UNH SEA GRANT PROGRAMS

DEVELOPMENT OF A COMPUTER PROGRAM TO SIMULATE WIND WAVE GENERATION, REFRACTION, AND SHOALING IN THE GULF OF MAINE

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Report to the Office of National Sea Grant Programs

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DEVELOPMENT OF A COMPUTER PROGRAM TO SIMULATE WIND WAVE GENERATION, REFRACTION, AND SHOALING IN THE GULF OF MAINE

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Dr. Godfrey H. Savage,	Director, Engineering Design and Analysis Laboratory, University of New Hampshire and Principal Investigator on the project of which this work is a small part, who saw the need for sea state data in the Gulf of Maine and the role of the refraction program in obtaining such data; and
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INTRODUCTION

Offshore development is coming to New England. Whether it comes in the form of a near-shore nuclear power plant, an offshore tanker terminal and submarine pipeline, or an oil field on Georges Bank, there will be a vital need for quantitative information on expected sea conditions. In the relatively shallow waters of much of the Gulf of Maine, this information is highly dependent on location because of bottom effects on surface waves. These bottom effects, including refraction, shoaling, friction, and percolation, can cause dramatic differences in sea state in areas only a short distance apart. In addition to sea state, wave direction can also be critically important. Wave forces on a pipeline, for example, may be minimized by keeping the route orthogonal to the wavefronts of the expected maximum waves.[(1)]

Usually these data are obtained in one of two ways. If a proposed site is near a shipping lane, a Coast Guard station, or a weather ship, then records of the sea state in the area may already exist. If this fortunate coincidence does not occur, instrumentation—either bottom or buoy deployed—must be installed to record wave data. The minimum recording period is one year in order to determine seasonality of the sea conditions.

An alternate method, requiring neither a fortunate location nor a year of data recording for each individual site, would be to simulate surface wave propagation on a digital computer. With such a program, it might be possible to determine the characteristics of the deep water incident waves affecting a large section of the continental shelf by extrapolating the data obtained from one point in the area. These deep water values could then be used to predict the expected sea state anywhere within this section.

A number of computer programs have been developed to solve the equations governing surface wave refraction by numerical methods.[2] None of them, however, takes the effect of wind into account, although this combination has been suggested by St. Denis.[3] If these programs are to be applied to areas as large as the Gulf of Maine, with corresponding long propagation distances, the effect of wind must be considered since the surface waves being refracted are wind generated. This paper describes the modification of an existing refraction program to include the effect of wind and the application of that program to the Gulf of Maine.

Making Use of This Program

The selected refraction program plots the predicted wave paths, in addition to presenting them in numerical form. This feature makes the program valuable for teaching a coastal engineering class or for demonstrating coastal processes to the public domain in site selection hearings on offshore construction. Such graphic demonstration permits a much better conceptual understanding by the general public than is possible through numerical presentation of data. Judiciously used in conjunction with other decision-making tools, the graphic computer model should greatly improve mutual understanding between the technocrats and the public on coastal questions.

REFRACTION PROGRAM

The wave refraction program used here was written by R. S. Dobson in 1967, and modified in 1968 by B. Perry, R. L. Street, and T. R. Mogel, all of the Civil Engineering Department at Stanford University.(4) It has been used in California to aid in harbor location.(5) The program is based on linear small-amplitude progressive wave theory with its attendant assumptions:

1) Wave amplitude is assumed to be small compared to wave length. The error incurred by this assumption has been estimated as approximately 3% for $.002 \leq H/L \leq .03$.(6)
2) The wave profile is assumed to be an exact sinusoid.
3) Flow is assumed to be two-dimensional, inviscid, irrotational, incompressible, and of constant density.

The original program(4) considered the processes of refraction and shoaling of surface waves. Refraction, the bending of surface waves due to the dependence of wave speed on water depth, occurs when the wave crest is not parallel to the bottom contours. The portion of the wave in shoal water slows, while the remainder in deeper water maintains its speed. This results in the turning of the wave toward shallow water. Refraction theory requires some further assumptions:

4) The bottom contours are assumed to be smooth. However, the results of the graphical methods employed by the refraction program have been shown to correlate well with actual refraction patterns as determined from aerial photographs.(4)
5) It is assumed that no energy is transmitted along the wave crest.

