated Velocity = 22.5 mph

All wind velocities given are at 30 feet

	Jan	Feb	Mar	April	May	June	July	August	Sept	Oct	Nov	Dec	Yr
Average Velocity (mph)	17.0	11.2	11.8	10.5	9.0	10.0	9.4	9.4	10.9	13.3	12.6	14.9	11.7
⁴⁵ Average Output Power kW	793	369	382	298	166	304	249	254	353	536	442	555	394

Figure 20. Down period duration curves for G. E. wind turbines.

500 KW machines are equivalent to slightly more than one 1.5 MW machine since together they produce an average power output of 500 kW/hr per year. If one operates these two systems as fuel savers, the large machine would have a slight economic advantage since its cost is \$ 500/kW or \$ 750,000 vs. the two smaller machines which cost \$ 1,000/kW or a total of \$ 1,000,000.

However, if these two systems are operated as part of a base load system the optimum economic design probably will be different. One would expect that the two 500kW machines operating together will have less than the 1972 hour of down time of a single machine. This is particularly true if the two turbines were separated along the coast by tens of miles.⁷

Thus, the energy storage requirements of the two smaller machines are expected to be much less than the energy storage system for the large machine. (3640 hours of down time) It may be possible, that even though the two 500kW wind turbines cost \$ 250,000 more than the large 1.5MW turbine, that total capital investment for wind turbine plus storage system is less for the system comprising smaller machines than may be the case for the larger machine. In addition, a system made up of several turbines has the advantage of better probable reliability over a single large unit.

Another conclusion is apparent. The 1.5 MW machine, which has been designed for optimum operation in locations where the average wind speed is 18 mph at 30 feet, does not perform efficiently on the Lake Michigan shore, except in the Lansing Shoals location. Lansing Shoals is probably representative of many other over-water locations and not coastal locations. It does not perform optimally, not only as part of a base load system, but also as a fuel saver, since the average wind speeds are generally less than 15 mph. It is believed that a 1.5 MW machine designed for an average wind speed of 15 mph would perform more economically as a fuel saver and if it had a low cut in velocity, would also require less energy storage for operation as a part of a base load system.

At a given height, the attenuation of the wind energy is significant as it passes from lakeshore sites to inland sites as evidenced by Figure 17 in Second 2 and by Tables 6 and 7. Based on the preliminary

yearly wind energy estimates, finding economic inland sites near the city of Hart does not appear promising. Also, since the G.E. wind turbine design has lower rated and cut-in wind speeds than the Kaman designs, G.E. performs better both on the lakeshore and at inland sites.

These conclusions are preliminary. Further study is required to determine the optimum design criteria. For example, the following questions must be answered: (1) how many, what size, and where should the wind turbines be located, (2) how large a base load system of hydro plus wind can be constructed, (3) how should it be operated; by month and by day and (4) does a mix of large and small wind turbines providing for both fuel saver and base load operation make sense?

These and other points are discussed in Section 10: Future work.

4.2. Assessment of Existing Transmission Line Grid

It is unlikely that possible high-wind generation sites will be close to or within the Hart electric system distribution area. Thus, it was necessary to assess the capabilities of the existing transmission lines in the high-wind areas surrounding Hart, see map in Figure 21. If these lines lacked the capacity to carry wind-generated electricity, costs of new transmission lines would be part of total system cost, a probable negative. An area of about 100 square miles was evaluated, this area is marked on the map. Most of this area is serviced by the Oceana Electric Cooperative which, like the Hart, purchases energy from the Wolverine G and T Cooperative. Thus, Oceana and Hart are interconnected via Wolverine. Oceana's lines are both three phase at 12.5 kV and single phase at 7.2 kV. Most of the lines serving the high-wind shoreline areas are 7.2 kV single phase. The Wolverine Electric Cooperative has a 69 kV three-phase "backbone" system passing through the middle of the area with three substations feeding Oceana and Hart.

A set of lines, marked on the map, was assessed for ampacity and voltage drop. The lower-voltage distribution lines chosen emanated from the substations and fed load in areas that were thought to be high-wind regions. This choice was made in the summer of 1975

before appreciable wind data had been gathered. The length and configuration of a selection of these lines is shown in Figures 22 through 24. The impedance and ampacity (allowable current before thermal damage) of each section was calculated and then a table of power capacity versus voltage drop was computed--with a power factor assumption of 0.8. The results for three-phase distribution lines is given in Figure 25 which indicates, for example, that a line ten miles long will have a voltage drop of 5% when 134 kW is transferred. The single-phase lines were immediately omitted because the voltage drop was prohibitive at substantial power levels. If these distribution right-of-ways were to be used to feed power into Hart via Oceana and Wolverine, it would be necessary to string additional wires and convert them to three-phases lines. Similar calculations were completed for the 69 kV Wolverine grid.

For example, the line from the Shelby substation at the southern end of the test area to the Hart substation has a capacity of 7 MVA with a 2% voltage drop--more than adequate for a 1.5 MW wind station. This is 7 MVA and exceeds present scheduled power transfer by several MVA.

Conclusions:

The 69 kV Wolverine network has the capacity to transfer power equal to the entire Hart peak demand while the three-phase Oceana distribution network could handle several wind stations on modified lines, of a capacity up to several hundred kW. The 500kW G.E. and Kaman machines would be tied into short sections 2 miles or less of the Oceana distribution network and the 1.5 MW wind turbines must be tied directly into the kW Wolverine network. The calculations leading to these conclusions are available (they were done by visiting Professor Julius Preminger while at MSU--an experienced power engineer) but are not included in this progress report.

5. HYDRO POWER ASSESSMENT

5.1. Fuel-Saver Mode of Operation

"Fuel-saver" mode of wind power systems is being shown applicable to small electric systems such as the Hart system. This is primarily because present generation relies mostly on natural gas and/or

Figure 22. 69kV lines considered (sketch) in Hart area.

All lines are of 3/0 ASCR conductor.

A. Lines originating from SILVER LAKE SUBSTATION

Figure 23. Sketch of 12.5/7.2 kV lines considered.

B. Lines originating from SHELBY SUBSTATION

Figure 24.

TABLE: Transferred power in kw for a 3 phase #6 copper line assuming P.F.= 0.8 and 12.5/7.2kV, as a function of voltage drop in % and distance in miles.

Voltage DROP %	DISTANCE → MILES				
	2	4	6	8	10
2	269	135	90	68	54
5	667	334	222	167	134
10	1334	667	443	333	269

The capacity limit for #6 copper conductors is 110A, so for this case the ampacity limit of the considered line $S = \sqrt{3} \cdot 12.5 \cdot 110 = \cong 2300 \text{ kVa}$ is overruled by the voltage drop limitations.

Figure 25. Voltage drop table for Hart area distribution lines.

diesel oil for fuel. The cost of these fuels, which are expected to continue their rapid advance in price, are likely to favor capital investment in wind power facilities. This holds as long as no new capital facilities for system expansion are required, i.e., as long as existing plant satisfies current demand. However, this does not entirely hold true for Hart, nor does it for similar situations, small municipal and rural electric systems, which are faced with an annual load growth in the 5% to 7% range. Such load growth cannot be accommodated with wind power facilities operating in the "fuel saver" mode.

5.2 Wind Power as a Part of Base Load Capability

Energy for the Hart municipal electric system is normally supplied from three sources: (1) diesel power using either oil or gas as a fuel, (2) the Wolverine Rural Electric Cooperative, which also generates using oil or gas as a fuel, and also purchases a part of its requirements from large utilities, and (3) hydro generation using the South Branch of the Pentwater River. Hart, as is the case with most other utilities, is in need of additional generating capability, or additional supply from external sources, where the same problem prevails. One alternative is to use the Hart hydroelectric facility in combination with a wind power system. The mode of operation would have to be so arranged that the hydro facility is used during periods when the wind falls below a certain energy level.

