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**Subject:**
**Great Lakes Wind and Wave Guidance**

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This bulletin, which was prepared by Mr. Lawrence D. Burroughs of the National Centers for Environmental Prediction (NCEP) and Mr. J. Paul Dallavalle of the Techniques Development Laboratory, describes the automated wind guidance for 12 sectors on the Great Lakes and the automated wave guidance that uses the wind guidance as input. The wind forecasts are made with modified perfect prognosis (MPP) equations applied to Regional Analysis and Forecast Systems (RAFS) output. The wave forecasts are made by an empirical statistical technique.

The RAFS-based wind/wave forecast system for the Great Lakes was implemented on March 11, 1993, and replaced an older system based on the Limited-area Fine-mesh Model (LFM). The World Meteorological organization (WMO) bulletin header for these guidance products was changed from FZUS4 KWBC to FQUS22 KWBC on November 3, 1993.

This bulletin combines the descriptions of the Great Lakes Wind and Wave guidance products into a single bulletin and supersedes Technical Procedures Bulletins No. 322 (National Weather Service, 1983) and No. 127 (National Weather Service, 1974), which are now operationally obsolete.

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# GREAT LAKES WIND AND WAVE GUIDANCE


# by L. D. Burroughs and J. P. Dallavalle


## 1. INTRODUCTION

Wind and wave forecasts over the Great Lakes are important to many U.S. citizens and visitors for a wide variety of reasons. The Great Lakes Wind Forecast System has been operationally providing guidance to marine forecasters in one form or other since 1972. Over the years the system has changed several times to accommodate model changes in the NCEP jobstream. The last major change to the system occurred in 1993, but was not documented until now.

Likewise, the Great Lakes Wave Forecast System has been in operation since 1974 (National Weather Service 1974). It depends on the Great Lakes Wind Forecast System for its wind input. In anticipation of the withdrawal of the LFM from the NCEP jobstream, we rederived the wind forecast equations by using the MPP technique (National Weather Service 1987). Ten years of data were used to derive the equations. The new equations were implemented on March 11, 1993. On November 3, 1993, the WMO bulletin header was changed from FZUS4 KWBC to FQUS22 KWBC. No other changes in the systems have taken place since then.

## 2. METHOD

### a. Wind Forecasts

Single sector and regional approaches based on the MPP technique were used. The result was the derivation of a set of regional and sector equations. The MPP approach consists of using LFM initialization and 6-h projection data as though they were observed data. The appropriate predictand data (observed winds at specific hours) are then related to the LFM variables. A set of equations is derived for the 00- and 06-h projection on each cycle and for each season. These equations are then applied to the Regional Analysis and Forecast System (RAFS) (National Weather Service 1985) output at each projection as shown in Table 1.

### b. Wave Forecasts

The wave forecasts are based upon the automated wind forecasts for the Great Lakes and extend out to 36 hours at 12-h intervals. Wave forecasts at the points within any lake section are based on the wind forecasts for that section of the lake. Wave height calculations are based upon the method of Bretschneider (1970, 1973). The basic method relates the wave heights to the wind speed, fetch length, and duration time. The usual application of the method calls for the subjective estimation of such variables as fetch length and wind duration time. Many alterations to the method were made so that it could be completely automated (Pore 1977).

## 3. DEVELOPMENT AND DEFINITIONS

### a. Wind Forecasts

### 1) Predictands--Winds

Wind speed and direction reports at 0000, 0600, 1200, and 1800 UTC were obtained from marine observations taken on all five Great Lakes spanning the period from January 1978 through December 1988. The observations were obtained by anemometer-equipped vessels (anemometers are located approximately 20 meters above the lake surface) participating in the Great Lakes Marine Observation Program. At a given observation time, the observation with the maximum wind speed measured within a lake sector was taken to represent the wind at the center of that sector. Observations were stratified into warm (April-September) and cool (October-March) seasons. Because of ice on the lakes during January through March, there are fewer observations from the ships in the cool season than the warm season.

### 2) Predictors

Table 2 lists the basic and derived variables offered to the screening regression program along with their projection times. Since these predictors were archived at grid points, they were interpolated to the centers of the sectors shown in Fig. 1.

### 3) Equation Development

Wind speed (s) forecasts can be developed by deriving unbiased estimates of the u- and v-wind components and computing s from them. Glahn (1970) has shown this underestimates the wind speed. Therefore, we derived a separate equation for s. Separate equations were also derived for the u- and v-wind components. Forecasts from the u- and v-wind components are used to predict wind direction.