6) The water surface is assumed to be a plane.

In addition to these theoretical assumptions, there were some additional assumptions explained in the original program implicit in the sense that certain processes were neglected:

7) Wave energy reflection is assumed to be negligible. (Approximately 10% of the wave energy is reflected for a slope of 11°.)[7]

8) Diffraction is assumed to be negligible.

9) Energy dissipation by bottom effects, i.e., percolation and friction, is assumed to be negligible.

10) The effect of wind on the waves during refraction is neglected.

Assumptions 6, 9, and 10 were valid for California coastal studies because of the narrow continental shelf in that area. Refraction, shoaling, and other bottom effects were important over a short distance only. When the program is to be used for a coastal area with a wide bottom-affected zone, the validity of these three assumptions becomes questionable. The planar surface assumption has been investigated. The bottom friction and percolation assumption is presently being examined. This paper offers a possible approach to removing the assumption that the wind effect is negligible.

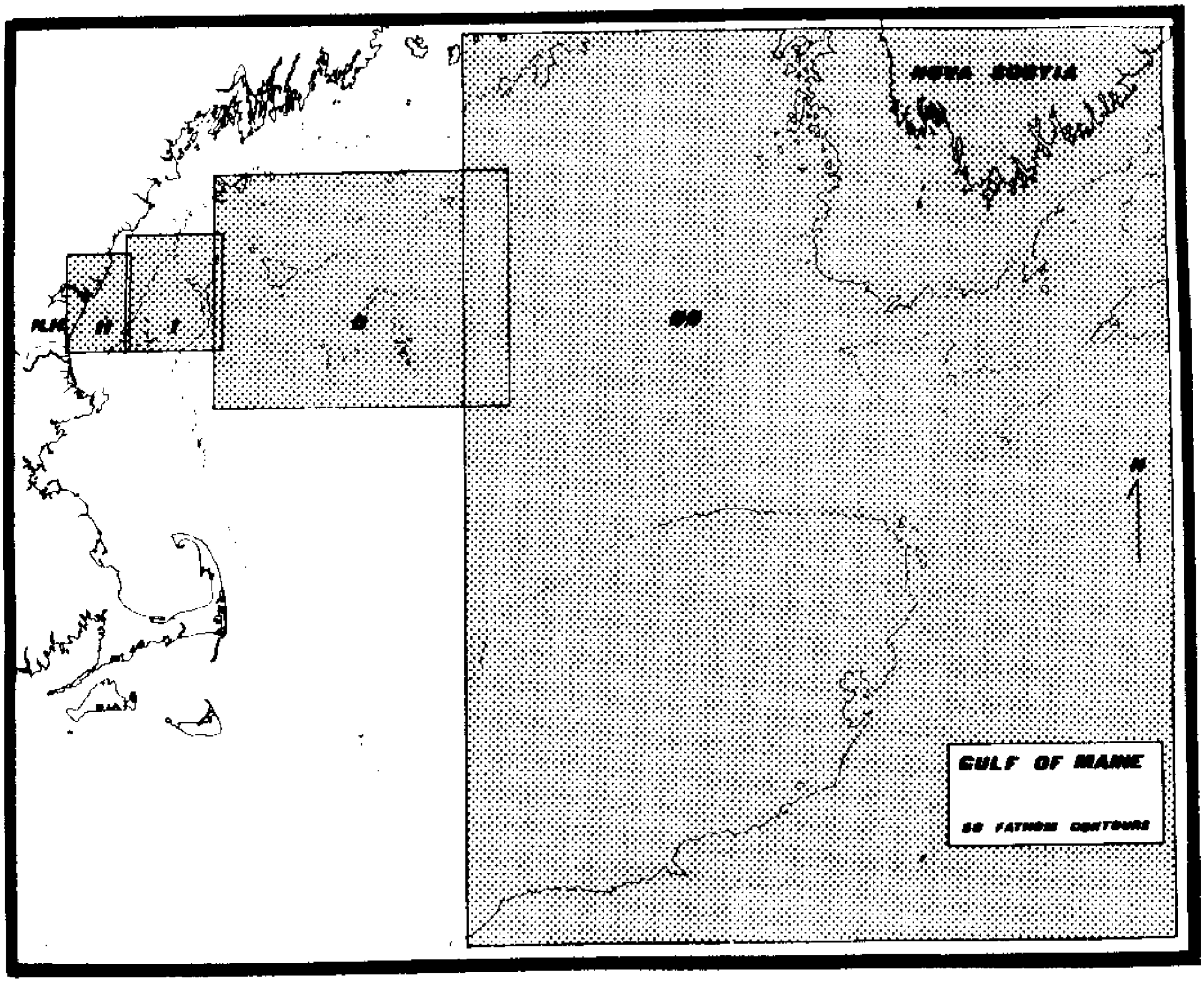
BATHYMETRY OF THE GULF OF MAINE

Before the wave refraction program could be applied to the coast of New Hampshire, it was necessary to obtain bathymetric data for the Gulf of Maine. National Ocean Survey plans to publish bathymetric charts of the entire Gulf of Maine. At present, two of the approximately ten charts planned have been completed. These two, 0808N-69 and 0808N-50, were valuable in obtaining more detailed depth data near shore, the area west of 70° longitude. U. S. Coast and Geodetic Survey Chart 71, Gulf of Maine and Georges Bank, was the source of all depth data for the area east of 70° longitude.

It was necessary to transform the depth data on the charts to a form more palatable to the computer. A piece of transparent material was placed over each chart, and a selected area on each was ruled off in a grid-like pattern, using the scale markings on the chart margins for spacing. The depth at each grid intersection was interpolated from the chart and written on a coding form. The information was then punched on cards, and finally stored