5.3 History and Capability of Present Hart Hydro

The Hart hydro was built in 1926 by damming the South Branch of the Pentwater River, which flows westerly into Lake Michigan at Pentwater, about 10 miles from the Hart hydro dam. The impoundment created Hart Lake with a surface area of about 240 acres at an elevation of about 622 feet above sea level. The head so obtained is about 32 feet, which means that the tailwater is at an elevation of about 590 feet. Lake Michigan's normal elevation is about 578 ft.

As with most of the several hundred hydros which operated in Michigan at one time--now approximately 100 operating--they were built in "waterwheel" fashion, i.e. "flowthrough", with no significant storage capacity. In other words, the impoundments were created

simply to gain head (*). Therefore, the Hart Lake impoundment has almost no storage capacity, other than the storage contained in the lake, which is necessary to maintain the 32 ft. head.

When there is excess water, the "waste gates" are opened far enough to prevent raising the level of Hart Lake appreciably above the 622 ft. elevation. As will be shown later, about one-half of the annual discharge does not generate power.

Generating capability is relatively small, although it did satisfy the needs of the city of Hart initially, from 1927 to 1934. The two wheels originally installed have a name plate rating of 300 kW. The U.S. Geological Survey rated this installation (in 1958) at 270kW, and determined an efficiency factor of between 70 % and 76 % depending on the state of the facility. The probable average efficiency is 73 %, which is 10 to 15 percentage points below what a modern installation would be. A four year assessment of the 1971-1974 experience indicates that the average power output from the hydro facility is 94 kW.

5.4 Investigation of Hart Hydro Converted to Energy Storage Mode

Using the Hart hydro as an energy storage reservoir would call for a substantial increase in impoundment capacity, as well as an expansion of hydro generating capability to fall into line with wind power generating capability. For example, if a base load wind-hydro combination power capability were 1000 kW, the hydroelectric capability would need to be 1000 kw.

Not considering pumped storage at this point of the investigation, the basic limitation imposed on such a scheme is the volume of water flowing in the river system under study. Volume is referred to as discharge.

Investigation disclosed that longitudinal discharge data for the Pentwater was never collected and therefore, not available. To make an estimate of the hydro-storage potential of Hart Lake, it became

(*) A listing of hydro impoundments in Michigan is maintained by the Michigan Water Resources Commission, Department of Natural Resources, Lansing, Michigan. Pond averages, not including Lake Superior, range upward to 18,770 acres; heads range from 608 feet to 6 feet. A listing of more detail can also be found in HYDROELECTRIC POWER RESOURCES OF THE UNITED STATES, Developed and Undeveloped, Federal Power Commission, Washington, December 1972.

necessary to learn about the discharge characteristics of the South Branch of the Pentwater.

5.5 Hydro Inventory of the South Branch of the Pentwater Watershed, and Storage Capability of Hart Lake Enlarged
The hydrogeneration records tell us how much hydroelectric power was produced, see Table 10.

TABLE 10. Four-Year Production at the Hart Hydroelectric Plant
(in 1,000 kWh/mo)

	1971	1972	4 year Average	1973	1974
Jan	1	100	124	149	120
Feb	115	86	101	102	104
Mar	185	146	158	165	136
Apr	166	135	129	128	88
May	111	101	111	138	94
June	91	53	88	77	133
July	46	42	48	54	52
Aug	47	56	59	49	86
Sept	39	52	48	43	59
Oct	51	86	73	64	94
Nov	79	93	90	84	106
Dec	137	94	101	85	89

This information in turn tells us how much water was used for generation. However, no records have been kept on the discharge through the waste gates.

The discharge through the two wheels can be estimated:

$$Q = \frac{11.8 \times 2 \times 135}{32 \times .73} = 136.4 \text{ ft.}^3/\text{sec (at 1.0 governor setting)}$$

where

Q is the discharge in ft.³/sec.

11.8 is a constant

32 is the head in ft.

.73 is the probable efficiency

(from HYDRAULICS HANDBOOK, D. V. Davis and K. E. Sorenson, Handbook of Applied Hydraulics, McGraw-Hill, New York, 1969, pp.29-11 and pp. 24-27)

Actual production experience reflects an annual discharge through the wheels of:

$$1,103,000 \times \frac{136.4}{270} \times 60 \times 60 = 2.0 \times 10^9 \text{ ft.}^3$$

where

1,103,000 is the 4 year average annual production in kWh (see Table 20)

136.4 is Q

270 is the wheel rating in kW as rated by the U.S. Geological Survey

Estimated total discharge (method used for estimating is described in the following):

$$\text{Estimated annual discharge} = 116.25 \times 60 \times 60 \times 24 \times 365 = 3.7 \times 10^9 \text{ ft.}^3$$

where

116.25 is the estimated Q for the South Branch of the Pentwater.

The above shows that the present hydrogenerating capability at Hart is twice the production. It further shows that water availability on an annual basis is almost twice the production. This is due mainly to lack of hydro storage capacity.

Three tasks were performed and will be described in the following: (1) an estimate of the discharge of the Pentwater South Branch was made, (2) Hart Lake was surveyed to determine by how much the storage capacity could be increased, i.e., how much the level could be raised, before encountering very costly and perhaps insurmountable difficulties, and (3) a cost index and guidelines for use in economic cost estimates covering hydrostorage expansion was established.

TABLE 11 Estimated Stage Discharge for South Branch of Pentwater River at Hart Hydro (in ft³/sec using Watershed Area Ratios from above Table A 1.)

1974-74	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Mean
Using White River/ Pentwater Ratio	65	74	86	121	129	178	222	204	158	112	93	72	126
Using Pere Marquette Pentwater Ratio	53	62	71	85	101	133	163	135	137	93	76	68	98
Monthly Mean (derived from the 2 ratios)	59	68	78	103	115	155	193	170	148	103	85	70	112

ACCURACY = Better Than ⁺ - 20%

TABLE 12 Stage Discharge (in ft³/sec) / Watershed Area (in mi²), Comparison between White, Pere Marquette and South Branch Pentwater Rivers.

1973-74	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Mean	Dec. 11 '74 (3)
White (1)	.79	.89	1.04	1.46	1.56	2.15	2.67	1.90	1.90	1.35	1.12	.865	1.52	1.01
Pere Marquette (1)	.64	.75	.86	1.03	1.22	1.61	1.96	1.63	1.65	1.12	.915	.818	1.18	.90
Pentwater (2)			1.08	1.07*		1.92	1.06*		1.31	.21*		1.09	1.27	.97

*probably inaccurate due to ice or hydro operation

(1) For location of stage discharge recorders and other pertinent data, see information published by the U.S. Geological Survey

(2) Crest stage indicator located .8 mi below Hart hydro dam, read by eye about once per month, therefore, infrequently data is not considered reliable. Readings were begun in Dec. 1973.

(3) Inserted to show comparison with Dec. 1973 data.

5.5.1. Estimate of Discharge, South Branch of Pentwater River

Two sources of information -- unfortunately not entirely independent of each other -- were used to obtain the monthly and annual discharge for the Pentwater South Branch (watershed area = 83 mi^2 , see Table 11, Watershed, South Branch of Pentwater River). One source was the correlation with the two adjacent watersheds, the Pere Marquette River to the north (709 mi^2) and the White River to the south, (380 mi^2) see Table 12, Watersheds, Lower Peninsula of Michigan. The other source was an estimate made by the U.S. Geological Survey during 1972-73 covering discharge from the entire Pentwater River watershed (177 mi^2) into Lake Michigan, reduced on a ratio basis (83 mi^2) to a stage discharge at the Hart Hydro.

