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WIND-WAVE GENERATION ON RESTRICTED FETCHES

by

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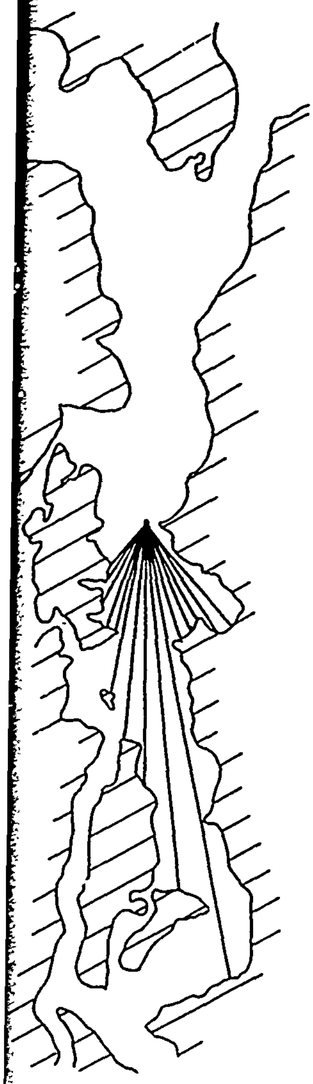

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13. ABSTRACT *(Maximum 200 words)*

Wind-wave generation in lakes, rivers, bays, and reservoirs is generally limited by the geometry of the water body, which is often very irregular. Most approaches to this problem consider wave generation only in the direction of the wind with fetch lengths averaged over small arcs of large arcs. Donelan proposed wave generation on fetch lengths in off-wind directions with reduced wind forcing (reduced by the cosine of the angle between the off-wind and wind directions) for the Great Lakes. The model described in this report, NARFET, is based on the Donelan concept, allowing wave generation in off-wind directions. Expressions are developed for significant wave height and peak period as a function of fetch geometry and wind speed based on linear regressions of wave data collected on Puget Sound, Washington; Fort Peck Reservoir, Montana; Denison Reservoir, Texas; and Lake Ontario. The mean wave direction is determined by maximizing the wave period. The equations differ from those given by Donelan, which were developed for the longer, more regular-shaped fetches of the Great Lakes. The NARFET model is quick and inexpensive (runs on a personal computer), yet considers the complexity of fetch geometry.

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PREFACE

The investigation described in this report was authorized as a part of the Civil Works Research and Development Program by Headquarters, US Army Corps of Engineers (HQUSACE). Work was performed under Work Unit 31592, "Wave Estimation for Design, Coastal Flooding Program," at the Coastal Engineering Research Center (CERC), of the US Army Engineer Waterways Experiment Station (WES). Messrs. John H. Lockhart, Jr., and John G. Housley were HQUSACE Technical Monitors. Dr. C. Linwood Vincent is the CERC Program Manager.

This study was conducted from July 1987 through May 1988 by Ms. Jane M. Smith, Hydraulic Engineer, CERC. The study was done under the general supervision of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., Chief and Assistant Chief, CERC, respectively; and under the direct supervision of Mr. H. Lee Butler, Chief, Research Division; Dr. Edward F. Thompson, former Chief, Coastal Oceanography Branch, and Dr. Robert E. Jensen, Principal Investigator, Wave Estimation for Design Work Unit, CERC. Dr. Steven A. Hughes, Wave Dynamics Division, CERC, provided technical review of this report, and Ms. Victoria L. Edwards, CERC, did word processing.

Commander and Director of WES during the publication of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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CONTENTS

WIND-WAVE GENERATION ON RESTRICTED FETCHES

PART I: INTRODUCTION

Background

1. Wind-wave generation in lakes, rivers, bays, and reservoirs is generally limited by the geometry of the water body, which is often very irregular. In the open ocean, wave generation is limited by the extent of the meteorological disturbances, where the fetch widths are of the same order of magnitude as the fetch lengths, and only the length, not the shape of the fetch, is considered important. Although the effect of fetch length is fairly well understood, the effect of fetch shape (especially for very irregular or narrow fetches) has received only limited attention.

2. Fetch lengths for restricted fetches are normally measured from the shoreline to the point of interest, in the direction of the wind. The Shore Protection Manual (SPM) (1984) recommends applying this straight-line fetch length to wave forecasting curves or equations, giving no consideration to the fetch geometry. Other methods proposed for restricted fetch wave generation consider fetch lengths in off-wind directions by applying weighting factors (a function of the cosine of the angle between the off-wind and wind directions) to the fetch lengths and averaging these weighted lengths over large arcs on either side of the wind direction. These methods tend to reduce fetch lengths through averaging. Another method, developed for the Great Lakes, considers wave generation on fetch lengths in off-wind directions with a reduced wind forcing (reduced by the cosine of the angle between the off-wind and wind direction). This method has been successful on the Great Lakes, but has not been tested for very irregular or narrow fetches. Complex numerical models of wind-wave generation are also applicable to restricted fetches, but the effort, cost, and computer resources for the required resolution make them uneconomical for small projects.

Scope

3. The purpose of this report is to present the development and application of the restricted fetch wind-wave generation model NARFET. Methods

developed in previous studies were reviewed and tested with field data. Based on the strong points of the previous methods and the field data, an improved model (NARFET) was developed. The model is quick and inexpensive, yet includes the complexity of fetch geometry not considered in the SPM method. The model considers only constant, steady-state winds over the fetch. The effect of depth is not included (most applications are in relatively deep water).

PART II: MODEL DEVELOPMENT

Previous Work

4. The first method used to account for the effect of fetch shape was the effective fetch method proposed by Saville (1954). Saville assumed that wind transfers energy to the water surface in the direction of the wind and in all directions within 45 deg either side of the wind direction. For off-wind directions, the amount of energy transferred is modified by the cosine of the angle between the off-wind and wind directions. An effective fetch was determined and applied to wave forecasting curves or equations developed for unrestricted fetches (SPM 1966) to predict significant wave height and period or energy spectrum. The effective fetch was defined as follows:

$$F_{eff} = \frac{\Sigma X_i \cos^2 \theta_i}{\Sigma \cos \theta_i} \qquad (1)$$

where

F_{eff} = effective fetch*

X_i = length of the straight-line fetch

θ_i = angle from mean wind direction

Straight-line fetches were measured at increments of 6 deg over a 90-deg arc (45 deg either side of the mean wind direction). This method usually predicts lower wave heights and periods than when fetch shape is not considered. This method was recommended by the SPM (1966). More recent SPM (1984) guidance recommends using a simple fetch with the wave forecasting curves. The simple fetch is determined by arithmetically averaging straight-line fetches at increments of 3 deg over a 24-deg arc (12 deg either side of the mean wind direction). This method is more conservative than the effective fetch method in most cases, and it is easier to apply. Both these methods assume wave direction is coincident with wind direction, and the shape of the energy spectrum is not affected by fetch shape.

5. Seymour (1977) argued that these two assumptions, wind and wave direction coincident and spectral shape unaffected by fetch shape, were not

---

* For convenience, symbols are listed and defined in the Notation (Appendix D).

valid. He suggested that both frequency and directional spread of the energy spectrum would be broader for a restricted fetch than for the open ocean, so he proposed the spectral contribution method. This method assumed a cosine-squared direction distribution of wave energy over a 180-deg arc (90 deg either side of the wind direction). The energy in a given spectral component S_i is given by:

$$S_i(f,\theta_i,F_i) = 0.6366\Delta\theta S(f,F_i) \cos^2 \theta_i \tag{2}$$

where

S_i = energy spectral component
f = frequency
F_i = fetch in θ_i direction
$\Delta\theta$ = angle increment
$S(f,F_i)$ = either the JONSWAP (Hasselmann et al. 1973) or Bretschneider (1963) energy spectrum

The spectrum is obtained by summing the energy in each frequency component over all directions. This method is tedious, but it has the advantage of considering fetch geometry as well as wind direction in estimating wave direction. This method tends to give lower wave heights and longer peak periods than the effective fetch and simple fetch methods. The shape of the energy spectrum is questionable because it does not account for smearing caused by wave-wave interaction which tends to smooth the spectral shape to a similar form.

6. The effective fetch, simple fetch, and spectral contribution methods all allow the user to select the relationship of wave height and period to fetch and wind speed. The equations derived from the JONSWAP experiment (Hasselmann et al. 1973) are commonly used:

$$\begin{aligned} H &= 0.0016g^{-0.5}X^{0.5}U \\ f_p &= 3.5g^{0.67}X^{-0.33}U^{-0.33} \end{aligned} \tag{3}$$

where

H = significant wave height
g = gravitational acceleration
X = fetch

U = wind speed

f_p = peak frequency

Donelan (1980) developed slightly different relationships for H and f_p based on data collected in the Great Lakes:

$$H = 0.00366 g^{-0.62} F^{0.38} (U \cos \phi)^{1.24}$$
$$f_p = 1.85 g^{0.77} F^{-0.23} (U \cos \phi)^{-0.54} \tag{4}$$

where ϕ is the angle between the wind and wave direction and F is the straight-line fetch in the direction of the waves. He does not assume that the wind and wave directions are the same, but for wave prediction, maximizes the product:

$$(\cos \phi)^{0.54} F^{0.23} \tag{5}$$

which is derived from maximizing the wave period (reciprocal of Equation 4). This product is a function of fetch geometry. Donelan's approach can be summarized as balancing a reduced wind forcing $U \cos (\phi)$ with increased fetch distance in an off-wind direction. Donelan's model gives excellent results for wave direction in Great Lakes experiments. The model has been criticized by Walsh et al. (in preparation) because theoretical considerations suggest that wave energy is a linear function of fetch, and therefore, wave height should be a function of fetch to the 0.5 power (Rottier and Vincent 1982).

7. Walsh et al. use Donelan's basic model form and assume (a) an exponent ρ in the $\cos (\phi)$ term to account for a reduced effectiveness of wind in off-wind directions, (b) wave height is proportional to fetch to the 0.5 power, and (c) wave direction given by Donelan's model is correct, but both H and T (period, $1/f_p$) should be maximized. With these assumptions, they give the following expressions:

$$H = 0.0017 F^{0.5} g^{-0.5} U (\cos \phi)^{1.63}$$
$$f_p = 2.3 F^{-0.29} g^{0.71} U^{-0.42} (\cos \phi)^{-0.685} \tag{6}$$

The models of both Donelan and Walsh et al. are easy to apply, but neither has been tested for narrow, restricted fetches.

8. Sophisticated numerical finite-difference models of large-scale wave generation have been developed in recent years (e.g., SHALWV model (Hughes and Jensen 1986)) based on momentum transfer from the wind to the waves. This type of model is applicable to wave generation on restricted fetches, but requires small spatial grid cells and time steps to resolve the fetch shape, making simulations expensive. Also, many of the complexities in the models are normally not needed for restricted fetch applications (spatially and temporally varying wind fields, swell propagation, shallow-water effects).