on disc. The location of the four grids, and their size and grid spacing, is shown in Figure 1. Near shore, where it is more likely that wave data will be needed and where depth data is more complete, a finer mesh size was used. The mesh size increases from 1/4 mile to 5 miles, going from the westernmost grid, INNER INNER, to the easternmost, OUTER OUTER.

WIND WAVE GENERATION

The generation of wind waves, like many other natural processes, has been described and studied both theoretically and empirically. St. Denis has written a good brief review of wave generation theories,[8] while Kinsman describes them in some detail.[9] At present, however, for operational purposes the empirical methods are still preferred. These are described in several sources.[10] [11] There are two basically different approaches to the problem of relating wave characteristics to wind parameters empirically. These are the spectrum method of Pierson, Neumann, and James, and the significant wave method originated by Sverdrup and Munk and later modified by



Grid	Spacing (nautical miles)	Size (grid units)	Data Points
II: Inner Inner	1/4	101 x 65	6565
I: Inner	1/2	61 x 51	3111
O: Outer	1	61 x 101	6161
OO: Outer Outer	5	46 x 48	2208
		Total number of data points:	18,045

Figure 1 Refraction Grid Key

Bretschneider. The latter approach has been chosen for this project because it can be adapted to the refraction program, which treats one incident wave at a time in order to permit a graphical presentation of wave rays. This monochromatic approach can be used to do spectral analysis by treating each frequency component separately.[12] The path of one point on a wave crest is known as a wave ray. The pattern created by superimposing a number of wave rays has classically been used to pinpoint areas of wave energy concentration or diffusion.

Empirical relationships between wind speed, fetch length and wave height are available in both graphical and numerical form. The latter was selected as being more suitable for use in a computer logic. The equations selected for use in this study are those of B. Wilson[13] because a recently published comparison[14] of wave forecasts with actual wave observations concludes that Wilson's formulations are probably the most accurate.