The monthly figures so arrived at were averaged which gives us the figures in Table 13.

Table 13. Average Monthly Stage Discharge and Electric Energy Equivalent at Hart Hydro

1972-72 Month	Average Monthly Discharge at Hart Hydro	Electric Energy Equivalent
October	$82 \text{ ft}^3/\text{sec.}$	162 kW
November	85	168
December	91	180
January	142	281
February	124	246
March	158	313
April	157	311
May	159	315
June	137	271
July	100	198
August	86	170
September	<u>74</u>	<u>146</u>
Crude Annual Avg.	$116 \text{ ft}^3/\text{sec.}$	230 kW

Given suitable storage capacity, the above roughly represents the amount of water available for compensating for wind power variation and lull periods as applicable to the city of Hart. Note that the 230 kW average is over twice the actual average power performance now being achieved by the city of Hart.

5.5.2. Survey of Hart Lake Storage Potential

The dam, the hydro plant, and the entire shoreline of Hart Lake were inspected and surveyed. Arbitrary increases of the Hart Lake level in one ft. increments were considered starting with the above normal level of 622 ft. asl. The effect on shoreline land and property was noted and mapped, see Figure 26, MAP OF HART LAKE.

It was found that 628 ft. is a threshold to a series of additional problems and costs. For example, the Mill Pond, fed by Russell Creek, is now controlled to about 628 ft. asl. Below 628 this part would be unaffected but going higher would involve more shoreline, many more properties. The Mill Pond is the city's swimming hole.

Since wind data was being assembled concurrently with this investigation, and wind deficiency information was not yet available, an assumption had to be made, namely that the available South Branch discharge would preclude a storage scheme larger than a 6 ft. increase in lake level would provide. It goes without saying, that this assumption will be carefully checked out.

An up to 6 ft. increase was examined in terms of one ft. increments. No matter how much the level is raised, there are some basic and major costs, replacement of the bridge and approaches crossing Hart Lake, for example. Granted, the bridge is old and will have to be replaced anyway. The cost of land flooded as the lake level rises is nominal when compared with the problem of compensating riparian owners for affecting the shoreline and the variation in lake level. Another illustration, environmental and societal issues have to be faced with any increase. Hart Lake is used for sport fishing, therefore, this aspect must be investigated in more detail if economic justification can be established.

The city of Hart for itself owns or controls a substantial part of the Hart Lake shoreline. The private riparian rights situation will have to be investigated in more detail by researching the title records, plat dedications, and tax assessment rolls.

The map of Hart Lake was redrawn to show areas which would flood by an increase in level up to 6 ft, (see Figure 26, Map of Hart Lake). The incremental increase of lake area was determined as 300,000 ft²

per ft. of increase in level. In other words, 6 ft. of lake level increase would consume about 40 acres of land.

At normal (622 ft asl), the lake surface is 10,500,000 ft² or 240 acres (the Water Resources Commission, Michigan Department of Natural Resources as of 11/14/67 lists the impoundment area of Hart Lake as 400 acres).

At a mean surface of 260 acres and 6 ft. of storage depth, storage capacity of Hart Lake is

$$(10,500,000 + 900,000) \times 6 = 68,400,000 \text{ ft.}^3$$

One ft³/sec. of discharge at 32 ft head will produce roughly 2 kW. Therefore, the storage capacity contained in 6 ft. would be 136,800,000 kW.

$$\frac{136,800,000}{3,600} = 38,000 \text{ kWh of storage capacity}$$

or a 1000 kW system could run for 38 hours, not considering the inflow.

When considering the inflow, the following water conservation equation would apply:

$$-R_1 t + R_2 t = h(10.5 \times 10^6) \quad \text{for } 0 \leq h \leq 1 \text{ ft}$$

$$-R_1 t + R_2 t = h(10.5 \times 10^6) + (.3 \times 10^6)(h-1) \text{ for } 1 \leq h \leq 6 \text{ ft}$$

h expressed in ft.

R₁ is volume outflow in ft³/sec.

R₂ is volume inflow in ft³/sec.

This is the equation which will have to be related to a wind-power availability equation in order to optimize a system. It must be remembered that the 6 ft. lake elevation increase used in the foregoing is arbitrary and subject to change up or down as the wind-hydro system is optimized. Optimization of the system would seek to (1) utilize as nearly as possible all of the water available, and (2) to improve hydro generation efficiency, as operated in conjunction with a wind power system.

5.5.3. Economic Cost of Hydro Storage and Generation Facility

Economic Cost factors are:

- (1) hydro generating machinery

- (2) turbine gallery and building
- (3) dam
- (4) bridges and roadways
- (5) lakeshore

For rough or preliminary estimating purposes, the following cost indexes may be applied:

- (1) To increase hydro generation capacity would cost \$ 100 to \$ 150/installed kW (source: James Leffel and Co.).
- (2) The turbine gallery and building part would cost between \$ 1.50 to \$ 3.00/ft³ of building volume (source: Bechtel Corp.).
- (3) Work on dam comes in three parts:
 - (a) concrete work at hydro inlet, gates, etc., estimate is \$ 20/yd³ of concrete (source: Bechtel Corp.).
 - (b) earthfill \$ 1/yd³, see attached analysis for earthfill requirements at various lake levels (source: Engineering News Record).
 - (c) spillway if necessary (there is no spillway now), \$ 20/yd³ if concrete work in place (source: Bechtel Corp.).
- (4) Modification of the US-31 highway bridge would require about \$10,000. The old bridge 32' X 88' which is about worn out, would take \$ 85,000 for bridge replacement plus \$ 60,000 for the approaches = \$ 145,000 (source: Michigan Department of Highways and Transportation).
- (5) The map of Hart Lake was redrawn, see Figure 26, to show flooding of land at various lake levels. Land flooded by the increase in lake level elevation would cost \$ 200/acre. Lake frontage is now appraised at \$ 70/linear ft (source: Hart City Assessor). Buildings and structures affected are few and less than \$ 100,000 would be required to compensate.

Steep bank property owners may have to be compensated by a nominal amount. This has to be investigated further when doing economic impact and attitude study.

If desired, an independent appraisal by a qualified consulting engineering firm can be had for about \$ 2,000 (contact Gerald R. Bacus, Fargo Engineering in Chicago).

Environmental factors have not yet been accounted for. An impact assessment would require a certain amount of survey work among property owners and local citizens. Perhaps this could be combined with the attitude studies concerning wind power utilization (University of Illinois). Hart Lake is now used for sport fishing which is another factor to be considered.

To bring the above into focus, assume a 1,000 kW hydro-storage and generating installation:

Hydro machinery	\$ 150,000
Turbine building	200,000
Dam	100,000
Roads and Bridges	175,000
Land and buildings compensation	<u>200,000</u>
	\$ 825,000

As of now, the above is no more than an indication of a cost target. Once the wind data has been brought down to where it can be used for system optimization, a more reliable estimate can be made. The figures presented tend to encourage continuing the investigation and a comparison with alternatives.

5.5.4: Significance of the Wind-Power Hydro-Power Combination for Michigan

There are several hundred hydro sites in Michigan. According to the Federal Power Commission, 83 are now operating. Some of the hydro-impoundments have been abandoned, some are now in use for other purposes, and 32 are listed as "undeveloped". The 1967 listing of the Water Resources Commission, Michigan Department of Natural Resources, (*) shows a much larger number. Many of these

(*) Unpublished Departmental paper

sites are in areas of low density distribution of electricity, mostly rural electric and small municipal electric systems. Moreover, many are located in or adjacent to regions with annual wind speed averages of 14 mi/hr or even higher, regions where the seasonal demand for lighting, space-heating and water-heating tends to match seasonal wind patterns. This will be substantial as a part of the present study.