For a given observation time, measured wind speed and the associated u- and v-wind components were correlated with the interpolated fields from the LFM. A forward-selection screening program was used to compute a sequence of multiple regression equations by considering the predictands (u, v, and s) simultaneously. This was done so the individual forecast equations for u, v, and s give more consistent results. The potential predictor having the highest correlation with any one of the predictands was chosen initially. This same variable was then used as a predictor in all three equations. At each following step, the potential predictor with the highest partial correlation with any one of the predictands, after the effect of the previously selected predictors was removed, was added to the equation. This process was continued until 10 terms had been selected or none of the remaining potential predictors contributed 1.0 percent or more to the reduction of the variance for any predictand. As a result, some of the equations may have less than 10 terms. Separate sets of equations were derived for each season (warm or cool). There are separate sector equations for all sectors except those on Lake Ontario during the warm season. There were insufficient data to derive separate sector equations for that lake, so a regional equation was created from which forecasts for both sectors are computed. Similarly, there were sufficient data during the cool season to derive only a regional equation from which forecasts for all 12 sectors are made. In day-to-day operations, the equations are applied with RAFS output in accordance with the method shown in Table 1. The resulting computations of u, v, and s are used to determine the wind speed and direction for each projection from 6 to 48 hours.

## b. Wave Forecasts

When the Great Lakes wave forecast system was proposed, TDL consulted with the NWS Eastern and Central Regions. This resulted in the decision to produce wave forecasts at the 64 points which are shown in Figs. 2, 3, 4, 5, and 6. For each forecast point, fetch lengths for directions at $15^{o}$ intervals are tabulated. Some of these are corrected for fetch width restrictions by the method of Saville (1954). Fetch length is then chosen for the wind direction at forecast time. No consideration is given to the effect of ice on the reduction of fetch length. This means that during late winter the actual fetch lengths will be less than those used in the calculations. The effect of duration time of the wind--the length of time the wind has been from the same general direction--is important in wave generation. The duration time is determined objectively for each forecast time by examining the forecast wind directions during the previous 30 hours at 6-hour intervals. The time that the wind is within 45o of the wind at forecast time is used. In this manner the duration time is estimated to be 3, 9, 15, 21, 27, or 33 hours. Suppose the forecast wind direction at a forecast time of 36 hours is 050 and at 30 hours (6 hours before) is 150; the two directions differ by more than 45 degrees and the effective duration of the wind from direction 050 is estimated to be 3 hours from 33-h to 36-h. If the direction at 30 hours is 080 and the direction at 24 hours is 150, then, since the forecast direction at 30 hours is within 45 degrees of the forecast wind direction at 36 hours, the effective duration is 9 hours - an estimated 6 hours from 27-h to 33-h and an estimated 3 hours from 33-h to 36-h.

An effective wind speed is determined by weighting the winds over the duration time such that the winds closest to forecast time are weighted the heaviest. An effective fetch is calculated as a function of the duration time and the effective wind speed. The effective fetch is compared to the real fetch (the actual distance a wave can travel in a given direction), and the smaller of the two is used in the wave height calculation. Significant wave height and wave period are then calculated by the Bretschneider method (1970, 1973). For complete details on the system, see Pore (1977).

## 4. FORECAST DISSEMINATION

The Great Lakes wind and wave forecasts are transmitted as a part of the FQUS22 bulletin over Family of Services. The bulletin is available at approximately 0500 and 1700 UTC daily and may be obtained on AFOS by typing:

NMCMRPGLW

An example is shown in Fig. 7.

### a. Wind Forecasts

In each bulletin there is one line of forecasts at 6-h intervals from 6 - 48 hours for each sector. The time headings (06Z, 12Z, 18Z, 00Z, etc.) of the bulletin correspond to the valid times of the forecasts. The wind forecast format is ddff where dd is wind direction in tens of degrees and ff is the wind speed in knots. For wind speeds of 100 knots or greater, 50 is added to dd, and the remainder of the wind speed over 100 knots is coded in ff. For example, a wind of 270 at 100 knots would be coded 7700. Where there are missing values, a 9999 is coded.