MODIFICATION OF THE REFRACTION PROGRAM

The empirical equations added to the refraction program, the so-called Formulas IV[13] of Wilson, combine the important wind wave variables, wind speed, wave height, wave celerity, and fetch length, into dimensionless parameters. Two equations are used; one describes the wave speed parameter terms of wind speed and fetch:

$$\frac{c}{U} = 1.37 \{1 - [1 + 0.008(\frac{gF}{U^2})^{1/3}]^{-5}\} \qquad (1)$$

where H = significant wave height, ft

c = wave celerity, ft/sec

F = fetch length, ft

g = gravitational acceleration, ft/sec^2

U = wind speed, ft/sec

The other equation shows the dependence of wave height on wind speed and fetch:

$$\frac{gH}{U^2} = 0.30 \{1 - [1 + 0.004(\frac{gF}{U^2})^{1/2}]^{-2}\} \qquad (2)$$

The significant wave height is defined as the mean height of the highest one-third of the waves present at the point of interest in space and time. The significant period is the mean period of the highest third of the waves. The distance over which the wind is acting on the water is the fetch length. By substituting the expression $c = \frac{g}{2\pi} T$, Eq. (1) may also be written[15]

$$\frac{gT}{U} = 8.60 \{1 - [1 + 0.008(\frac{gF}{U^2})^{1/3}]^{-5}\} \qquad (3)$$

As a first approximation, a uniform wind velocity is assumed. In order to adjust the refraction program to incorporate the wind effects described by the empirical formulae of Wilson, the following logic has been employed:

1) An initial significant period, starting point, and wind velocity are chosen.
2) The initial fetch is computed using Eq. (3).
3) Using this fetch value, Eq. (2) is used to determine the initial significant wave height.
4) The location of the next point on the ray, and the depth at that location, are calculated. The ray is not propagated continuously, but in discrete increments.
5) If the depth is sufficient to preclude bottom effects, the ray step added in Step 4 above is added to the current fetch value.
   a. This fetch value is used in Eq. (2) and (3) to calculate a new significant wave height and period.

b. Return to Step 4 above.

6) If the depth is such that the wave is bottom affected, an equivalent deep water fetch length is calculated using Eq. (2) and the significant wave height calculated in the previous ray increment. This calculated fetch is called an "equivalent deep water fetch"(16) because after the initial bottom-affected increment, the height used to calculate it includes the bottom effects of shoaling and refraction.

7) To the equivalent deep-water fetch is added an increment equal to the product of time step and wave celerity.

8) Significant wave height and period are calculated using Eq. (2) and (3) and the fetch computed in Step 7 above.

9) Refraction and shoaling coefficients are calculated and applied to the significant wave height to obtain the bottom-affected wave height.

10) Return to Step 4 above.

Figure 2 is a simplified flow chart of the modified refraction program. The subroutines and their functions are listed in Appendix A. Appendix B is a listing of the modified program.

A typical series of computer plots generated by the refraction program before the inclusion of wind effects is shown in Figures 3-6. The rays, numbered 1-7 for identification purposes, were started in the area just south of Nova Scotia on the outer outer grid, Figure 3, with an initial propagation direction of due west.

The small rectangle on the upper left edge of the outer outer grid outlines the overlap, or match area, between this grid and the next grid