The Federal Power Commission, for Michigan alone, lists 387 MW "developed" and 279 MW as "undeveloped" hydro sites.^(*) Almost all of the hydros in the Great Lakes region were built during the early decades of this century, or even before, and as mentioned in the foregoing, were built in "water-wheel" fashion, i.e., flow-through, no appreciable storage. Because of this, one can suspect that the water in the respective watersheds is materially underutilized, for the generation of electricity as is indicated in the Hart case.

Energy conversion by these hydro plants, because they are old, is probably less efficient than it could be. If the facilities were to be enlarged when converting to energy storage systems, as that they can be used in combination with wind-power systems, an efficiency gain of perhaps ten percentage points could be expected. At the same time, water utilization could be increased, perhaps by more than 50 % as appears to be the case for the Hart hydro.

Assuming a 50-50 match of wind-power and hydro-power, one can visualize more than 1,000 MW derived from such a combination in Michigan. This could be all baseload generation, obviously requiring no fuel. The energy would be consumed near where it is produced, thereby reducing transmission losses and in some cases transmission facilities costs.

The hydro possibilities in Michigan have been neglected for many years. The relatively low cost of fossil fuels made it so. During the 1920's, 14 river systems in Michigan were studied for their hydro potential.^(**) This type of work was abandoned for the same reason.

(*) Hydroelectric Power Resources of the United States, Developed and Undeveloped, Federal Power Commission, Washington, December 1972.

(**) Unpublished studies by Wisler et al, University of Michigan, for the Michigan Conservation Department. Copies are in the State Library.

Some of these studies could possibly form a basis for a broader examination of the potential.

The Hart study outcome with respect to hydro storage alone should not be construed as being applicable to other systems without similar tests covering a few other representative locations. Hart is one of the small systems. Each and every system is different, as is the local availability of wind power. Therefore, broadened study, beyond what is indicated for Hart, is called for before solid conclusions can be drawn.

The Hart hydro situation will be reported on as definitively as is possible. It is expected that the information so provided will permit a judgment with respect to further study of the potential for wind-power/hydro-power systems in the Great Lakes region, to determine whether it is one viable alternative.

6. RESULTS OF PRELIMINARY ECONOMIC ANALYSIS

6.1. Introduction

This section concerns itself with the preliminary economics of using WECS to supply energy to the Hart electric system. Developed here is a crude estimate, not necessarily a viable proposal to the city of Hart. It is merely an indication of whether wind power is a cost effective option for Hart or similar situations. This estimate, when refined by the end of the first year grant-period, is expected to be an assessment to determine whether going into a year II effort is worthwhile in terms of providing definitive information, information which would be used by the city of Hart and others to make decisions concerning their future energy supply with a reasonable degree of confidence.

The economics of using WECS as a fuel saver is presented below. These results are specialized to the boundary conditions, i.e., interest rates, wind energy, fuel prices, etc., in this case applied to the city of Hart and its electric system. A rough estimate of the cost of a baseload wind-hydro system is also presented. Additionally, other energy alternatives known to be available for the city of Hart are also reviewed.

6.2. Fuel Saver Economics

A general equation, which includes all the economic variables such as initial capital investment, interest rate, amortization period, etc. was derived using basic mathematics of finance.⁷ This equation is given as:

$$S = (1 + r_1)^n a A + \frac{(1 + r_1)^n - 1}{r_1} \beta (1 + r_2)^n P 8760A - \frac{(1 + r_1)^n - 1}{r_1} (1 + r_3)^n y P 8760A \quad (1)$$

where the following are defined

- a = total capital cost of WECS expressed in \$/m² (per m² of swept area A)
- n = amortization period
- r_1 = interest rate on the initial capital investment
- A = swept area of the wind turbine in m²
- β = operating and maintenance costs expressed in \$/kWh at time $n=0$
- r_2 = percent increase per year of the operating and maintenance costs
- P = average wind power/m² produced by a specific wind turbine given a region's wind characteristics
- y = fuel costs in \$/kWh at time $n=0$
- r_3 = percent increase per year of the fuel cost in \$/kWh
- S = balance left of the initial capital investment after n years

The left hand side of equation (1), the balance S of the initial capital investment after n periods, is equal to three separate terms. The first term represents the initial capital investment compounded at an interest rate r_1 for n periods. The second term represents the operation and maintenance costs added to the initial capital investment each period and the last term represents the amount of money returned each period for the energy generated during that period. P , the average wind power/m², is a function of the region's wind characteristics and of the specific wind turbine. That is, it is proportional to the area under the region's wind power duration curves which is

defined by specifying the wind turbines cut-in, rated, and cut-off wind speeds.

Equation (1) is a general equation which can be solved several different ways. For example, given wind power densities, fuel costs, amortization period, interest rate, etc. the maximum allowable capital investment per wind turbine swept square meter, can be determined. Sensitivities of the economics to base fuel cost, to percent increases in fuel costs, etc., can also be calculated.

The example of wind turbines as a fuel saver for the city of Hart is worked out below. In this example, P was determined for the G.E. and Kaman wind turbines using Muskegon, Ludington, or 1975 MSU measured wind characteristics. The other variables were determined by using the best information available from the city of Hart and REA co-ops in Michigan. Specifically, these assumptions are:

1. A 7 % interest rate, r_1 . This is the interest rate that the city of Hart pays on its municipal bonds. REA interest rates generally vary between 7 and 8 %.
2. The amortization period $n = 30$ years
3. The operating and maintenance cost, β , were assumed to be \$.0066/kWh
4. For this first case, $r_2 = r_3 = 0$
5. P 8760A was taken from the energy calculations for the different machines. (See Tables 6, 7, and 8)

Using these assumptions and the machine characteristics of the four different NASA machines, equation (1) was solved for y , the energy cost required to amortize the initial capital investment in 30 years. The results of these calculations are shown in Table 13. It was assumed that the energy produced by the wind turbines has a value independent of the time of day, month or year it is consumed. This is a simplification since for most applications, energy prices for fuel-saver wind turbines must be priced with electrical demand and other methods for generation of power. In later reports, more sophisticated economic models will account for user demand, competitive peaking power, etc.

The economics of the fuel saver mode become more attractive, if the assumption is made that costs of fossil fuels and operating and maintenance increase each year. That is, if in addition to the above assumptions 1, 2, 3 and 5, the following assumption is also made:

1. Private and government speculative studies of energy costs for Michigan have projected increases in fossil fuel costs from 7 to 9% per year for the next 10 years. Thus, a rate corrected for inflation $r_3 = 3\%$ over the amortization period was assumed.

Equation (1) was resolved by incorporating this additional assumption and solving for y , the allowable fossil fuel cost at $n = 0$ required to amortize the initial capital investment in 30 years. Computer calculations are shown in Figure 27 where the base ($n = 0$) fossil fuel costs y vs. average power density are plotted for a number of assumed capital investment costs a . These curves can be used to determine the fossil fuel costs for a given wind turbine if the average power density P available to the wind turbine and the capital investment is known. For example using Muskegon 1972 wind data, the P for the G. E. 500 kW is $.106 \text{ kW/m}^2$ while the P for the 1,500 kW machine is $.118 \text{ kW/m}^2$ respectively. The intersection between these capital costs and the respective power densities are shown in Figure 27 along with the resulting fossil fuel costs. These fossil fuel costs are \$.0145/kWh for the 500kW wind turbine and \$.015/kWh for the 1.5 MW wind turbine. Thus, wind turbines located on the lakeshore will be economic if they are used to replace energy from diesel oil or coal fired generating plants where the fuel costs are in excess of 1.5¢/kWh.