Data

9. Limited wave data from four sources were compiled to test the models developed in the previous studies and to consider improved methods. The sites include Denison Reservoir, Texas (two locations) (US Army Corps of Engineers 1962); Fort Peck Reservoir, Montana (two locations) (US Army Corps of Engineers 1962); Puget Sound, Washington (Nelson and Broderick 1986); and Lake Ontario (Bishop 1983). The data set consisted of 54 cases. These cases were chosen by the following criteria:

a. Sea conditions not fully developed.
b. Steady wind speed.
c. Steady wind direction.
d. Sea conditions not duration limited.

The wind speed was averaged over the duration of each case, adjusted to the 10-m elevation, and adjusted for air-sea temperature difference (SPM 1984). Wave heights and periods were averaged starting after the minimum duration for fetch-limited conditions. The maximum wave height was 2.00 m on Lake Ontario and the minimum wave height was 0.21 m on Puget Sound. The maximum wave period was 6.6 sec (Lake Ontario), and the minimum wave period was 2.2 sec (Denison Reservoir).

10. Fetch lengths were determined for each case based on averages of straight-line fetches measured at 6-deg increments and averaged over 15-deg arcs. The fetch and direction that maximized Donelan's expression (Equation 5) were also determined for each of the 54 cases. The maximum fetch was 182.0 km on Lake Ontario, and the minimum fetch was 2.0 km on Denison Reservoir. The data are given in Appendix A.

Comparison of Models

11. The models described earlier were intercompared based on the field data. The effective fetch and spectral contribution methods were eliminated from consideration early in the study. Figure 1 shows a comparison of the energy spectrum calculated from the simple fetch, effective fetch, and spectral contribution methods for one wave condition at Puget Sound (the most restricted fetch of the four sites). Table 1 summarizes the results from this case.

Table 1

Comparison of Parameters for Puget Sound Test Case 2

Method	Fetch*, km	H , m	f_p , Hz
Simple fetch	23.3	0.84	0.24
Effective fetch	10.3	0.49	0.32
Spectral contribution	--	0.46	0.23
Measured	--	0.98	0.27

* Calculated according to original reference.

The Donelan and Walsh et al. models give results similar to the simple fetch model. In some comparisons, the effective fetch and spectral contribution results were comparable to the simple fetch results, but the simple fetch model approximates the measured data better in the majority of cases. The effective fetch and spectral contribution methods generally underestimate the wave heights and periods, so these methods are not considered further.

12. The remaining two approaches for consideration are wave generation in the direction of the wind (simple fetch), and wave generation in an off-wind direction due to reduced wind forcing along a greater fetch (Donelan or Walsh et al.). Both approaches give similar results. Early comparison could not distinguish between differences due to fetch and differences due to the expressions used to calculate H and T from the fetch and wind speed. Comparisons of H calculated versus H measured and f_p calculated and f_p measured are given in Figures 2a-2f for the simple fetch, Donelan, and Walsh et al. models. These plots show that the simple fetch method tends to underpredict wave height and overpredict peak wave frequency. The simple fetch method underestimates the waves when the winds blow across the short axis of

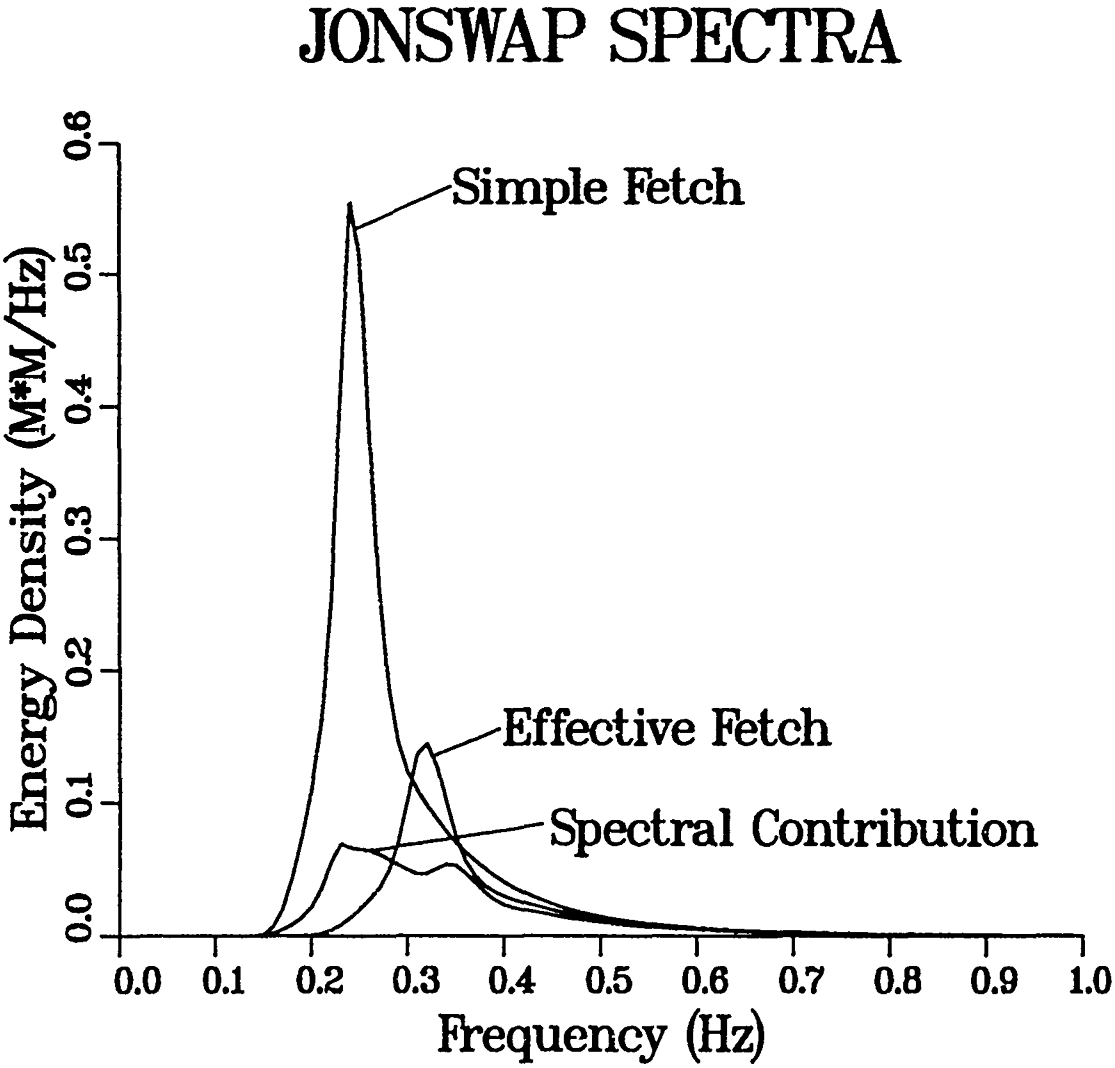
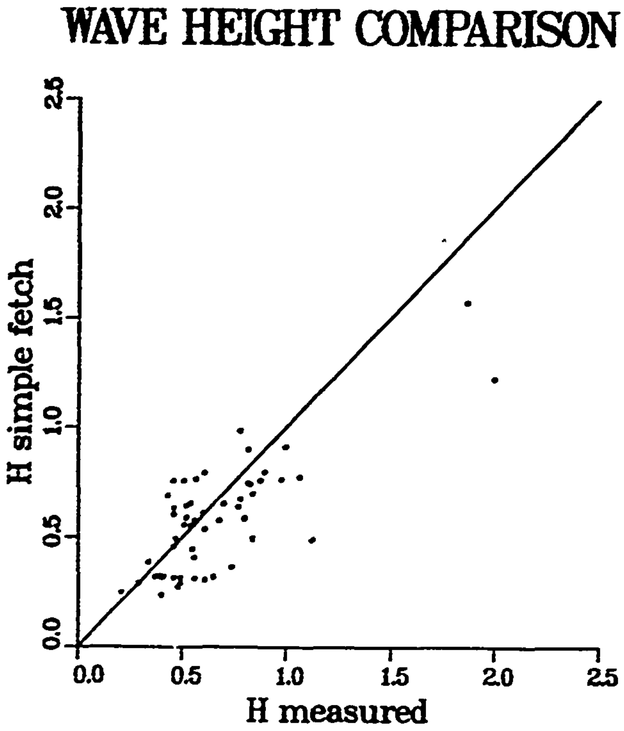
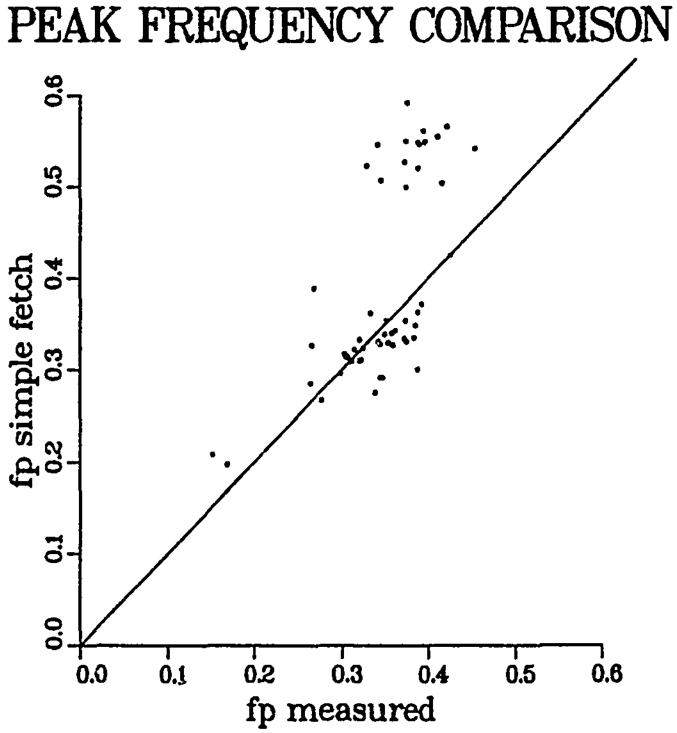


Figure 1. Comparison of spectra calculated by simple fetch, effective fetch, and spectral contribution methods