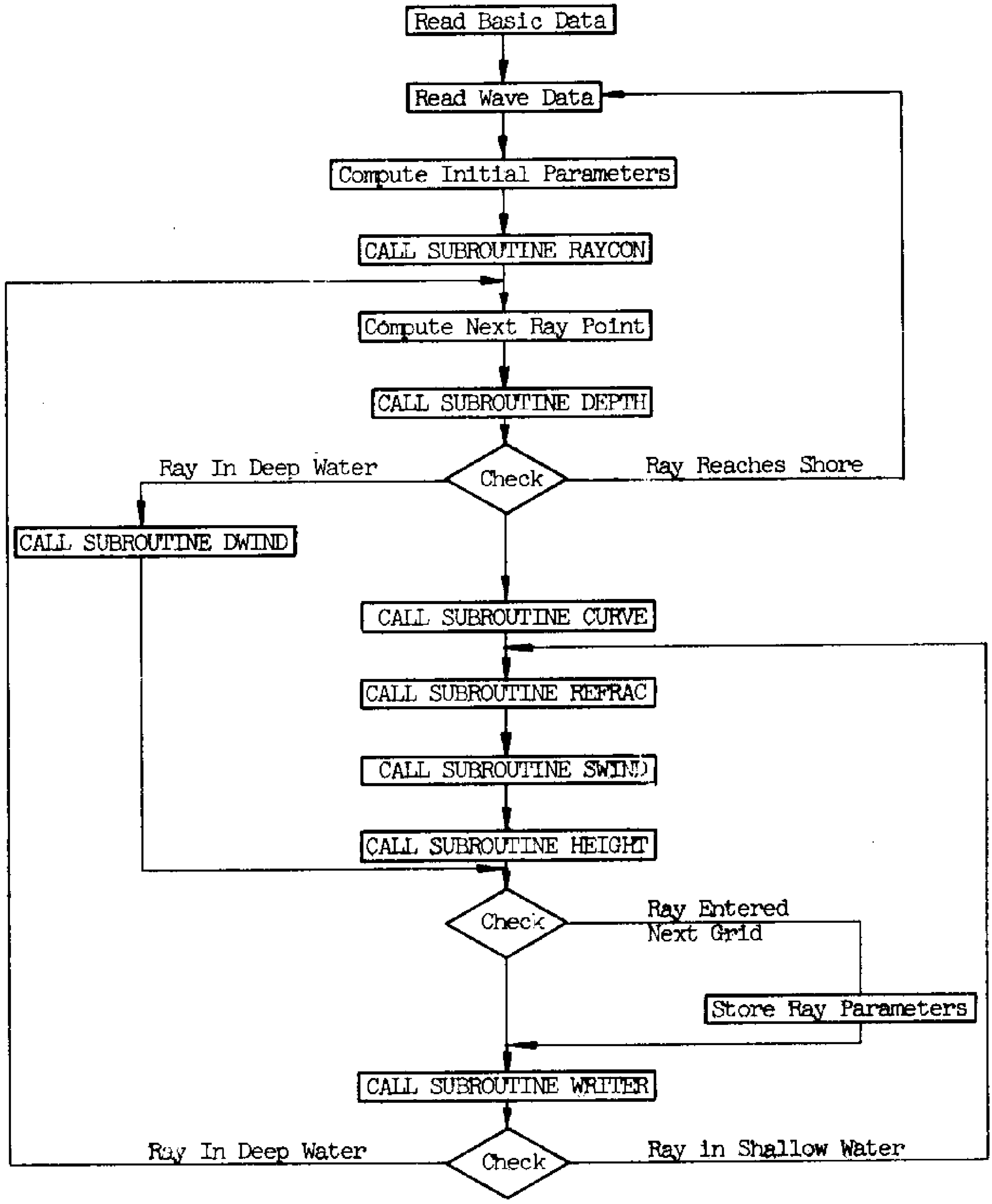


Figure 2 Simplified Flow Chart for Wave Refraction Program

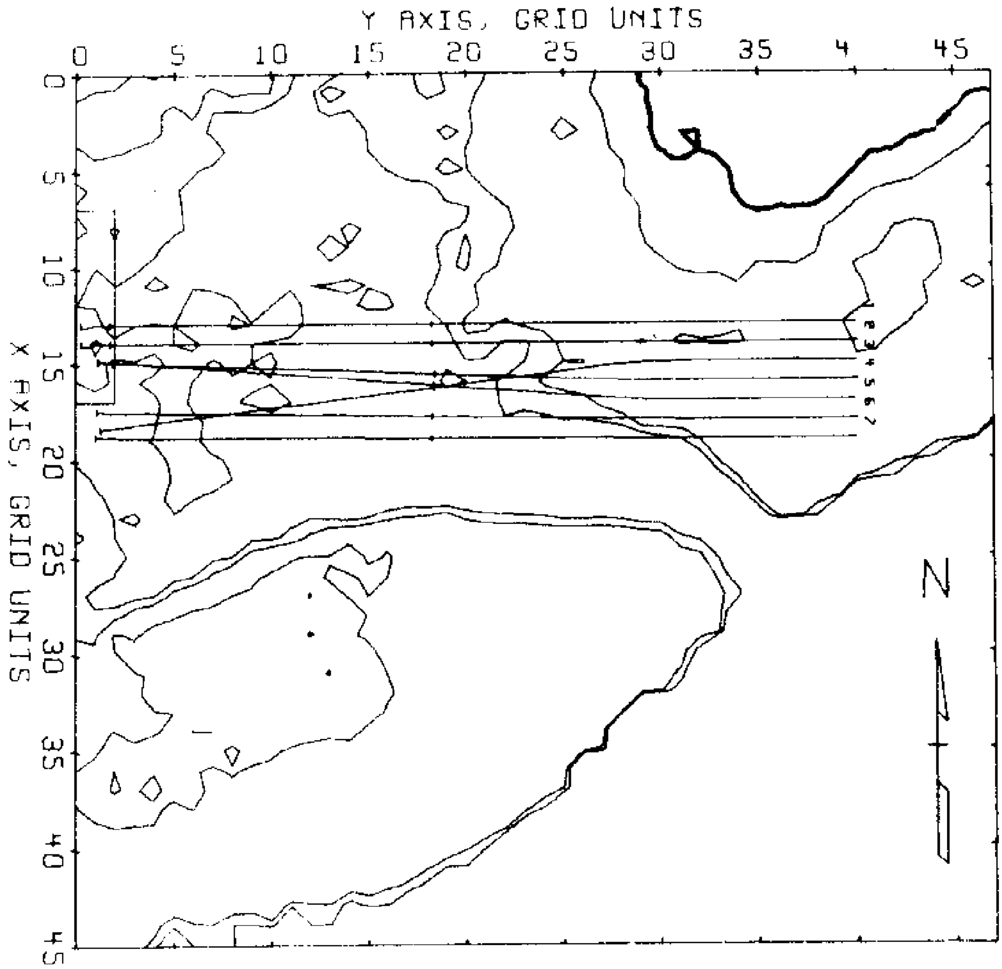