The present energy cost of operating the diesel plant when burning oil are 2.65¢/kWh for fuel and 1¢/kWh for operating and maintenance costs. Thus, even though the economics shown in Table 14 are tentative and approximate, they demonstrate that wind turbines located on the lakeshore could be employed economically as fuel savers by operating in parallel with the present diesel system.

Figure 27. Fuel cost vs. average power density for different capital investment.

TABLE 14

¢/kWh for the G.E. and Kaman Wind Turbines

Operated as Fuel Savers

 $r_1 = .07$ - $n = 30$ years - $r_2 = r_3 = 0$ - $\beta = \$.0066/\text{kWh}$

<u>Machine</u>	<u>Initial Capital Investment* a A</u>	<u>Wind Region 1972 Muskegon-Ludington Shore Line</u>	<u>Wind Region City of Hart (1975)</u>
G.E. 500kW	\$523, 000	2.7 ¢/kWh	4.9 ¢/kWh
Kaman 500kW	\$536, 000	3.9 ¢/kWh	8.5 ¢/kWh
G.E. 1.5 MW	\$709, 500	2.35 ¢/kWh	5.6 ¢/kWh
Kaman 1.5 MW	\$786, 000	3.1 ¢/kWh	9.7 ¢/kWh

*Includes \$36, 000 for site costs.

Other general conclusions are:

- (1) the economics strongly favor lakeshore locations over the city of Hart locations.
- (2) The cost (\$ /kWh) differences between the 500 kW and the 1.5 MW machines are not substantial. Thus, when considering that the 500 kW machine has the technical advantage of producing more uniform power over the year, i.e., it has less down time, than a 1.5 MW machine, it appears that a system of 500 kW machines may be the most useful solution for wind turbines in the G.L. region.

6.3. The Economics of a Base-load Wind Turbine-Hydro System

A crude estimate of the costs of using wind turbines in conjunction with the city of Hart hydro facility to generate baseload electric energy is presented here. An energy delivery system supplying a base-load demand of 600 kW is assumed. This system consists of two 500kW G.E. wind turbines located on the shore of Lake Michigan, about 8 miles west of Hart Lake. Each wind turbine will provide an average power per hr of 235 to 250 kW over an entire year.

Table 15 summarizes some further assumptions and the economics of the system. If the wind turbines cost \$ 1,000/kW installed and the hydro facility \$ 800/kW installed, then electric energy can be generated at a cost of 3.2¢/kWh. This is not an optimum design. However, it demonstrates that the wind and hydro combination shows economic promise for base-load or load-following operations. It is emphasized that more detailed study is required to provide more exact design. For example, it is expected that the baseload capacity will vary from season to season since the availability of wind and water varies with the seasons. Further study of the wind-hydro applications will be proposed as part of a year II research effort.

6.4. Benchmark Economics

Two cost-benefit projections will be prepared with the support of this project. The first one, reported on in this section, is nearly complete and uses estimated kWh costs of total demand including wind-generated energy using average monthly wind-velocity projections based upon our wind measurements. The second projection described

TABLE 15

Baseload Wind Hydro Generation Economics

Two 500 kW G.E. Machines at \$ 1,000/kW =	\$ 1,000,000
600 kW hydro facility at \$ 800/kW	<u>480,000</u>
Total initial capital investment	\$ 1,480,000
Other assumptions	
interest rate 8%	
amortization period -wind - 25 years	
hydro-30 years	
Operating rate of combined wind-hydro system = 95 % or 4,993,200 kWh/yr	

Money Costs per year

Wind	$\frac{.08(1.08)^{25}}{(1.08)^{25} - 1} (\$ 10^6) =$	93,700
Hydro	$\frac{.08(1.08)^{30}}{(1.08)^{30} - 1} \$ 480,000 =$	<u>42,638</u>
		\$ 136,338

Money Cost kWh
$$\frac{\$ 136,338}{4,993,200} = \$.027/\text{kWh}$$

Operating and maintenance	\$.005/kWh
Total electric energy cost	\$.032/kWh

in Section 9 will be programmed next year and is based upon hourly wind velocity and demand, and thus, recognizes the random character of wind and demand variations. The goal of both projections is to prepare estimated operating statements for the Hart utility using wind generation at feasible sites. In order to evaluate these estimates, it is necessary to compare them with a projection where wind is not used. This reference of "benchmark" projection must account for expected load growth, estimated increases in the cost of oil, gas, and purchased energy, and for generation additions to the Hart system caused by expected load growth.

The MSU research team began with a 5-year monthly projection, using 1974 and 1975 operating data as a base, with the output to be a sequence of predicted energy costs for the Hart utility. The daily operating logs, fuel invoices, and monthly operating statements of Hart were used to find the kWh produced by each diesel, the hydro facility, and to account for energy purchased from Wolverine. Wolverine was consulted to give expected purchase costs and dispatch strategy. The direct costs for each energy source are listed so that a production cost per kWh can be calculated.

Using such historical data as a base, the load is increased on a monthly basis equivalent to a yearly 7 % growth, as is the fuel cost and the cost of purchased power. The cost of oil is assumed to increase 8 % per year and natural gas 25 % per year while Wolverine direct or energy charges are increased 19 % per year. When the load minus existing capacity exceeds the average margin (spinning reserve factor) an extra generator is added. A 4 MW generator was added in April 1975 and is assumed to be a diesel operating with the same efficiency as the existing large diesel and with the same annual fuel mix which is 20 % oil and 80 % natural gas. Part of this table of calculations is shown in Table 16 indicating predicted demand and energy costs for three months per year for five years. This table was abstracted from a large table including each month from 1974 to 1980 and operating data for each energy source. It is too large to put into this report. The assumptions used to generate the data shown are as follows:

TABLE 16

SELECTED RESULTS OF BENCHMARK OPERATING COST PROJECTION -- ENERGY ONLY

Year Month	Total Demand MWH	Supplied By Wolverine MWH	Supplied By Hart Hydro Diesel MWH	Hart Oil /kWh	Fuel Cost Gas	Wolverine Costs \$/kWh	TOTAL Fuel and Energy Costs
1/74	1339.2	355.2	120 864	.0224	.0074	.0157	\$ 14,562 .011
5/74	1105.4	526.4	94 485	.0226	.0069	.0166	13,607 .0123
9/74	1937.4	1137.4	59 741	.0320	.0080	.0196	31,778 .0164
1/75	1417.6	777.6	27 613	.0219	.0081	.0171	19,954 .0141
5/75	1383	1080	98 205	.0263	.0067	.0104	24,209 .0175
9/75	1569.8	724.8	120 725	.0279	.0114	.0266	29,937 .0191
1/76	1474.9	670.4	73.5 731	.0305	.0134	.0239	28,318 .0192
5/76	1331.3	810.3	96 345	.0313	.0145	.0286	31,624 .0238
9/76	1876.4	1053.9	89.5 733	.0321	.0157	.0372	51,117 .0283
1/77	1578.1	855.9	50.3 672	.0329	.0166	.0335	42,126 .0267
5/77	1424.5	567.9	97 759.6	.0337	.0183	.0304	33,504 .0235
9/77	2007.7	549.5	104.8 1353.4	.0347	.0196	.0322	48,308 .0241
1/78	1688.6	607.6	61.9 1019.1	.0355	.0210	.0342	45,136 .0267
5/78	1524.2	607.2	96.5 820.1	.0365	.0229	.0362	42,991 .0282
9/78	2148.3	588.0	97.1 1963.1	.0374	.0247	.0384	63,434 .0291
1/79	1806.4	650.2	56 1100.6	.0383	.0263	.0407	58,050 .0321
5/79	1630.9	650.6	96.8 883.5	.0393	.0286	.0431	55,200 .0338
9/79	2298.6	629.2	100.9 1568.5	.0903	.0306	.0457	79,793 .0347
1/80	1933.3	697.7	59 1178.6	.0414	.0329	.0485	74,618 .0386

- 1) Load diversity is preserved by increasing total demand in, say January 1977, by multiplying January 1976 demand by 1.07. Some first-order smoothing of demand data was done from 1974 - 1976.
- 2) Hydro energy periodicity maintained by smoothed prediction without growth.
- 3) Diesel-generated energy provided by a 20% oil and 80% gas mixture to reflect current and expected operating practice.
- 4) Wolverine costs, after new generator added in April 1977, adjusted to remove demand charges because Hart can then provide daytime spinning reserve for Wolverine.
- 5) The addition of the new generator will not change the Hart policy of using Wolverine to provide energy from 11 p.m. to 7 a.m. After April 1977, the added generator (which Hart is already considering) will provide all of Hart's daytime and evening demand.
- 6) No labor, overhead, lubricating oil, repair, or capital costs are included so the hydro energy is costless for this projection.