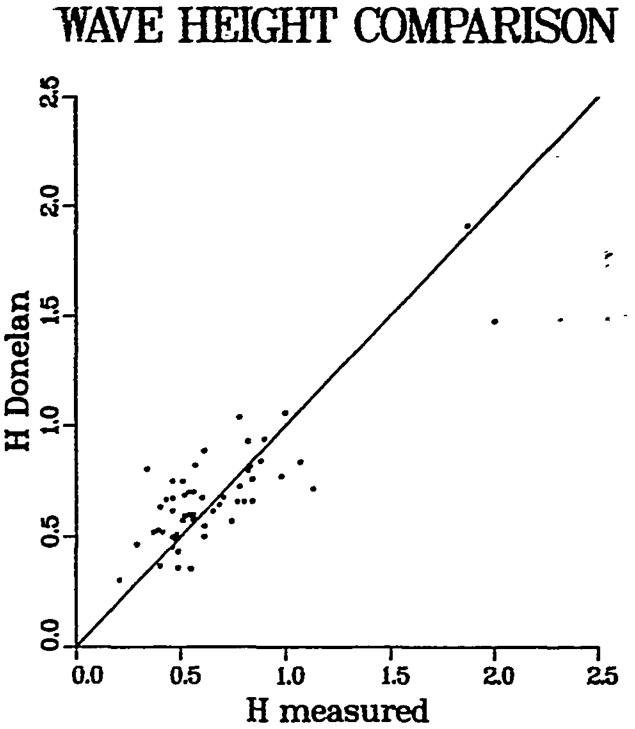


a. H from simple fetch method

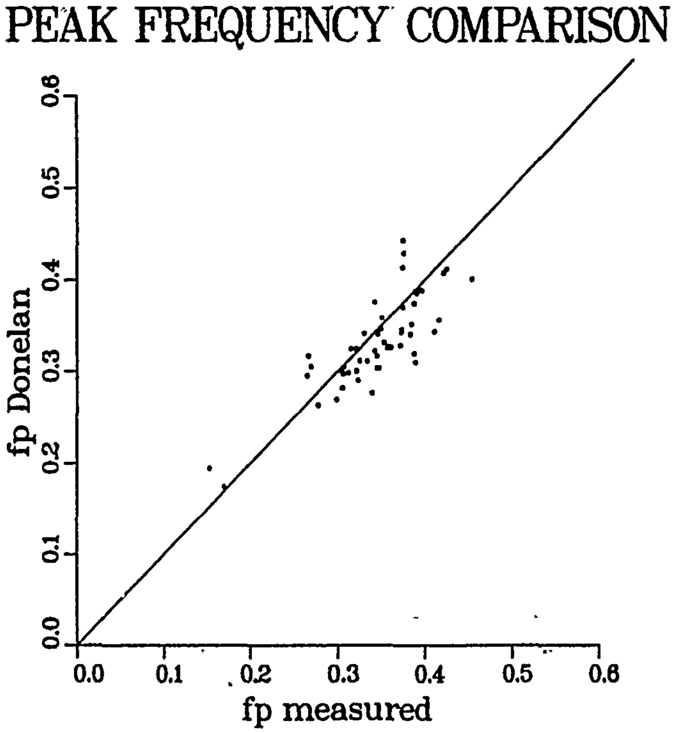


b. f_p from simple fetch method

Figure 2. Comparisons of calculated versus measured H and f_p (Sheet 1 of 3)

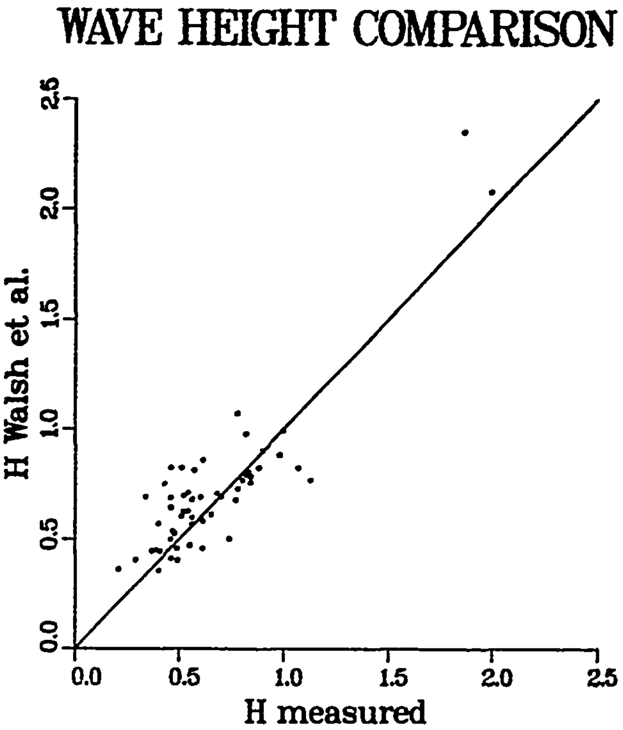


c. H from Donelan method

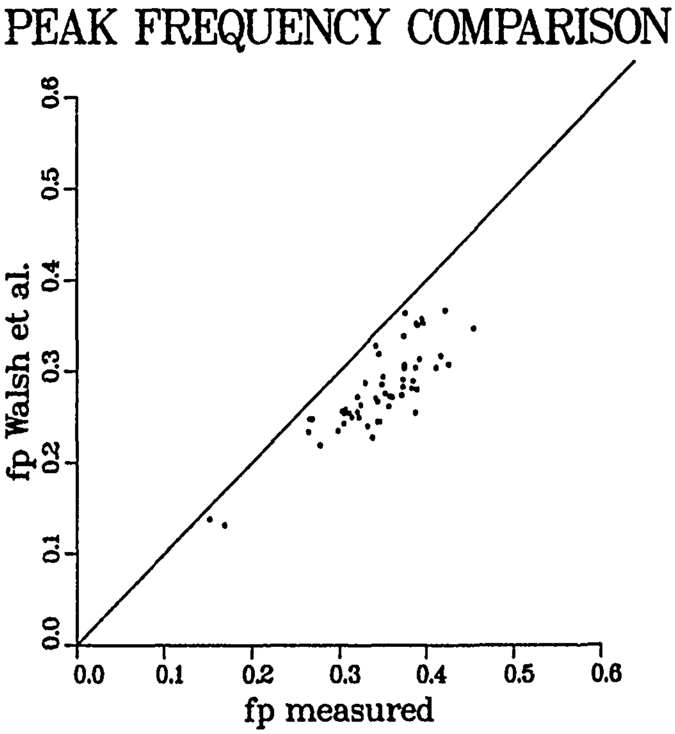


d. f_p from Donelan method

Figure 2. (Sheet 2 of 3)



e. H from Walsh et al. method



f. f_p from Walsh et al. method

Figure 2. (Sheet 3 of 3)

water body. In these test cases, the simple fetch method underestimates wave height by as much as 40 percent for larger wave conditions (and by greater percentages for lower wave conditions). The Donelan model is superior to the Walsh et al. model in predicting wave frequency, but slightly inferior in predicting wave height.

Improved Model

13. The wave data were nondimensionalized and plotted to seek improved expressions for wave height and peak frequency. The Donelan concept, allowing wave development in off-wind directions, was used. The dimensionless wave parameters are:

$$\bar{H} = \frac{Hg}{(U')^2}$$

$$\bar{f}_p = \frac{f_p U'}{g} \tag{7}$$

$$\bar{X} = \frac{Fg}{(U')^2}$$

where

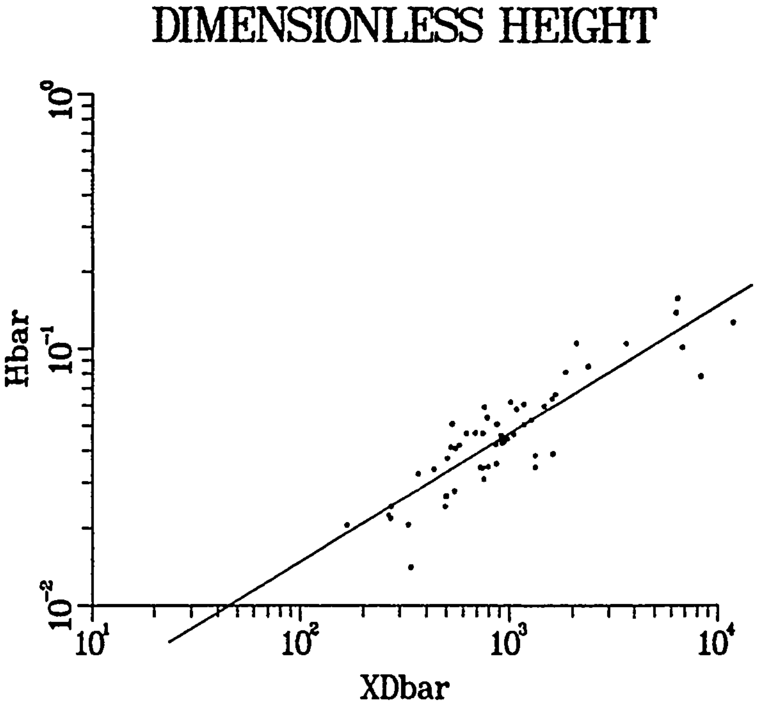
$\bar{H}$ = dimensionless significant wave height
$U' = U (\cos \phi)$
$\bar{f}_p$ = dimensionless peak frequency
$\bar{X}$ = dimensionless fetch in wave direction

Linear regression analysis of the logarithms of the dimensionless parameters gave the following expressions for H and f_p as a function of X :

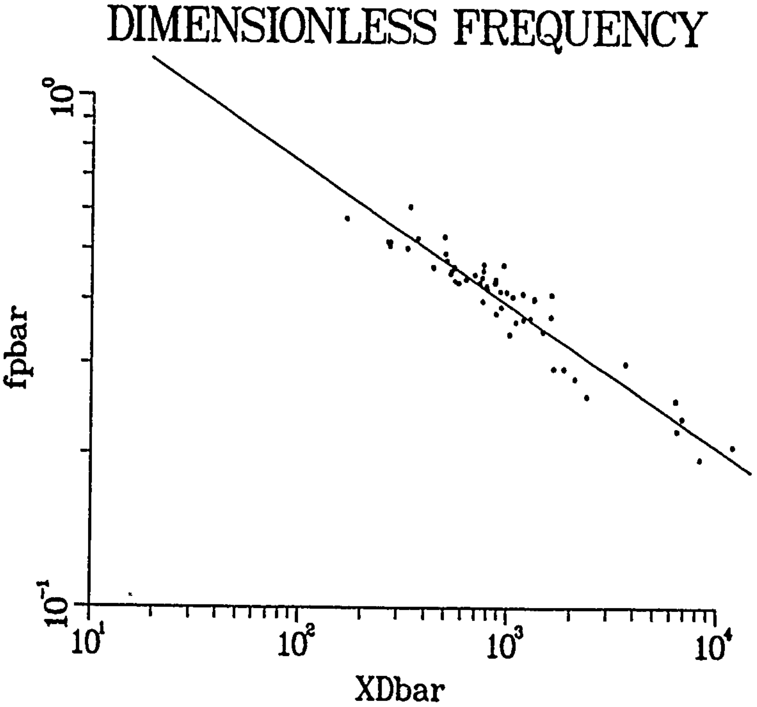
$$\bar{H} = 0.0015\bar{X}^{0.50}$$

$$\bar{f}_p = 2.6\bar{X}^{-0.28} \tag{8}$$

Figure 3 shows these expressions in graphical form with the data. The dimensionless expressions (Equation 8) are equivalent to the following.



a. Dimensionless wave height versus fetch



b. Dimensionless peak frequency versus fetch

Figure 3. Dimensionless $\overline{H}$ and $\overline{f}_p$ versus $\overline{X}$ with least squares regression

$$
\begin{aligned}
H &= 0.0015 g^{-0.5} F^{0.5} (U \cos \phi) \\
f_p &= 2.6 g^{0.72} F^{-0.28} (U \cos \phi)^{-0.44}
\end{aligned}
\tag{9}
$$

Note the similarity of the wave height equation to the JONSWAP height equation used in the SPM (1984). Both the height and peak frequency expressions are similar to the Walsh et al. equations. Multivariate regressions were run allowing the exponent of the cosine term to vary (as in Equation 6), but only slightly different values were obtained and the decrease in the variance was very small.