### b. Wave Forecasts

The Great Lakes wave forecast program is run twice daily after the 0000 UTC and 1200 UTC RAFS runs and the subsequent Great Lakes wind forecast runs. The forecast wave heights are printed to the nearest foot for the 64 forecast points for each of four forecast projections, 00-, 12-, 24-, and 36-h. The format of the message is shown in Fig. 7. The point numbers are identified in Figures 2 through 6. Occasionally there will not be sufficient historical wind data to make all of the wave forecasts because of missing model runs, missing Great Lakes wind forecast runs, or computer problems. When this happens, missing values of wave forecasts will be indicated by the value 99; forecasts can be missing for specific projections entirely or simply for individual points within a projection.

## 5. OPERATIONAL CONSIDERATIONS

### a. Wind Forecasts

The regression equations are dependent on the behavior of the numerical model output. When the forecaster has reason to believe that the model is not performing properly for a given situation, he or she should modify the automated wind forecast accordingly. For example, if a trough or front has intensified or accelerated more than predicted by the model, corresponding changes to the guidance should be considered. Specific localized conditions and mesoscale features detected by real-time, ground-based, or satellite observations also should be taken into account.

When wind speeds are below 8 knots, forecast wind directions may vary substantially from observed wind directions. This is generally due to the boundary layer circulation being weak and decoupled from the circulation above it. Under these conditions the forecast equations do not perform well, and the forecaster will need to adjust the automated guidance.

The wind direction and speed forecasts are for the height of a vessel's anemometer (about 20 m). The wind speed near the surface (5 m) may be different depending on the difference in the air and lake surface temperatures. According to Pore (1982), for unstable situations the forecast wind speed will be about 1.5 times the near surface wind speed, and for stable conditions the forecast wind speed will be about 1.7 times the near surface wind speed. For all stabilities taken together, the factor will be 1.6; i.e., for a wind speed of 16 kt at 20 m, the near surface wind is 10 kt on the average. Little change in direction between the anemometer wind and the near surface wind was noticed, despite variations in stability.

## b. Wave Forecasts

Wave forecasts are generally higher than observed. This is because the Bretschneider wave height forecast equation was developed on wind speeds at 10 m, while the winds used from the wind forecast system are taken to be at a height of approximately 20 m. These winds will generally be higher than those at 10 m, except during periods when the atmospheric boundary layer is highly unstable.

No consideration is given to the effect of ice on the reduction of fetch length. This means that during late winter the actual fetch lengths will be less than those used in the calculations, and ,therefore, wave heights will be less than forecast.

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National Weather Service
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**Table 1.** The application of the MPP forecast equations to each cycle and projection of RAFS output. Equation identification is given by cycle/projection.

| | RAFS | |
|---|---|---|
| PROJ | 0000 UTC CYCLE | 1200 UTC CYCLE |
| 06 | 00/06 | 12/06 |
| 12 | 12/00 | 00/00 |
| 18 | 12/06 | 00/06 |
| 24 | 00/00 | 12/00 |
| 30 | 00/06 | 12/06 |
| 36 | 12/00 | 00/00 |
| 42 | 12/06 | 00/06 |
| 48 | 00/00 | 12/00 |