Inspection of Table 15 indicates that Hart's September energy peak is predicted to increase to 2,298 MWh in September 1979 from an actual 1,570 in September 1975. The energy costs (fuel costs) per KWh are predicted to increase from 1.91 ¢/KWh in September 1975 to 3.86 ¢/KWh in January 1980. This may indicate a positive potential for wind power in a fuel-saving mode.

In addition to serving as a reference for this study, the projection will also be of use to Hart and Wolverine in their future planning. Since the help given by the involved utilities has been substantial, we wish to provide information which will aid them also.

6.5. Energy Alternatives for the City of Hart

Whether a WECS will be adopted by a small rural or municipal power system is dependent on the economics of alternatives. The construction of large oil, coal fired or nuclear plants is not a possibility for Hart or Wolverine REA by themselves. They can cooperate with

either a group of small companies like themselves or cooperate with a larger power company to gain access to bulk supply.

An option that has been recently made available to small power companies in Michigan by the Consumers Power Company is to offer for each company to buy a share in large power plants now under construction. Table 17 summarizes the various costs involved for the City of Hart if they were to choose this option. Research continuing with year II will compare these and other energy alternatives open to the City of Hart with the costs of "fuel saver" and baseload WECS.

7. THE ENVIRONMENTAL IMPACT OF WIND TURBINES AND THEIR OPERATION IN THE HART, OCEANA COUNTY, MICHIGAN, AREA

7.1. Introduction

The economic objective in selecting sites for wind turbines is to optimize energy output over time consistent with economic and environmental considerations. However, such optimum locations and configurations may be in conflict with human and ethical values such that the impact may preclude certain ventures, or that arrangements to mitigate the impact to a point of acceptability may be required.

Therefore, in planning wind turbine installations, an impact analysis is called for. Such an analysis may actually be required under the Environmental Protection Act or similar state legislation. If not otherwise provided, a full technology assessment of wind power operation could be required.

It is not practical for purposes of the present study to go into that much analysis and evaluation. In its place there is presented an overview of potential impact considerations, as they affect the study area, namely the Hart, Michigan, area including parts of Oceana County. This overview would probably hold true for most of the high winds areas along Lake Michigan.

Five provisional wind turbine sites in different environmental settings were chosen for a comparative analysis and to indicate possible impact problems. These are some of the sites which were instrumented to gather wind data for the project. The location of these sites is shown in Figure 28.

TABLE 17

Energy Alternatives for the City of Hart

All figures are adjusted to reflect 1980 estimates, 1982 for Midland.

KARN #4 663 MW (oil) \$ 188/kw

$$\text{Fuel} \quad \frac{\$ 3.23 \text{ (per M Btu)} \times 11,000 \text{ (heat rate in Btu)}}{1,000,000} = \$.035/\text{kWh}$$

$$O + M \quad \frac{\$ 1,191,016 \text{ (estimated annual cost)}}{663,000 \times 24 \times 565 \times .7 \text{ (plant factor)}} = \$.0002/\text{kWh}$$

CAMPBELL #3 800 MW (coal) \$ 459/kW

$$\text{Fuel} \quad \frac{\$ 2.03 \times 9,200}{1,000,000} = \$.019/\text{kWh}$$

$$O + M \quad \frac{\$ 8,000,000}{800,000 \times 24 \times 365 \times .7} = \$.0016/\text{kWh}$$

MIDLAND #1 and 2 1,271 MW (nuclear) \$ 673/kw

$$\text{Fuel} \quad \$.0066$$

$$O + M + \text{Insurance} \quad \frac{\$ 12,000,000}{1,271,000 \times 24 \times 365 \times .7} = \$.0015/\text{kWh}$$

Add to the above Transmission Service based on 100% capacity factor:

$$\begin{array}{r} \text{Demand charge (varies with capacity factor)} \quad \$.0015/\text{kWh} \\ \quad \quad \quad \underline{\quad .0003 \quad} \\ \quad \quad \quad \$.0018/\text{kWh} \end{array}$$

plus transmission losses estimated at 4%.

Standby provisions (at cost) have to be made to provide for the contingency of the plant shared going down for any cause.

Source for the above information: Consumers Power Company, November 1975.

7.2. Five Provisional Wind Turbine Sites: A, B, C, D and E, Hart Area, Oceana County, Michigan

7.2.1. Site A. Little Point Sable.

This site is located in a low-profile sand dune area near the beach of Lake Michigan (elevation 578' asl). It is just south of the approximately 100' high Little Point Sable lighthouse. The latter is not now operative, but is still under the control of the U. S. Coast Guard. The surrounding land is owned by the federal government, but is under the jurisdiction of the Michigan Department of Natural Resources. Silver Lake State Park is just to the north and east. There are some summer cottage settlements in the area located on private land, settlement density is relatively low. The dunes along Lake Michigan are considered environmentally sensitive, especially the large dunes between Silver Lake and Lake Michigan. Electric service to the area is single-phase, see Section 5, and would have to be changed to three-phase in order to connect to a large wind turbine. If too objectionable, the lines could be run underground.

7.2.2. Site B. Taylor Road and 34th Street.

This site is in rural, but only partly farmed, surroundings. Elevation is 640' asl. It is adjacent to a 69 kv substation, terminus of a high-line from the Wolverine Cooperative and a distribution point for the Oceana Electric Cooperative. The site is attractive because of the proximity of the substation. There are only a few low-grade rural residences nearby. Land of the site itself has not been used for several years. Its ownership is in private hands.

7.2.3. Site C. Silver Hills Farms.

Setting is in a substantial commercial tree-fruit and asparagus-growing enterprise. Elevation is approximately 800' asl. This farm is professionally managed, has a number of large farm buildings in excellent condition. There are only a few scattered farm-type residences in the vicinity. This location is suitable for multiple land use, i. e., wind turbines and agricultural uses of the land. In practice, fruit trees are kept low for mechanical harvesting and spraying, and therefore should not materially interfere with wind turbine application. This is subject to verification. The owner would want assurance that the wind turbines would not interfere with crop production, which also would have to be verified. It could be the other way around. Manager is very cooperative and favorable toward

wind power.

7.2.4. Site D. Atop Hart Hill Just Off Tyler Road.

This site is at a relatively high elevation (740' asl) located in what may be called the commercial-rural fringe of the City of Hart. Wind turbines installed in this area would be prominent in that they could be seen from afar. Residential settlement is sparse enough to present no problem. Unlike the previously described sites, this site is within the Hart electric service area and adjacent to Hart three-phase distribution. Multiple land use potential is also applicable to this site. Owner is very cooperative and also favorable toward wind power.

7.2.5. Site E. 72nd Street North of Tyler Road.

This site is in a suburban-commercial-agricultural setting within the Hart electric service area. Elevation is about 680' asl (Hart Lake is 622' asl). This site is just west of Hart Lake.