14. Figure 4 compares measured wave height and peak frequency to values predicted by Equation 9. The proportion of the variation in the wave height and period explained by the different models (Simple Fetch, Donelan, Walsh et al., and Equation 9) can be expressed by the correlation coefficient r which is defined as follows:

$$
r(y) = \sqrt{1 - \frac{\Sigma (y - \hat{y})^2}{(y - \bar{y})^2}} \tag{10}
$$

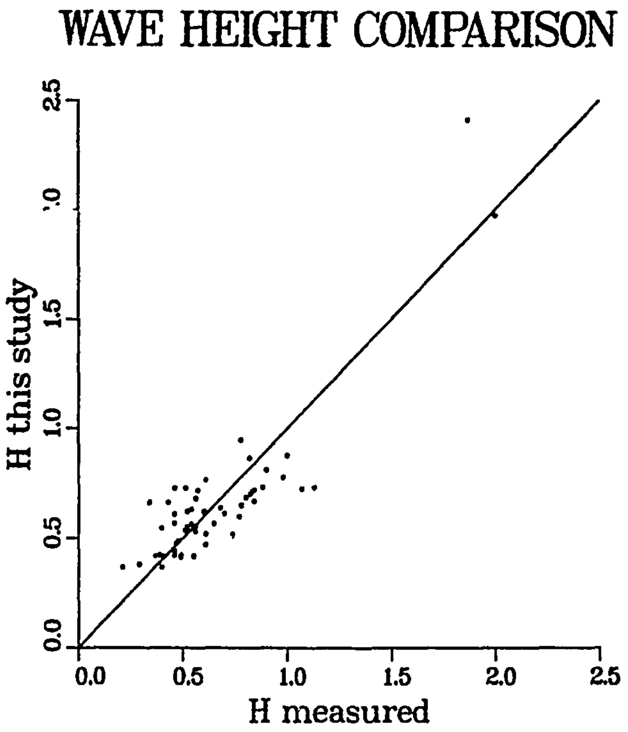
where $\bar{y}$ is the measured value (H or T), $\hat{y}$ is the predicted value (given by one of the models), and y is the mean of the measured values. The correlation coefficients are given in Table 2.

Table 2

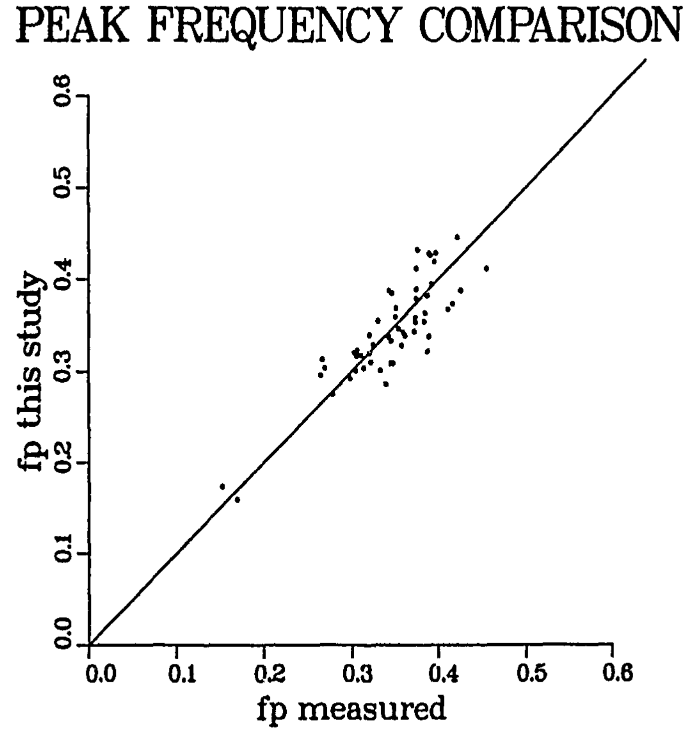
Correlation Coefficients of Measured versus Predicted Values

Model	r(H)	r(T)
Simple fetch	0.73	0.66
Donelan	0.83	0.89
Walsh et al.	0.85	0.0
Equation 9	0.87	0.94

The correlation coefficients for the wave heights are very close for the Donelan model, Walsh et al. model, and this study, but the differences in the correlation of the periods are greater. (The correlation coefficient for wave period is slightly higher than for peak frequency for all models. Period is used here because it is more intuitive for most engineers.) The correlation coefficient for period for Walsh et al. is zero because the expression



a. H from this study versus measurement



b. f_p from this study versus measurement

Figure 4. Comparison of H and f_p calculated from this study and measured

predicts the mean so poorly. The mean measured value of T predicts the measurements better than the Walsh et al. predicted values. Equation 9 best explains the variance in H and T . This is expected since Equation 9 was derived from this data set.

15. The model produced here represents an improvement over the SPM (1984) and Donelan methods. For straight shoreline fetch situations, the results are very similar to JONSWAP. For off-angle shorelines, the model appears to do as well as or better than the other methods.

PART III: MODEL APPLICATION

16. The computer program NARFET is based on Equation 9. The program models wind-wave growth based on the assumptions that:

- a. Waves are locally generated and fetch-limited.
- b. Water depths across the fetch are deep based on the peak frequency (depth is greater than half the wave length).
- c. Wind speed and direction are steady (spatially and temporally).

The model is intended for narrow-fetch applications. As fetch width increases, the fetch calculated by the model will approach the straight-line fetch in the wind direction, and the significant wave height and peak period will be similar to the SPM results. Interactive input to the program describes the fetch geometry and the wind forcing. The program output is significant wave height, peak period, and mean direction. NARFET is written in FORTRAN and runs on a personal computer. This section of the report describes the program input and output. A sample run of the program is given in Appendix B, and a program listing is given in Appendix C.

Program Input

17. The program accepts interactive responses to input questions. Responses must be numeric (e.g., lengths, speeds, directions) or alphabetic (e.g., units, yes/no). Alphabetic responses are shortened to one-letter abbreviations given in parentheses. Capital letters should be used. When a file name is requested, the number of characters in the name (including the extension) is limited to eight (e.g., TEST.DAT).

Fetch geometry

18. The first question asked by the program is "Do you wish to enter fetch geometry interactively or from a file?" The first time the program is run for a site, the geometry must be entered interactively. The fetch geometry from a run may be written to a file during the run, and that file can be used as input for subsequent runs.

19. Fetch geometry is described by radial fetch lengths measured from the shoreline to the point of interest at even angle increments. The next interactive questions ask for the angle increment between input fetches, the direction of the first fetch relative to the point of interest, and the number of input lengths. The angle increments must be small enough to resolve the

shoreline, typically 5 to 10 deg. Linear interpolation is used between input values. For many applications it is not necessary to input fetch lengths around the full 360-deg arc, so the program allows the user to start from any angle (angles are measured clockwise from north and represent the direction winds/waves are coming from) and input any number of lengths (up to a 360-deg arc). For example, for winds blowing along the long axis of the water body, only a small arc of fetch lengths is needed. For winds blowing along the short axis, fetch lengths along an arc of up to 180 deg may be needed. If a complete 360-deg arc is not entered, the unspecified lengths are set to zero and no wave generation will occur in those directions.

20. The program requests fetch lengths starting from the specified starting direction and proceeding clockwise at the input angle increment. Fetch lengths should be measured off a large-scale chart representing the shoreline for the design water elevation. The units of the fetch lengths may be kilometres, feet, miles, or nautical miles. The program converts all units to metres for internal calculations. Figure 5 is an example of the fetch geometry in southern Puget Sound. An angle increment of 6 deg was used. Twenty-three fetch lengths were measured starting from an angle of 126 deg from north. See Appendix B for this sample run. After all radial lengths are entered, the program lists the lengths, so the user can check for errors. Errors can be corrected by entering the number of values to be changed, then entering the angle and new radial length for each change.

21. NARFET internally interpolates fetch lengths at 1-deg increments around the entire 360-deg arc. Then the program averages fetch lengths over 15-deg arcs centered on each 1-deg increment. These fetch lengths are used to calculate wave conditions. The option is given to write this information to a file for future runs, in which case a file name is requested.