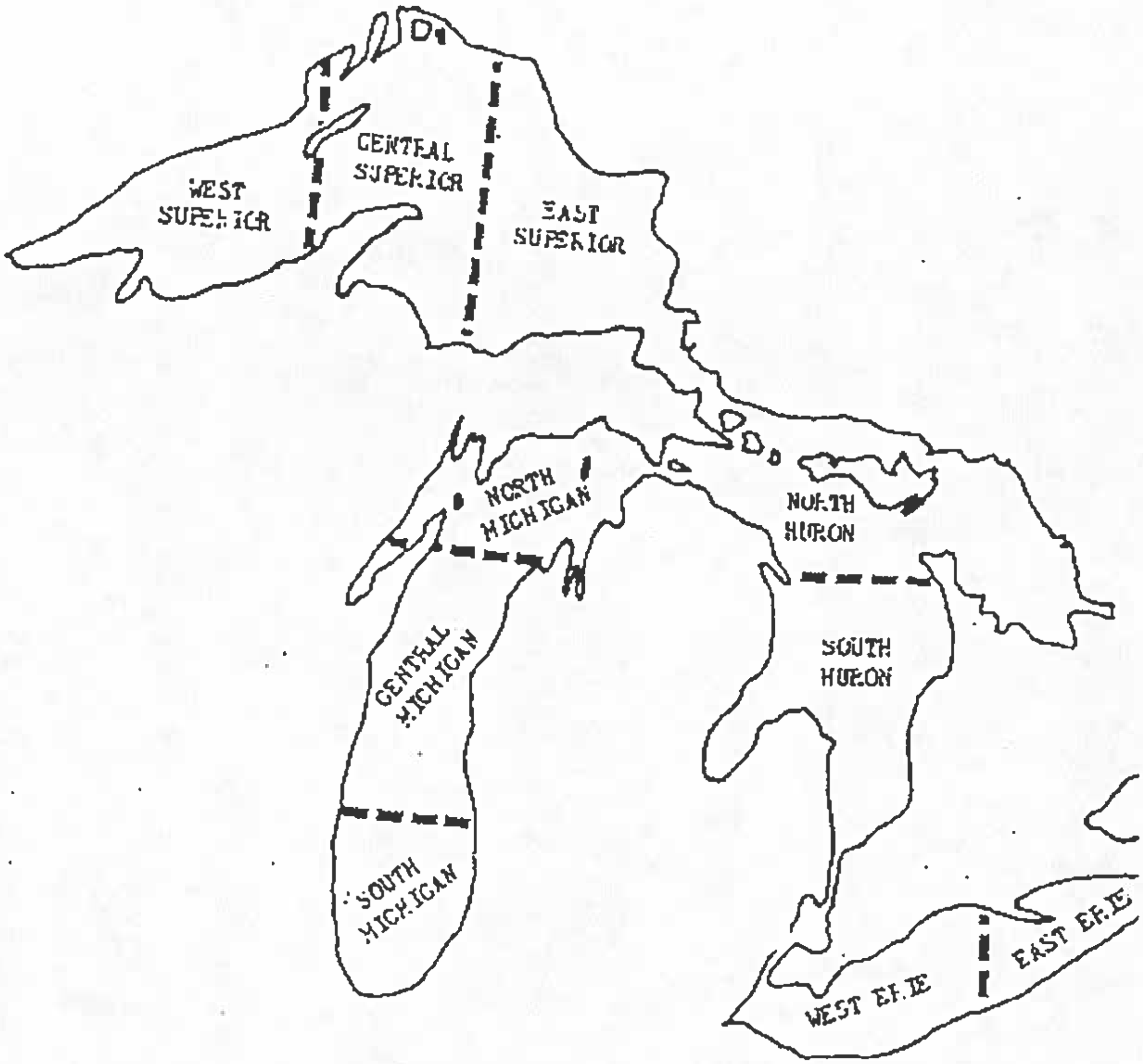


Figure 1. Location of the 12 Great Lakes sectors for which wind forecas

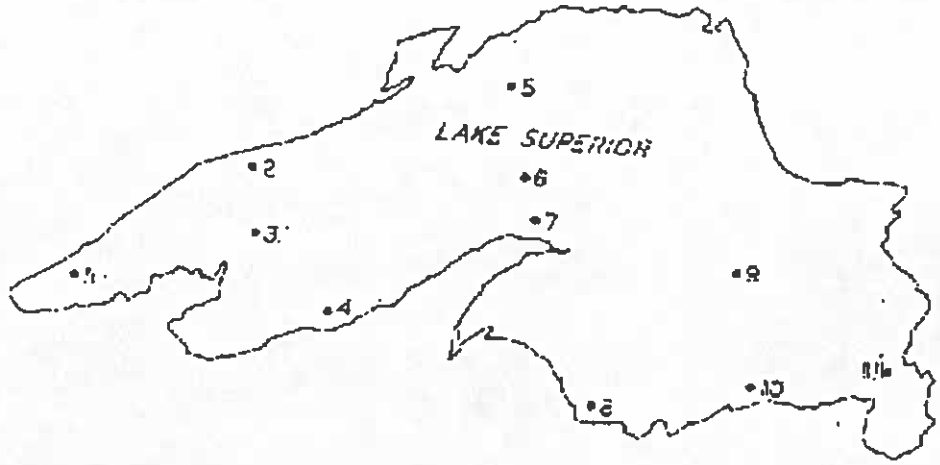


Figure 2. The 11 wave-forecast points on Lake Superior.