7.2.6. General Comments

All of the owners of the sites described above indicated willingness to permit installation of one wind turbine. Everyone was very cooperative when asked for permission to install a wind data measuring tower. In other words, no negative attitude toward wind power could be detected. What would happen in the event where larger numbers of wind turbines were to be erected, is a question one would have to research with perhaps different approaches. There appears to be little question that environmental impact effects would not be serious enough to prevent serving Hart and/or Oceana Electric Cooperative with wind power. This statement is tentative and subject to further analysis of the problem.

7.3. The Impact Rating of the Five Sites

The following Table 18, Impact Rating of Five Sites, is a rough appraisal of the situation as found in our investigation to date. Individual wind turbine sites were assumed to be approximately 10 acres in size.

TABLE 18

Impact Rating of Five Sites

<u>SITE</u>	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>
Nature of Impact					
Air	N	N	N	N	N
Water	N to L	N	N	N	N
Soil and Land Use	L to M	L	L	L	L
Fish and Wildlife	N	N	N	N	N
Vegetation	N to L	N	N	N	N
Noise	N	N	N	N	N
Safety	N*	N*	N*	N*	N*
Vibration	N	N	N	N	N
Transmission	M	N	L	L	N
Visual	H	M	L to M	H	M
Aesthetics	M to H	L to M	L to M	M to H	M
Terrestrial	L	N to L	N	L	N to L
E-M Wave Inter- ference	N	N	N	N	N

Vandalism Risks - technically belongs under public safety

*Barring Major Disaster

H = Substantial impact, may raise objections

M = Nominal impact, probably can mitigate

L = Negligible impact

N = No impact

A discussion of these rankings follows:

- Air** The construction and operation of large wind turbines will have no effect on air quality nor will it contribute to materially altering the existing macroscale wind patterns; for example, the wind drainage which is relevant to fruit orchards and other agricultural activities of Oceana County. Wake effects would have to be studied in detail.
- Water** An adverse impact to aquatic systems would not be created, if adequate measures were employed to prevent soil erosion in the right of way and along the access road, particularly during the construction phase.
- Soil and
Land Use** Construction procedures should be maintained for the protection of the natural environment, in particular with respect to problems of soil erosion, i. e., ground surface should be left as natural as is practical. Damaged ground cover will have to be replaced.
- There are no serious problems which can be foreseen as a result of construction on farm land. Once construction has been completed, the surrounding area may easily recover assuming reasonable care. In fact, both economically and ecologically, multiple land use might be encouraged.
- Wildlife** Any disturbance to wildlife would be short lived, i. e., through the construction period. Due to the relatively low speed of the blades (40 mph), no serious threat to bird-life in the vicinity is assumed. This assumption will need to be subjected to empirical verification. After discussions with the State of Michigan Department of Natural Resources personnel, it was felt that bird kill due to wind turbines would be no greater than the bird kill on high voltage transmission towers. However, an unknown variable is the effect of the rotating blade on the birds. The Michigan DNR official felt that the moving blade would chase the birds off.
- Vegetation** Whenever man changes the landscape, he modifies the microclimate by creating minor changes in the wind,

temperature, humidity and soil moisture. Other manifestations are changes in earth surface roughness, changed reflectivity and altered heat and water storage capacity resulting from changes of trees, brushland, etc. Yet, whereas some of these changes are likely to occur during and after construction, they are not likely to be a serious enough problem warranting consideration.

Noise

The wind going through area of the windmill under load is expected to make no more noise than the wind going through a grove of trees, or through a high-tension power line.

E-M Wave Interference (high-frequency radio communications)

The only interference results predominantly from the windmill tower and rotating blade in the immediate area of the windmill. The extent of this interference should be the subject of a more thorough investigation. Any other interference would be as the result of the transmission line, which would be the same as any transmission line.

Safety

By comparison, properly designed, constructed and tested large wind turbine installations should be the near safest of all possible major energy conversion systems.

The study area is located on the northern fringe of the American mid-continent tornado path. Design and operating criteria would have to take this into account in any event. This would, at the same time, take care of risks posed by some of the vicious storms which are occasionally, but infrequently, experienced on Lake Michigan.

Unfortunately, not too much is known about safety risks associated with icing conditions.

Modern technology should be able to overcome the problem which caused one of the blades of the Grandpa's Knob to fail and travel a reported 70 feet.

Transmission

No particular problem is foreseen. The area is well covered by transmission and distribution lines of the Hart electric system, the Oceana Electric Cooperative System,

the Wolverine Cooperative distribution system, as well as lines in substations of Consumers Power Company.

In fact, distributed wind turbine operation could help reduce transmission losses, which for these systems run up to about 12%.

Visual

Whereas it may be desirable to keep towers off of hillcrests and out of open areas of high visibility, this is not too compatible with effective wind turbine operation. Moreover, it may be desirable to avoid "scenic" areas, yet often the best sites may also be the most "scenic." One is not sure of this, the many windmills in Europe which are still there are considered "scenic" treasures. Whether the visual impact of wind turbines in prominent locations is sufficiently objectionable to retard development of wind turbine systems is in the least unknown at this time. The issue is further beclouded by the fact that modern wind turbines initially are likely to be a novelty and therefore readily acceptable structures wherever they may be located.

Aesthetics

Aesthetic design of wind turbine installation could do much to make them fit into natural surroundings, considering observer positions and background patterns. Whether lattice towers or any other kind of a tower would have to be determined by the proposed location. Color schemes may be important. Non-reflective paints may be a must.

Initially, wind turbine installations will bring with them potential disruption of the environment by curiosity seekers, tourists and vandals. There is the risk of litter and traffic jams. Such events would have to be carefully controlled from the very beginning. Properly handled, this could bring economic benefits.

Vandalism Risks

Aside from environmental impact questions, the problem of vandalism has to be faced. For example, the electric utilities have been troubled for many years with damage from gun and rifle fire. Such damage could be aggravated

if certain people or groups in this minority objected to wind turbine installation. (How does one keep marksmen from using rotating--or idle--turbine blades for practice targets?)

7.4. Summary

Questions of impact have been considered and discussed. Subject to much more detailed analysis and assessment, which would exceed the scope of the present study, it can be said with reasonable confidence that--from environmental, human and ethical values points of view--application of wind power to small electric systems, such as those which serve the study area, is possible. Objections are likely to be quite limited. The exception could be installations on the beaches of Lake Michigan. The magnitude of that problem would have to be determined empirically.

Up to this point, this part of the study was able only to "scratch the surface." The investigation centered on only five sample sites which may be representative. More intensive study will undoubtedly bring to light more facts. Whether such facts turn out to be much less affirmative than what has been described herein appears to be doubtful. Yet, this should not discourage a more intensive treatment of the impact question which will continue to be a part of this study.

8. SYSTEMS MODEL FOR THE HART POWER SYSTEM WITH WIND TURBINES

8.1. Need for Evaluation Model

The cost-benefit analysis for the Hart system with wind-turbines discussed in Section 6 is based upon monthly average wind velocities and monthly energy consumption in kwh. In other words, this is a deterministic average estimate which does not account for fluctuations in wind and in power demand. When the proposal for this project was written, the investigators anticipated that an evaluation method, statistically accounting for the random nature of wind, water flow, fuel prices, and demand, would be needed for a definitive statement as to the economic feasibility of wind generation for the Hart and similar systems. It was contemplated that several different scenarios, involving several sizes of

wind generators at several locations would be evaluated against the benchmark scenario discussed in Section 7. The output of these evaluations would be a probabilistic distribution of costs and benefits so that conclusions could be stated in statistical terms, i.e.,: the probability that the benefits will exceed the costs will be, say, 0.9 for a certain configuration. Obviously, worst and best case scenarios can also be run but the investigators believe it is better to recognize explicitly the random nature of the wind as an energy source. The statistical approach allows for random fluctuations in demand, in fuel prices, and in water flow.