Wind forcing

22. Wind forcing is represented by wind speed, direction, and duration over the water body. Wind fields are distorted by frictional effects, so the measurement elevation, the boundary layer stability, and the measurement location (overland or overwater) are also needed to adjust the wind speed to standard conditions. The simplified corrections to the wind speed used in NARFET are based on these three factors. The correction methods are given in the SPM. The standard elevation of wind measurements is 10 m, so in the program wind speeds are adjusted to the 10-m elevation. The air-sea temperature difference represents the boundary layer stability. If the air-sea

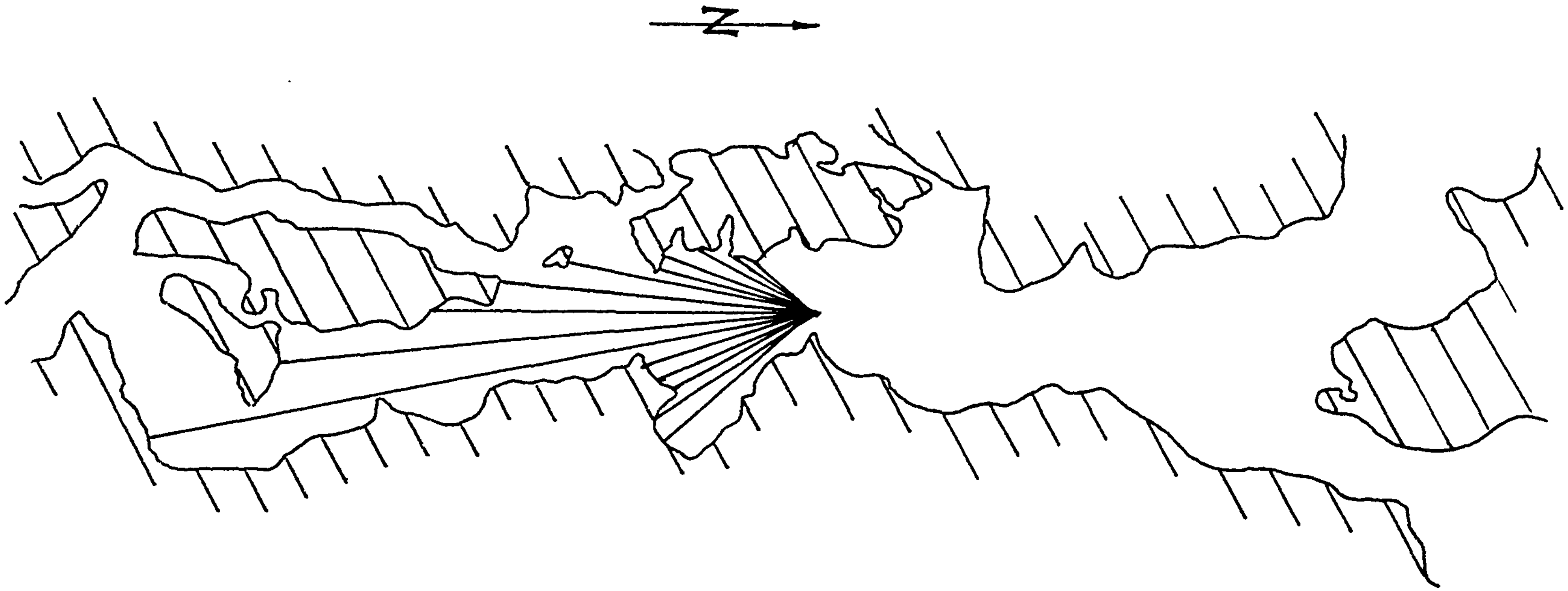


Figure 5. Fetch geometry for southern Puget Sound

temperature difference is unknown, the SPM recommends a correction factor of 1.1 (unstable condition). This correction factor is equivalent to an air-sea temperature difference of approximately -3° C. Overland wind conditions differ from overwater conditions because of increases in surface roughness overland. An additional correction is made if winds are based on overland measurements.

23. After these three corrections to the wind speed are made, the wind speed is converted to a wind stress factor by applying the nonconstant coefficient of drag correction (SPM). Wave growth is driven by wind stress, which is a function of wind speed and a drag coefficient. The drag coefficient is also a function of wind speed. This correction accounts for the change in the drag coefficient with wind speed (making winds more effective at high wind speeds), and it increases wave heights at high wind speeds. The nonconstant coefficient of drag correction was not used in developing NARFET (this is an area of present research), but current Corps of Engineers guidance recommends using the correction. The duration input is used to check if wave generation is limited by duration. The program does not convert very short duration wind observations (e.g., fastest mile wind speeds) to longer durations.

Program Output

24. When all input is complete, NARFET determines the direction of wave generation from the input wind direction by maximizing the wave period from Equation 9. The maximum period is achieved when:

$$(\cos \phi)^{0.44} F^{0.28} \tag{11}$$

is maximized, where F is the 15-deg averaged fetch length at an angle ϕ with the wind direction. When the fetch and angle that maximize Equation 11 are determined, the fetch, angle, and wind speed are applied to Equation 9 to calculate wave height and period.

25. The purpose of this study was to redefine the fetch for fetch-limited conditions, but it is difficult to know a priori if fetch-limited conditions exist. Therefore, the program checks for exceedence of duration-limited and fully developed conditions. Duration-limited conditions exist if the integral of the transit time (inverse of wave celerity) across the fetch exceeds the wind duration. If duration is the limiting factor, the SPM

expression for duration-limited conditions is used. Duration-limited wave generation in the off-wind direction is allowed. Wave conditions are also compared with fully developed conditions (based on the expression in the SPM) for the input wind speed. If fully developed conditions are exceeded, the SPM expression is used to calculate wave height and period. Shallow-water wave conditions can be estimated by applying the fetch calculated by Equation 11 to the shallow-water wave forecasting curves in the SPM (1984).

26. The program prints the wave height (in feet and meters), period, and direction at the end of the run. Input wind conditions (including the wind speed adjusted for elevation, stability, and location) are also printed for easy reference. The program states whether the solution is fetch-limited, duration-limited, or fully developed. The option is given to calculate additional wave conditions for new wind input or terminate the run.

PART IV: CONCLUSIONS

27. Wave generation in off-wind directions is significant for restricted fetch geometries. Models that do not consider generation in off-wind directions underestimate wave conditions for winds blowing along the shorter fetches of an irregularly shaped water body. Estimation of fetch lengths over large arcs (90 to 180 deg), as in the effective fetch and spectral contribution models, also underestimates wave conditions. The model proposed by Donelan gives reasonable results for restricted fetches, but it has been criticized because of the relationship between fetch and wave height. A better expression, based on the data set compiled for this study, is given by Equation 9. Additional data are needed to independently verify Equation 9. The simple computer program NARFET applies Equation 9 to calculate wave height, period, and direction given fetch geometry and wind forcing.

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APPENDIX A: DATA

Puget Sound, Fort Peck Reservoir, Denison Reservoir, and Lake Ontario Data

ID	U (m/s)	Dir (deg)	Elev (ft)	Temp cor	H (m)	T (s)	X (km)	F (km)	ϕ (deg)	Dur (hr)
PS011083	10.76	184.3	30.	1.0	0.98	3.77	18.8	22.4	4.	6.0
PS040883	6.26	215.1	30.	1.0	0.21	2.67	5.9	22.4	36.	14.0
PS120883	8.45	190.3	30.	1.134	0.80	3.75	14.0	22.4	10.	6.0
PS121983	8.12	341.6	30.	1.145	0.84	3.00	10.6	29.0	20.	10.0
PS010384	5.21	177.3	30.	1.105	0.55	2.67	22.4	22.4	2.	6.0
PS012384	6.02	199.2	30.	1.025	0.49	2.35	9.8	22.4	20.	6.0
PS012584	10.40	207.5	30.	1.100	1.13	3.71	6.9	22.4	28.	4.0
F2090950	11.64	67.5	25.	1.0	0.46	2.69	10.5	11.2	6.	4.0
F2091650	10.23	67.5	25.	1.0	0.51	2.60	10.5	11.2	6.	2.5
F2101450	12.09	90.0	25.	1.0	0.54	2.92	10.4	11.4	10.	4.0
F2081151	12.44	90.0	25.	1.0	0.78	2.90	10.4	11.4	10.	3.0
F2082951	14.62	90.0	25.	1.0	0.61	3.10	10.4	11.4	10.	1.5
F2101151	11.65	112.5	25.	1.0	0.60	2.77	9.7	12.2	14.	2.0
F2060952	12.82	67.5	25.	1.0	0.84	3.08	10.5	11.2	6.	4.0
F2061052	13.96	67.5	25.	1.0	0.88	3.27	10.5	11.2	6.	2.0
F2061052	15.23	112.5	25.	1.0	0.90	3.28	9.7	12.2	14.	4.0
F2061152	16.77	67.5	25.	1.0	1.00	3.35	10.5	11.2	6.	4.0
F2061252	13.63	67.5	25.	1.0	0.83	3.30	10.5	11.2	6.	2.5
F2061452	11.90	90.0	25.	1.0	0.52	3.12	10.4	11.4	10.	3.0
F2081652	9.90	90.0	25.	1.0	0.61	2.85	10.4	11.4	10.	2.0
F2082052	8.49	90.0	25.	1.0	0.46	2.55	10.4	11.4	10.	3.0
F2082052	10.58	112.5	25.	1.0	0.54	2.68	9.7	12.2	14.	5.0
F2082152	9.12	90.0	25.	1.0	0.47	2.58	10.4	11.4	10.	3.0
F3081951	14.30	22.5	25.	1.0	0.78	3.60	16.8	17.8	4.	2.5
F3061252	13.07	22.5	25.	1.0	0.82	2.95	16.8	17.8	4.	5.5
F3061252	10.16	45.0	25.	1.0	0.68	2.80	11.4	17.1	15.	3.0
F3061452	11.00	22.5	25.	1.0	0.46	2.90	16.8	17.8	4.	3.0
F3062752	10.01	22.5	25.	1.0	0.43	2.58	16.8	17.8	4.	10.0
F3062952	10.99	22.5	25.	1.0	0.51	2.88	16.8	17.8	4.	3.5
DC110850	13.81	22.5	25.	1.0	0.40	2.43	1.9	8.1	28.	9.0
DC120550	16.73	22.5	25.	1.0	0.34	2.57	1.9	8.1	28.	7.0
DC032951	13.72	337.5	25.	1.0	0.39	2.56	2.0	4.6	24.	9.5
DC111551	13.52	337.5	25.	1.0	0.41	2.52	2.0	4.6	24.	4.0
DC121251	13.55	337.5	25.	1.0	0.37	2.57	2.0	4.6	24.	9.5
DC020952	14.05	0.0	25.	1.0	0.46	2.53	1.8	5.9	38.	3.5
DC022952	17.22	337.5	25.	1.0	0.56	2.89	2.0	4.6	24.	2.5
DC022952	12.35	337.5	25.	1.0	0.29	2.37	2.0	4.6	24.	2.5
DA111551	13.29	337.5	25.	1.0	0.82	3.26	11.2	11.2	0.	4.5
DA111551	11.34	0.0	25.	1.0	0.56	2.68	2.7	11.2	22.	2.5
DA111651	9.37	22.5	25.	1.0	0.40	2.66	2.3	10.0	38.	3.5
DA022952	13.80	337.5	25.	1.0	1.07	3.21	11.2	11.2	0.	4.0
DA022952	11.37	337.5	25.	1.0	0.77	2.83	11.2	11.2	0.	3.5

(Continued)

(Continued)