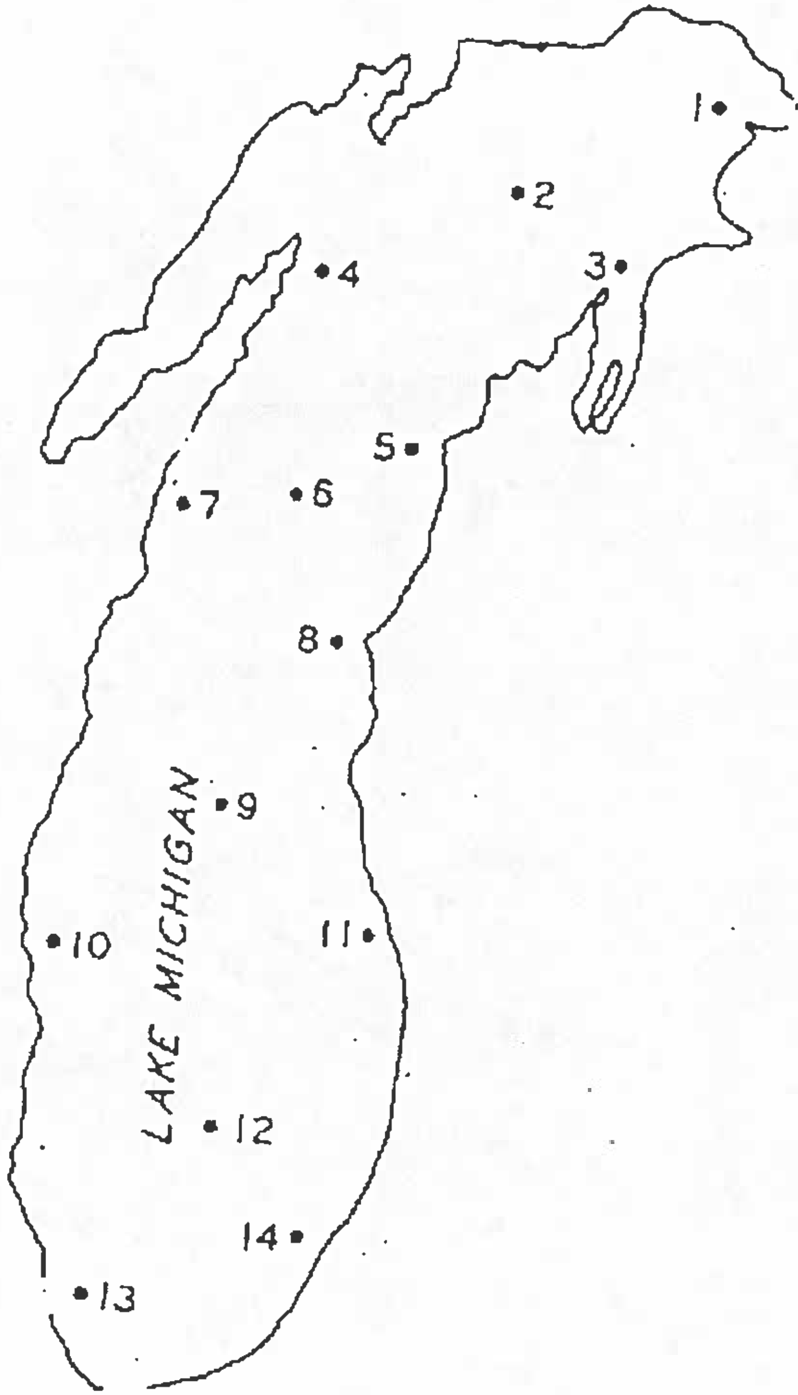


Figure 3. The 14 wave-forecast points on Lake Michigan.