8.2. Choice of Parameters in Evaluation Model

The choice of exogenous variables into the model, the basic time interval of computation, and the level of detail (aggregation) within the model is limited by the time interval over which data is available, the desired output variables, and the accuracy of available information on the conversion behavior of the wind generators. A basic time interval of one hour was determined because the load or demand data from operating logs of the Hart system is available at hourly intervals, and also because the wind recorder output tapes are difficult to read at less than hourly intervals, and further because a five-year run would involve $720 \text{ times } 12 \text{ times } 5 = 43,000$ output points. This number of data points is large, but feasible, whereas intervals of one second would yield too much output. This decision evokes the question of short-term wind fluctuations and the inaccuracy induced by assuming the wind to be constant over hourly intervals. The GE and Kaman prototype data available to the research team indicated that the various control systems in the wind stations have settling times on the order of one to two minutes implying a minimum time interval for a steady-state or static wind-generator model of one or two minutes. (It will be necessary for the MSU team to investigate gust statistics over the time scale from one minute to one hour to validate the assumption of accuracy of hourly wind averages.)

The choice of exogenous variables was immediate--rate variables (wind velocity, power in kW, and water flow in cfs) are more fundamental than level variables (energy) which can be readily found by integrating the rate variables. The exogenous rate variables chosen were wind velocity

WV at two or three sites, water flow into the hydro pond in cfs, and Hart load and losses in kW, PL. The other exogenous variable is cost of fuel--oil and natural gas. Other obvious variables such as temperature are included implicitly in PL.

8.3. Model Structure

From these choices, it then follows that model internal variables include power produced by wind PW, by Diesel PD, and purchased from Wolverine PW.

Internal model structure (interactions of variables and processes relating them) follows from the static assumption that the Hart demand PL is met by using all available wind power and producing the remainder by diesel and hydro or by purchase from Wolverine. The remaining structure is for costing and energy accounting. The model, shown in preliminary block-diagram form in Figure 29 can be changed to sell excess energy to Wolverine. This model and its implementation is discussed further in our proposal for an additional year of funding. At present, it is in the conceptual stage and programming and refinements have not been attempted.

Figure 29. Evaluation model.

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APPENDIX A.

MICHIGAN STATE UNIVERSITY 1974 WIND POWER STUDY PROJECT

The rising cost of electricity is a problem for all of us. One long-range possibility for lower cost electricity is the utilization of wind power to produce it. The idea of using the wind to do this kind of work is not new, but whether it can reduce the cost of electricity has yet to be demonstrated.

Michigan State University researchers are doing a study of the application of wind power to benefit the Hart municipal electric system. As part of this study, they need some information from you -- a user of electricity. We hope that you will respond.

Enclosed with your monthly bill is a questionnaire. Please take a little time to answer it as well as you can. Then return it to the Hart Hydro-electric Company in the enclosed envelope. Your cooperation will indeed be helpful.

1. Name of person filling out this form: _____

2. Address: _____

3. Your phone number: _____

4. How many people live in the above residence? _____

5. Give the ages of each male living in the residence:

6. Give the ages of each female living in the residence:

7. This residence is (check one):

_____ A house _____ basement _____ 1 story _____ 2 story

_____ An apartment in a house

_____ An apartment in an apartment house

_____ A mobile home

_____ Other (explain) _____

8. Is this residence rented by you? _____ Yes _____ No

If yes, to whom do you pay rent: Name _____

Address _____

Please answer the following questions only if you are reasonably sure of the answer.

9. About how many square feet of floor space are in this residence?

10. Is this home insulated? (Check all that apply)

_____ In the ceiling _____ 6 inches or less _____ 8 inches or less

_____ In the walls

_____ Under the floors (if there is no basement)

11. Does this residence have storm windows? _____ Yes _____ No

12. Home is heated by: (check one)

_____ Fuel oil _____ Bottle gas, L. P., butane, etc.

_____ Natural gas _____ Wood

_____ Electricity _____ Other (explain) _____

_____ Coal

13. This home has only space heaters: _____ Yes _____ No How many? _____

Do you occasionally use small electric heaters? _____ Yes _____ No

14. What type of air conditioning (check all that apply):

_____ Central air conditioning

_____ Electric _____ Natural gas

Size of central air conditioner: _____ BTU's

_____ Window

How many? _____

What size are the air conditioners? _____ BTU's

(See name plate for BTU size)

15. a. Water heater? _____ Yes _____ No Capacity _____ Gallons

_____ Electric

Quick recovery? _____ Yes _____ No

_____ Natural gas

_____ Oil

b. Range? ☐ Yes ☐ No

☐ Electric

How many burners?

☐ Natural gas

How many ovens?

☐ Wood

Self-cleaning oven? ☐ Yes ☐ No

☐ Coal

Microwave oven? ☐ Yes ☐ No

c. Refrigerator? ☐ Yes ☐ No ☐ Electric ☐ Gas

More than one? How many?

Frost-free freezer compartment? ☐ Yes ☐ No

Frost-free food compartment? ☐ Yes ☐ No

d. Freezer? ☐ Yes ☐ No Capacity cubic feet

Chest? ☐ Upright? ☐ Frost-free? ☐ Yes ☐ No

e. Televisions? ☐ Yes ☐ No

☐ Black and white How many?

☐ Color How many?

Does the color TV have instant-on? ☐ Yes ☐ No

16. Do you have a swimming pool? ☐ Yes ☐ No

17. Do you use an electric lawn mower? ☐ Yes ☐ No

Usually the lawn is mowed between:

☐ Early morning and 12 (noon) ☐ 12 (noon) and 4 p.m.

☐ 4 p.m. and sundown

Wind power availability is variable. When the wind blows, electricity can be generated; without sufficient wind, no electricity can be produced.

Right now we are measuring the wind power potential around Hart. In order to decide whether or not wind power will work for Hart, we must know when you use your appliances in your residence.

To the best of your knowledge, when do you use the following?

Dishwasher is used how many times weekly between:

4 a.m. and 12 (noon)

8 p.m. and 12 (midnight)

12 (noon) and 4 p.m.

Have no dishwasher

4 p.m. and 8 p.m.

Clothes dryer is used how many times weekly between:

4 a.m. and 12 (noon)	_____	8 p.m. and 12 (midnight)	_____
12 (noon) and 4 p.m.	_____	Have no clothes dryer	_____
4 p.m. and 8 p.m.	_____	Use coin laundry	_____
Is it a gas dryer? _____		Or an electric dryer? _____	

Clothes washer is used how many times weekly between:

4 a.m. and 12 (noon)	_____	8 p.m. and 12 (midnight)	_____
12 (noon) and 4 p.m.	_____	Have no clothes washer	_____
4 p.m. and 8 p.m.	_____	Use coin laundry	_____

I use cold water for washing:

_____ Always
_____ Sometimes
_____ Never

I use cold water for rinsing:

_____ Always
_____ Sometimes
_____ Never

How many showers are taken weekly between:

4 a.m. and 12 (noon)	_____
12 (noon) and 4 p.m.	_____
4 p.m. and 8 p.m.	_____
8 p.m. and 12 (midnight)	_____

Average length of shower is:

_____ minutes
_____ minutes
_____ minutes
_____ minutes

How many baths are taken weekly between:

4 a.m. and 12 (noon)	_____	4 p.m. and 8 p.m.	_____
12 (noon) and 4 p.m.	_____	8 p.m. and 12 (midnight)	_____

Thank you for the information and your time. Results of the study will be published when completed.