ID	U (m/s)	dir (deg)	elev (ft)	temp cor	H (m)	T (s)	X (km)	F (km)	ϕ (deg)	dur (hr)
DA031852	10.85	292.5	25.	1.0	0.49	2.20	2.6	9.5	38.	3.0
DA031852	13.50	292.5	25.	1.0	0.74	2.40	2.6	9.5	38.	5.5
DA041352	10.80	337.5	25.	1.0	0.46	2.61	11.2	11.2	0.	10.5
DA040452	13.62	337.5	25.	1.0	0.57	3.12	11.2	11.2	0.	6.0
DA040452	10.47	337.5	25.	1.0	0.52	2.86	11.2	11.2	0.	5.5
DA051052	11.61	0.0	25.	1.0	0.65	3.03	2.7	11.2	22.	5.0
DA051052	11.99	22.5	25.	1.0	0.61	2.92	2.3	10.0	38.	3.0
DA051052	9.98	0.0	25.	1.0	0.48	2.67	2.7	11.2	22.	3.0
DA112553	11.64	337.5	25.	1.0	0.70	2.79	11.2	11.2	0.	4.5
lo042215	12.59	133.0	13.	1.06	1.87	5.90	40.80	176.00	38.	11.0
lo042221	9.12	121.0	13.	1.04	2.00	6.57	49.00	182.33	27.	7.0
lo045505	7.62	357.0	13.	1.03	0.56	3.18	15.87	37.58	35.	3.0

APPENDIX B: SAMPLE RUN

NARFET

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *


          PROGRAM NARFET

THIS PROGRAM CALCULATES DEEPWATER WAVES FOR RESTRICTED FETCHES
BASED ON WIND SPEED, WIND DIRECTION, AND FETCH GEOMETRY


* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *




DO YOU WISH TO ENTER FETCH GEOMETRY (I)NTERACTIVELY
OR FROM A (F)ILE?
I


FETCH GEOMETRY IS DETERMINED BY INPUTTING RADIAL
LENGTHS MEASURED FROM THE POINT WHERE YOU WANT WAVE
INFORMATION TO THE LAND BOUNDARY OF THE WATER BODY

INPUT THE ANGLE INCREMENT BETWEEN RADIAL MEASUREMENTS (DEG)
6.



INPUT THE DIRECTION OF THE FIRST RADIAL WITH RESPECT TO
THE LOCATION OF INTEREST (IN DEGREES MEASURED CLOCKWISE
FROM NORTH)
126.


INPUT THE NUMBER OF RADIALS
23


INPUT UNITS OF RADIAL LENGTHS:  (K)ILOMETERS, (F)EET, (M)ILES, OR
(N)AUTICAL MILES
K


INPUT RADIAL LENGTH FOR 126.0 DEG
1.10


INPUT RADIAL LENGTH FOR 132.0 DEG
1.30

INPUT RADIAL LENGTH FOR 138.0 DEG
10.24
```

```
INPUT RADIAL LENGTH FOR 144.0 DEG
9.75

INPUT RADIAL LENGTH FOR 150.0 DEG
7.88

INPUT RADIAL LENGTH FOR 156.0 DEG
8.21

INPUT RADIAL LENGTH FOR 162.0 DEG
8.62

INPUT RADIAL LENGTH FOR 168.0 DEG
35.68

INPUT RADIAL LENGTH FOR 174.0 DEG
28.24

INPUT RADIAL LENGTH FOR 180.0 DEG
20.20

INPUT RADIAL LENGTH FOR 186.0 DEG
16.01

INPUT RADIAL LENGTH FOR 192.0 DEG
12.76

INPUT RADIAL LENGTH FOR 198.0 DEG
8.21

INPUT RADIAL LENGTH FOR 204.0 DEG
8.17

INPUT RADIAL LENGTH FOR 210.0 DEG
7.48

INPUT RADIAL LENGTH FOR 216.0 DEG
5.20

INPUT RADIAL LENGTH FOR 222.0 DEG
5.08
```

```
INPUT RADIAL LENGTH FOR 228.0 DEG
4.47


INPUT RADIAL LENGTH FOR 234.0 DEG
4.15


INPUT RADIAL LENGTH FOR 240.0 DEG
4.39


INPUT RADIAL LENGTH FOR 246.0 DEG
4.55


INPUT RADIAL LENGTH FOR 252.0 DEG
4.63


INPUT RADIAL LENGTH FOR 258.0 DEG
4.59


RECAP OF INPUT ANGLES AND RADIAL LENGTHS


ANGLE = 126.0  RADIAL LENGTH =     1.10
ANGLE = 132.0  RADIAL LENGTH =     1.30
ANGLE = 138.0  RADIAL LENGTH =    10.24
ANGLE = 144.0  RADIAL LENGTH =     9.75
ANGLE = 150.0  RADIAL LENGTH =     7.88
ANGLE = 156.0  RADIAL LENGTH =     8.21
ANGLE = 162.0  RADIAL LENGTH =     8.62
ANGLE = 168.0  RADIAL LENGTH =    35.68
ANGLE = 174.0  RADIAL LENGTH =    28.24
ANGLE = 180.0  RADIAL LENGTH =    20.20
ANGLE = 186.0  RADIAL LENGTH =    16.01
ANGLE = 192.0  RADIAL LENGTH =    12.76
ANGLE = 198.0  RADIAL LENGTH =     8.21
ANGLE = 204.0  RADIAL LENGTH =     8.17
ANGLE = 210.0  RADIAL LENGTH =     7.48
ANGLE = 216.0  RADIAL LENGTH =     5.20
ANGLE = 222.0  RADIAL LENGTH =     5.08
ANGLE = 228.0  RADIAL LENGTH =     4.47
ANGLE = 234.0  RADIAL LENGTH =     4.15
ANGLE = 240.0  RADIAL LENGTH =     4.39
ANGLE = 246.0  RADIAL LENGTH =     4.55
ANGLE = 252.0  RADIAL LENGTH =     4.63
ANGLE = 258.0  RADIAL LENGTH =     4.59

HOW MANY VALUES DO YOU WISH TO CHANGE?
(ENTER 0 FOR NONE)
0
```

```
DO YOU WISH TO SAVE FETCH GEOMETRY FOR
FUTURE RUNS? (Y OR N)
Y


ENTER FILE NAME (MAX OF 8 CHARACTERS) TO
SAVE FETCH GEOMETRY
PUGS.DAT


INPUT UNITS OF WIND MEASUREMENT ELEVATION:  (M)ETERS OR (F)EET
M


INPUT WIND MEASUREMENT ELEVATION
10.


IS THE OBSERVATION LOCATION OVER WATER (W) OR LAND (L)?
W


INPUT UNITS OF AIR-SEA TEMPERATURE DIFFERENCE:  DEGREES (C) OR (F)
C


INPUT UNITS OF WIND SPEED:  (M)ETERS/SEC, (F)EET/SEC, (K)NOTS,
OR MILES/HOUR (N)
M


INPUT AIR - SEA TEMPERATURE DIFFERENCE
-3.


INPUT WIND SPEED, WIND DIRECTION (DEG), AND DURATION (HR)
15.,200.,5.


INPUT CONDITIONS:
    ADJUSTED WIND SPEED (M/S) =  22.7   (  22.7 INPUT UNITS)
    WIND DIRECTION (DEG) = 200.0
    DURATION (HR) =   5.0
    AIR-SEA TEMP DIF (DEG C) =  -3.0


WAVE HEIGHT (M) =   1.6
WAVE HEIGHT (FT) =   5.3
WAVE PERIOD (S) =   4.7
WAVE DIRECTION (DEG) = 173.0
```

```
DURATION LIMIT (HR) =   2.9

FETCH LIMITED CONDITIONS


DO YOU WANT TO RUN ANOTHER WIND CONDITION?
Y


INPUT AIR - SEA TEMPERATURE DIFFERENCE
0.


INPUT WIND SPEED, WIND DIRECTION (DEG), AND DURATION (HR)
15.,175.,5.


INPUT CONDITIONS:
    ADJUSTED WIND SPEED (M/S) =  19.9    (  19.9 INPUT UNITS)
    WIND DIRECTION (DEG) = 175.0
    DURATION (HR) =   5.0
    AIR-SEA TEMP DIF (DEG C) =   0.0


SIGNIFICANT WAVE HEIGHT (M) =   1.6
SIGNIFICANT WAVE HEIGHT (FT) =   5.2
PEAK WAVE PERIOD (S) =   4.7
MEAN WAVE DIRECTION (DEG) = 172.0


DURATION LIMIT (HR) =   3.0

FETCH LIMITED CONDITIONS


DO YOU WANT TO RUN ANOTHER WIND CONDITION?
N


RUN COMPLETE
FORTRAN STOP
```

APPENDIX C: COMPUTER PROGRAM

```
      PROGRAM NARFET
C*******************PROGRAM NARFET*******************
C
C  PURPOSE:  TO PREDICT DEEPWATER SURFACE GRAVITY
C            WAVES FROM THE WIND ON RESTRICTED FETCHES
C
C  INPUT:    WS   WIND SPEED
C            WDIR WIND DIRECTION
C            DUR  DURATION
C            X    RADIAL FETCH DISTANCE
C            DANG ANGLE INCREMENT FOR FETCH MEASUREMENTS
C
C  OUTPUT:  H     WAVE HEIGHT
C           T     WAVE PERIOD
C           THETA WAVE DIRECTION
C
C
      DIMENSION X(361),ANG(361),XX(361)
      CHARACTER*1 IANS
      CHARACTER*8 OUTFIL
C
C     ZERO RADIAL LENGTH ARRAYS
C     X  -- INPUT ARRAY AT DANG INCREMENT
C     XX -- AVERAGED ARRAY AT 1 DEG INCREMENT
C
      G=9.81
      DO 10 I=1,361
      X(I)=0.0
      XX(I)=0.0
   10 CONTINUE
C
C     INTRODUCTION
C
      WRITE(*,20)
   20 FORMAT(1X,30('* '),//)
      WRITE(*,30)
   30 FORMAT(11X,'PROGRAM NARFET',//,
     *' THIS PROGRAM CALCULATES DEEPWATER WAVES FOR RESTRICTED FETCHES',
     */,' BASED ON WIND SPEED, WIND DIRECTION, AND FETCH GEOMETRY',//)
      WRITE(*,20)
      WRITE(*,35)
   35 FORMAT(//,' DO YOU WISH TO ENTER FETCH GEOMETRY (I)NTERACTIVELY',/,
     *' OR FROM A (F)ILE?')
      READ(*,100)IANS
      IF(IANS.EQ.'F')GO TO 155
C
C     START FETCH GEOMETRY INPUT
C     INPUT:  DANG - ANGLE INCREMENT
C             ANG1 - DIRECTION OF 1ST RADIAL INPUT
C             NANG - NUMBER OF INPUT RADIALS
C             FACX - UNITS OF RADIAL LENGTHS
C
      WRITE(*,40)
   40 FORMAT(//,' FETCH GEOMETRY IS DETERMINED BY INPUTING RADIAL',
```