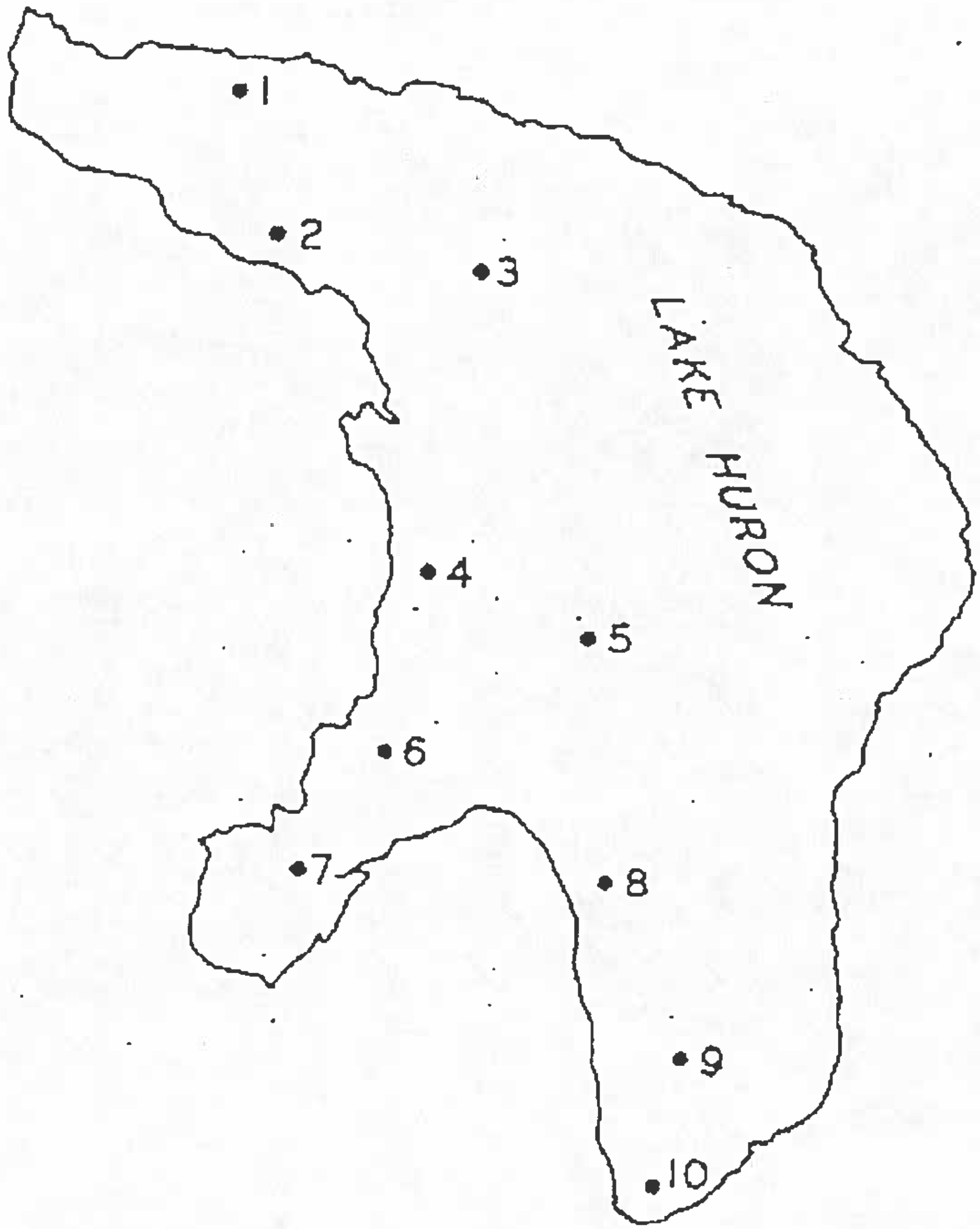


Figure 4. The 10 wave-forecast points on Lake Huron.

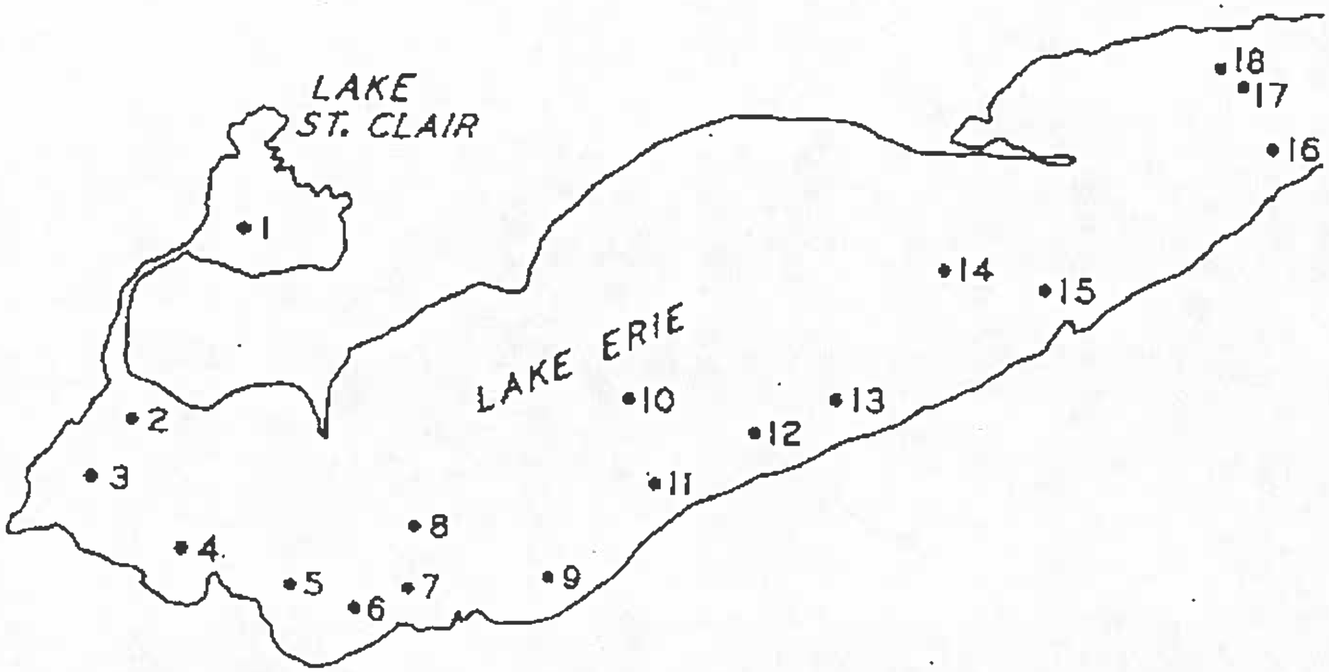


Figure 5. The 19 wave-forecast points on Lakes Sinclair and Er

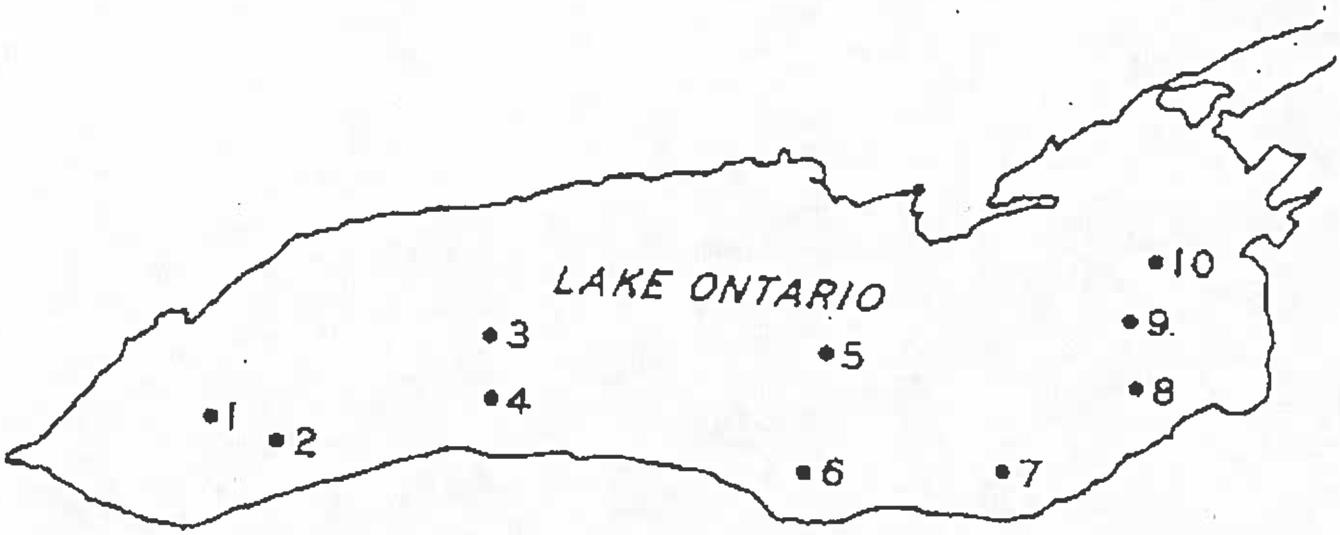


Figure 6. The 10 wave-forecast points on Lake Ontario.