```
     */,' LENGTHS MEASURED FROM THE POINT WHERE YOU WANT WAVE',
     */,' INFORMATION TO THE LAND BOUNDARY OF THE WATER BODY',/)
      WRITE(*,50)
   50 FORMAT(' INPUT THE ANGLE INCREMENT BETWEEN RADIAL MEASUREMENTS',
     *' (DEG)')
      READ(*,*)DANG
      WRITE(*,60)
   60 FORMAT(//,
     */,' INPUT THE DIRECTION OF THE FIRST RADIAL WITH RESPECT TO',
     */,' THE LOCATION OF INTEREST (IN DEGREES MEASURED CLOCKWISE',
     */,' FROM NORTH)')
      READ(*,*)ANG1
      WRITE(*,70)
   70 FORMAT(//,' INPUT THE NUMBER OF RADIALS')
      READ(*,*)NANG
      WRITE(*,80)
   80 FORMAT(//,' INPUT UNITS OF RADIAL LENGTHS:  (K)ILOMETERS,',
     *' (F)EET, (M)ILES, OR',/,' (N)AUTICAL MILES')
      READ(*,100)IANS
      FACX=1000.
      IF(IANS.EQ.'F')FACX=0.3048
      IF(IANS.EQ.'M')FACX=1609.3
      IF(IANS.EQ.'N')FACX=1852.0
C
C     READ IN ARRAY X OF RADIAL LENGTHS
C
      DO 110 I=1,NANG
      ANG(I)=ANG1+(I-1)*DANG
      IF(ANG(I).GE.360.)ANG(I)=ANG(I)-360.
      WRITE(*,120)ANG(I)
  120 FORMAT(//,' INPUT RADIAL LENGTH FOR ',F5.1,' DEG')
      READ(*,*)X(I)
      X(I)=X(I)
  110 CONTINUE
      NTOT=INT(360/DANG)+1
      X(NTOT)=X(1)
      ANG(NTOT)=ANG(1)
C
C     PRINT RADIAL LENGTH FOR CHECK
C
  121 WRITE(*,122)
  122 FORMAT(//,1X,'RECAP OF INPUT ANGLES AND RADIAL LENGTHS',//)
      DO 123 I=1,NANG
      WRITE(*,124)ANG(I),X(I)
  124 FORMAT(1X,'ANGLE = ',F5.1,'  RADIAL LENGTH =',F9.2)
  123 CONTINUE
      WRITE(*,125)
  125 FORMAT(//,1X,'HOW MANY VALUES DO YOU WISH TO CHANGE?',
     */,1X,'(ENTER 0 FOR NONE)')
      READ(*,*)NCHANGE
      IF(NCHANGE.EQ.0)GO TO 129
      DO 126 I=1,NCHANGE
      WRITE(*,127)
  127 FORMAT(1X,'INPUT ANGLE AND NEW RADIAL LENGTH')
      READ(*,*)ANGNEW,XNEW
```

```
      IF(ANGNEW.LT.ANG1)ANGNEW=ANGNEW+360
      NN=INT((ANGNEW-ANG1+0.5)/DANG)+1
      X(NN)=XNEW
 126  CONTINUE
      GO TO 121
 129  CONTINUE
      DO 130 I=1,NANG
      X(I)=X(I)*FACX
 130  CONTINUE
C
C    CALCULATE AVERAGED ARRAY OF RADIAL LENGTHS
C    AT 1 DEG INCREMENT
C
      J=INT(ANG1+0.5)+1
      XX(J)=X(1)
      DO 135 I=2,NTOT
      K1=INT(ANG1+(I-1)*DANG+0.5)+1
      NK=K1-J-1
      K=K1
      IF(K.GT.360)K=K-360
      IF(J.GT.360)J=J-360
      XX(K)=X(I)
      XDIF=XX(K)-XX(J)
      DO 140 II=1,NK
      KK=J+II
      IF(KK.GT.360)KK=KK-360
      XX(KK)=XX(J)+FLOAT(II)/FLOAT(NK+1)*XDIF
 140  CONTINUE
      J=K1
 135  CONTINUE
C
C     CALCULATE 15 DEG AVERAGE OF FETCH IN ARRAY X
C
      DO 150 I=1,360
      SUMX=0.0
      DO 151 J=1,15
      K=I-8+J
      IF(K.LT.1)K=K+360
      IF(K.GT.360)K=K-360
      SUMX=SUMX+XX(K)
 151  CONTINUE
      X(I)=SUMX/15.
 150  CONTINUE
      WRITE(*,152)
 152  FORMAT(//,' DO YOU WISH TO SAVE FETCH GEOMETRY FOR ',/
     *' FUTURE RUNS? (Y OR N)')
      READ(*,100)IANS
      IF(IANS.EQ.'N')GO  TO 159
      WRITE(*,153)
 153  FORMAT(//,' ENTER FILE NAME (MAX OF 8 CHARACTERS) TO',/
     *' SAVE FETCH GEOMETRY')
      READ(*,154)OUTFIL
```

```
  154  FORMAT(A8)
       OPEN(9,FILE=OUTFIL,STATUS='NEW')
       WRITE(9,156)(X(I),I=1,360)
  156  FORMAT(10F10.2)
       GO TO 159
  155  CONTINUE
       WRITE(*,157)
  157  FORMAT(//,' ENTER FILE NAME (MAX OF 8 CHARACTERS) OF',/
      *' INPUT FETCH GEOMETRY')
       READ(*,154)OUTFIL
       OPEN(9,FILE=OUTFIL,STATUS='OLD')
       READ(9,156)(X(I),I=1,360)
  159  CONTINUE
C
C      INPUT WIND CONDITIONS:
C           EL - ELEVATION OF WIND MEASUREMENT
C           FACE - UNIT CONVERSION FOR ELEVATION
C           LOC - LOCATION OF MEASUREMENT 0-WATER 1-LAND
C           DELT - AIR-SEA TEMPERATURE DIFFERENCE
C           FACT - UNIT CONVERSION FOR DELT
C           WS - WIND SPEED
C           FACW - UNIT CONVERSION FOR WIND SPEED
C           WDIR - WIND DIRECTION (DEG FROM NORTH)
C           DUR - DURATION OF AVERAGE WIND (HOURS)
C
       WRITE(*,160)
  160  FORMAT(//,' INPUT UNITS OF WIND MEASUREMENT ELEVATION:  ',
      *'(M)ETERS OR (F)EET')
       READ(*,100)IANS
       FACE=1.00
       IF(IANS.EQ.'F')FACE=0.3048
       WRITE(*,170)
  170  FORMAT(//,' INPUT WIND MEASUREMENT ELEVATION')
       READ(*,*)EL
       EL=EL*FACE
C
C      CHECK IF ELEVATION IS > 20M OR < 0.5 M
C
       IF(EL.GT.20.0.OR.EL.LT.0.5)THEN
       WRITE(*,180)
  180  FORMAT(' **** INVALID ELEVATION ****')
       GO TO 200
       ENDIF
       WRITE(*,185)
  185  FORMAT(//,' IS THE OBSERVATION LOCATION OVER WATER (W) OR',
      *' LAND (L)?')
       READ(*,100)IANS
       LOC=0
       IF(IANS.EQ.'L')LOC=1
       WRITE(*,190)
  190  FORMAT(//,' INPUT UNITS OF AIR-SEA TEMPERATURE DIFFERENCE:',
      *'  DEGREES (C) OR (F)')
       READ(*,100)IANS
       FACT=1.0
       IF(IANS.EQ.'F')FACT=5./9.
```

```
      WRITE(*,240)
  240 FORMAT(//,' INPUT UNITS OF WIND SPEED:  (M)ETERS/SEC,',
     *' (F)EET/SEC, (K)NOTS,',/,' OR MILES/HOUR (N)')
      READ(*,100)IANS
      FACW=1.0
      IF(IANS.EQ.'F')FACW=0.3048
      IF(IANS.EQ.'K')FACW=0.51444
      IF(IANS.EQ.'N')FACW=0.44704
  250 CONTINUE
      WRITE(*,210)
  210 FORMAT(//' INPUT AIR - SEA TEMPERATURE DIFFERENCE')
      READ(*,*)DELT
      DELT=FACT*DELT
C
C     CHECK IF DELT IS REASONABLE -20.0< DELT < 20.0
C
      IF(DELT.GT.20.0.OR.DELT.LT.-20.0)THEN
      WRITE(*,220)
  220 FORMAT(/,' **** INVALID TEMPERATURE DIFFERENCE ****')
      GO TO 200
      ENDIF
      WRITE(*,260)
  260 FORMAT(//,' INPUT WIND SPEED, WIND DIRECTION (DEG), AND',
     *' DURATION (HR)')
      READ(*,*)WS,WDIR,DUR
      WS=WS*FACW
C
C     CHECK IF WIND DIRECTION AND WIND SPEED ARE REASONABLE
C
      IF(WDIR.GT.360.OR.WDIR.LT.0.0)THEN
      WRITE(*,270)
  270 FORMAT(/' *** INVALID WIND DIRECTION ****')
      GO TO 200
      ENDIF
      IF(WS.LE.50.0)GO TO 300
      WRITE(*,280)
  280 FORMAT(//,' *** EXCESSIVE WIND SPEED ***  RESULTS INVALID')
  200 CONTINUE
      WRITE(*,290)
  290 FORMAT(/,' DO YOU WISH TO REENTER WIND CONDITIONS?')
      READ(*,100)IANS
      IF(IANS.EQ.'Y')GO TO 250
      STOP
  300 DUR=DUR*3600.
C
C     INPUT COMPLETE
C
C     ADJUST WIND SPEED FOR ELEVATION, LOCATION, AND DELT
C
      R=(10./EL)**(1./7.)
      WS=WS*R
      ADELT=ABS(DELT)
      ATL=LOG(ADELT+0.0004)/LOG(10.0)
      RT=0.932293978-0.089853651*ATL-0.020579278*ATL*ATL
      IF(DELT.LT.0.0)RT=2.0-RT
```