FQUS22 KWBC 141200

NGM PERF. PRG. WIND FORECASTS FOR THE GREAT LAKES

| LOCATION | 18Z | 00Z | 06Z | 12Z | 18Z | 00Z | 06Z | 12Z |
|---|---|---|---|---|---|---|---|---|
| EAST ONTARIO | 1911 | 1407 | 2113 | 2209 | 2309 | 2505 | 3210 | 3610 |
| WEST ONTARIO | 2012 | 1907 | 2213 | 2609 | 2408 | 3105 | 0110 | 0210 |
| EAST ERIE | 2316 | 2310 | 2314 | 2709 | 0108 | 3607 | 0512 | 0512 |
| WEST ERIE | 2116 | 2011 | 2316 | 3110 | 0809 | 0609 | 0514 | 0614 |
| SOUTH HURON | 2020 | 2116 | 2516 | 3412 | 0211 | 0313 | 0213 | 0512 |
| NORTH HURON | 1716 | 2415 | 2717 | 2913 | 2713 | 2713 | 2814 | 0711 |
| SOUTH MICHIGAN | 2114 | 2012 | 2911 | 3108 | 0312 | 0411 | 1113 | 1013 |
| CENTRAL MICHIGAN | 2116 | 2112 | 2612 | 2509 | 3408 | 0609 | 1213 | 1112 |
| NORTH MICHIGAN | 2218 | 2617 | 2514 | 2810 | 2612 | 2611 | 1809 | 0910 |
| EAST SUPERIOR | 2118 | 2518 | 2422 | 2621 | 2619 | 2514 | 2512 | 1812 |
| CENTRAL SUPERIOR | 2121 | 2221 | 2425 | 2523 | 2518 | 2414 | 2215 | 1712 |
| WEST SUPERIOR | 2320 | 2419 | 2414 | 2615 | 2315 | 2113 | 2107 | 1510 |

GREAT LAKES WAVE FORECAST HEIGHT IN FEET

00 HR

| POINT NO. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SUPERIOR | 02 | 02 | 02 | 02 | 04 | 03 | 02 | 02 | 04 | 02 | 03 | | | | | | |
| MICHIGAN | 02 | 03 | 02 | 04 | 05 | 05 | 05 | 05 | 05 | 02 | 05 | 04 | 02 | 03 | 02 | 03 | |
| HURON | 03 | 02 | 05 | 04 | 04 | 03 | 03 | 04 | 03 | 02 | | | | | | | |
| ERIE | 01 | 02 | 02 | 01 | 01 | 02 | 03 | 03 | 02 | 03 | 03 | 03 | 02 | 02 | 02 | 02 | 02 |
| ONTARIO | 01 | 01 | 02 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | | | | | | | |

12 HR

| POINT NO. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SUPERIOR | 03 | 04 | 04 | 04 | 02 | 05 | 02 | 02 | 04 | 04 | 03 | | | | | | |
| MICHIGAN | 02 | 02 | 02 | 02 | 04 | 03 | 02 | 04 | 03 | 01 | 04 | 03 | 02 | 02 | 02 | 03 | |
| HURON | 02 | 02 | 02 | 03 | 04 | 03 | 03 | 02 | 03 | 02 | | | | | | | |
| ERIE | 01 | 02 | 02 | 02 | 02 | 01 | 02 | 02 | 01 | 03 | 02 | 02 | 02 | 02 | 02 | 02 | 02 |
| ONTARIO | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | | | | | | | |

24 HR

| POINT NO. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SUPERIOR | 02 | 03 | 03 | 04 | 05 | 07 | 07 | 02 | 06 | 06 | 07 | | | | | | |
| MICHIGAN | 03 | 02 | 03 | 01 | 02 | 02 | 01 | 02 | 02 | 01 | 02 | 02 | 01 | 02 | 01 | 01 | |
| HURON | 02 | 02 | 03 | 02 | 02 | 02 | 02 | 02 | 03 | 02 | | | | | | | |
| ERIE | 01 | 01 | 01 | 02 | 02 | 02 | 02 | 02 | 02 | 02 | 02 | 02 | 01 | 01 | 01 | 01 | 01 |
| ONTARIO | 01 | 01 | 02 | 02 | 01 | 01 | 01 | 01 | 02 | 02 | | | | | | | |

36 HR

| POINT NO. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SUPERIOR | 02 | 03 | 02 | 01 | 02 | 05 | 02 | 02 | 05 | 04 | 04 | | | | | | |
| MICHIGAN | 02 | 02 | 03 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 02 | 02 | 02 | 01 | 02 | |
| HURON | 02 | 02 | 02 | 02 | 02 | 02 | 02 | 02 | 02 | 02 | | | | | | | |
| ERIE | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 |
| ONTARIO | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | | | | | | | |

Figure 7. Sample FQUS22 bulletin. The first part gives wind direction and speed foreca sectors. The second part presents wave forecasts at each forecast point. See text for de