```
      WS=RT*WS
      IF(LOC.EQ.1)WS=WS*(2.5*WS**(-0.265))
C
C     CORRECT WIND SPEED FOR NONCONSTANT COEFFICIENT OF DRAG
C
      WS=0.71*WS**1.23
C
C     DETERMINE WAVE DIRECTION FOR GIVEN WIND DIRECTION
C
      PRODMAX=0.0
      ICENT=INT(WDIR+0.5)+1
      DO 310 I=1,90
      K=ICENT+(I-1)
      KN=ICENT-(I-1)
      IF(KN.LT.1)KN=KN+360
      IF(K.GT.360)K=K-360
      IF(X(K).LT.X(KN))K=KN
      FTRY=X(K)
      PHITRY=FLOAT(I-1)
      THTRY=FLOAT(K-1)
      PRODTRY=FTRY**0.28*(COSD(PHITRY))**0.44
      IF(PRODTRY.GT.PRODMAX)THEN
      PRODMAX=PRODTRY
      F=FTRY
      PHI=PHITRY
      THETA=THTRY
      ENDIF
  310 CONTINUE
C
C     CALCULATE AND CHECK FOR DURATION LIMIT
C     AND FULL DEVELOPMENT
C
      ITYPE=1
      TMIN=51.09*F**(0.72)/(G**0.28*(WS*COSD(PHI))**0.44)
      IF(TMIN.LT.DUR)THEN
C
C      CALCULATE H AND T - NOT DURATION LIMITED
C
      H=0.0015*WS*COSD(PHI)*SQRT(F/G)
      FM=2.7*G**(0.72)/(F**0.28*(WS*COSD(PHI))**0.44)
      T=1/FM
C
C     CHECK FOR FULL DEVELOPMENT
C
      TFULL=8.134*(WS*COSD(PHI)/G)
      IF(T.GT.TFULL)CALL FULL(X,WDIR,G,DUR,PHI,THETA,T,H,ITYPE)
      ELSE
C
C     DURATION LIMITED
C
      CALL DURA(X,WS.WDIR,G,DUR,PHI,THETA,T,H,ITYPE)
      ENDIF
      DUR=DUR/3600.
      WSU=WS/FACW
      WRITE(*,420)WS,WSU,WDIR,DUR,DELT
```

```
 420  FORMAT(//,1X,'INPUT CONDITIONS:',/,
     *5X,'ADJUSTED WIND SPEED (M/S) =',F6.1,'   (',F6.1,' INPUT UNITS)',/,
     *5X,'WIND DIRECTION (DEG) =',F6.1,/,
     *5X,'DURATION (HR) =',F6.1,/,
     *5X,'AIR-SEA TEMP DIF (DEG C) =',F6.1)
      HFEET=H*3.28
      WRITE(*,430)H,HFEET,T,THETA
 430  FORMAT(//' SIGNIFICANT WAVE HEIGHT (M) = ',F5.1,/,
     *' SIGNIFICANT WAVE HEIGHT (FT) = ',F5.1,/,
     *' PEAK WAVE PERIOD (S) = ',F5.1,
     */,' MEAN WAVE DIRECTION (DEG) = ',F5.1)
      TMIN=TMIN/3600.
      WRITE(*,431)TMIN
 431  FORMAT(//,1X,'DURATION LIMIT (HR) = ',F5.1)
      IF(ITYPE.EQ.1)WRITE(*,435)
      IF(ITYPE.EQ.2)WRITE(*,436)
      IF(ITYPE.EQ.3)WRITE(*,437)
 435  FORMAT(/,' FETCH LIMITED CONDITIONS')
 436  FORMAT(/,' DURATION LIMITED CONDITIONS')
 437  FORMAT(/,' FULLY DEVELOPED CONDITIONS')
C
      WRITE(*,440)
 440  FORMAT(//,' DO YOU WANT TO RUN ANOTHER WIND CONDITION?')
      READ(*,100)IANS
 100  FORMAT(A1)
      IF(IANS.EQ.'Y')GO TO 250
      WRITE(*,450)
 450  FORMAT(//,' RUN COMPLETE')
      STOP
      END
C
C
C
      SUBROUTINE DURA(X,WS,WDIR,G,DUR,PHI,THETA,T,H,ITYPE)
C
C     SUBROUTINE TO DETERMINE MAX T FOR DURATION LIMITED
C     CONDITIONS AT OPTIMUM PHI, BUT FETCH LIMITED
C     CONDITIONS AT WDIR
C
      DIMENSION X(361)
C
C     DETERMINE T FOR SIMPLE FETCH
C
      ICENT=INT(WDIR+0.5)+1
      TMAX=0.0
C
C     LOOP THROUGH +/- 90 DEG UNTIL REACH DURATION-LIMITED
C     KEEP TRACK OF MAX FOR FETCH LIMITED (FOR DIRECTONS
C     NOT DURATION LIMITED) AND USE IF GREATER THAN
C     FIRST DURATION LIMITED CONDITION
C
      DO 10 I=1,90
      K=ICENT+(I-1)
      KN=ICENT-(I-1)
      IF(KN.LT.1)KN=KN+360
```

```
      IF(K.GT.360)K=K-360
      PHIK=FLOAT(I-1)
      IF(X(K).LT.X(KN))K=KN
C
C     CHECK IF DIRECTION K WITH PHIK IS DURATION LIMITED
C
      TMIN=47.12*X(K)**.72/(G**0.28*(WS*COSD(PHIK))**0.44)
      IF(TMIN.LE.DUR)GO TO 50
C
C     IT IS DURATION LIMITED, SO CALCULATE ASSOCIATED T
C
      TDUR=0.082*DUR**0.39*(WS*COSD(PHIK)/G)**0.61
C
C     CHECK IF FULLY DEVELOPED
C
      TFULL=8.134*(WS*COSD(PHIK)/G)
      IF(TDUR.GT.TFULL)THEN
      T=TFULL
      H=0.2433*(WS*COSD(PHIK))**2/G
      ITYPE=3
      ELSE
      T=TDUR
      H=0.000103*DUR**0.69*(WS*COSD(PHIK))**1.31/G**0.31
      ITYPE=2
      ENDIF
      IF(T.LE.TMAX)GO TO 20
C
C     T IS GREATER THAN PREVIOUS TMAX FROM FETCH LIMITED
C     CONDITIONS, SO RETURN
C
      PHI=PHIK
      THETA=FLOAT(K-1)
      RETURN
   20 CONTINUE
C
C     DURATION LIMITED, BUT PREVIOUS TMAX FROM FETCH
C     LIMITED CONDITIONS IS GREATER, SO USE PREVIOUS
C     TMAX AND CALCULATED ASSOCIATED H AND RETURN
C
      T=TMAX
      PHI=PHIMAX
      THETA=FLOAT(KMAX-1)
      H=HMAX
      ITYPE=ITYPEMAX
      RETURN
   50 CONTINUE
C
C     CONDITIONS STILL NOT DURATION LIMITED
C     CHECK IF T IS GREATER THAN TMAX AND CONTINUE
C
      T=X(K)**0.28*(WS*COSD(PHIK))**0.44/(2.7*G**0.72)
      H=0.0015*WS*COSD(PHIK)*SQRT(X(K)/G)
      ITYPE=1
C
C     CHECK IF FULLY DEVELOPED
```

```
C
      TFULL=8.134*(WS*COSD(PHIK)/G)
      IF(T.GT.TFULL)THEN
      T=TFULL
      H=0.2433*(WS*COSD(PHIK))**2/G
      ITYPE=3
      ENDIF
      IF(T.GT.TMAX)THEN
      TMAX=T
      HMAX=H
      PHIMAX=PHIK
      KMAX=K
      ITYPE=ITYPEMAX
      ENDIF
   10 CONTINUE
      WRITE(*,30)
   30 FORMAT(//,' ERROR, DURATION LIMITED CONDITIONS NOT FOUND')
      STOP
      END
C
C
C
      SUBROUTINE FULL(X,WS,WDIR,G,DUR,PHI,THETA,T,H,ITYPE)
C
C     SUBROUTINE TO DETERMINE MAX T FOR CASE OF FULLY DEVELOPED
C     CONDITIONS AT OPTIMUM PHI, BUT FETCH LIMITED
C     CONDITIONS AT WDIR
C
      DIMENSION X(361)
C
C     DETERMINE T FOR SIMPLE FETCH
C
      ICENT=INT(WDIR+0.5)+1
      TMAX=0.0
C
C     LOOP THROUGH +/- 90 DEG UNTIL REACH FULLY DEVELOPED
C     KEEP TRACK OF MAX FOR FETCH LIMITED (FOR DIRECTONS
C     NOT FULLY DEVELOPED) AND USE IF GREATER THAN
C     FIRST FULLY DEVELOPED CONDITION
C
      DO 10 I=1,90
      K=ICENT+(I-1)
      KN=ICENT-(I-1)
      IF(KN.LT.1)KN=KN+360
      IF(K.GT.360)K=K-360
      PHIK=FLOAT(I)
      IF(X(K).LT.X(KN))K=KN
C
C     CHECK IF DIRECTION K WITH PHIK IS FULLY DEVELOPED
C
      T=X(K)**0.28*(WS*COSD(PHI))**0.44/(2.7*G**0.72)
      TFULL=8.134*(WS*COSD(PHIK)/G)
      IF(TFULL.LT.T)THEN
C
C     IT IS FULLY DEVELOPED
```

```
C
      IF(TFULL.GT.TMAX)THEN
C
C     T IS GREATER THAN PREVIOUS TMAX FROM FETCH LIMITED
C     CONDITIONS, SO CALCULATE ASSOCIATION H AND RETURN
C
      PHI=PHIK
      T=TFULL
      H=0.2433*(WS*COSD(PHIK))**2/G
      THETA=FLOAT(K-1)
      ITYPE=3
      RETURN
      ELSE
C
C     FULLY DEVELOPED, BUT PREVIOUS TMAX FROM FETCH
C     LIMITED CONDITIONS IS GREATER, SO USE PREVIOUS
C     TMAX AND CALCULATE ASSOCIATED H AND RETURN
C
      T=TMAX
      PHI=PHIMAX
      THETA=FLOAT(KMAX-1)
      H=0.0015*WS*COSD(PHI)*SQRT(X(KMAX)/G)
      ITYPE=1
      RETURN
      ENDIF
      ELSE
C
C     CONDITIONS STILL NOT FULLY DEVELOPED
C     CHECK IF T IS GREATER THAN TMAX AND CONTINUE
C
      IF(T.GT.TMAX)THEN
      TMAX=T
      PHIMAX=PHIK
      KMAX=K
      ENDIF
      ENDIF
   10 CONTINUE
      WRITE(*,30)
   30 FORMAT(//,' ERROR, FULLY DEVELOPED CONDITIONS NOT FOUND')
      STOP
      END
C
      FUNCTION COSD(ANGLE)
      PI=4.*ATAN(1.0)
      COSD=COS(ANGLE*PI/180.)
      RETURN
      END
C
```

APPENDIX D: NOTATION

F	Straight-line fetch in the direction of the waves
F_{eff}	Effective fetch
f	Frequency
f_p	Peak frequency
$\bar{f}_p$	dimensionless peak frequency
g	Gravitational acceleration
H	Significant wave height
$\bar{H}$	Dimensionless significant wave height
r	Correlation coefficient
S_i	Component of energy spectrum
T	Peak wave period
U	Wind speed
U'	$U (\cos \phi)$
X	Fetch
X_i	Length of the straight-line fetch
$\bar{X}$	Dimensionless fetch in wave direction
y	Mean of the measured values
$\hat{y}$	Predicted value
$\bar{y}$	Measured value
θ_i	Angle from mean wind direction
$\Delta\theta$	Angle increment
ρ	Exponent in Walsh et al. expression
ϕ	Angle between the wind and wave direction