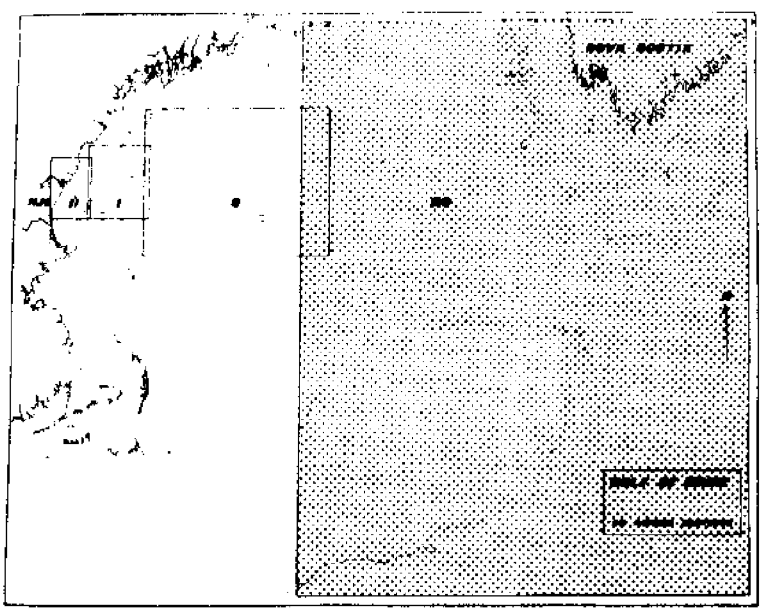


Figure 3 New Hampshire Coast

Outer Outer Grid

T=10 sec, U=0 knots



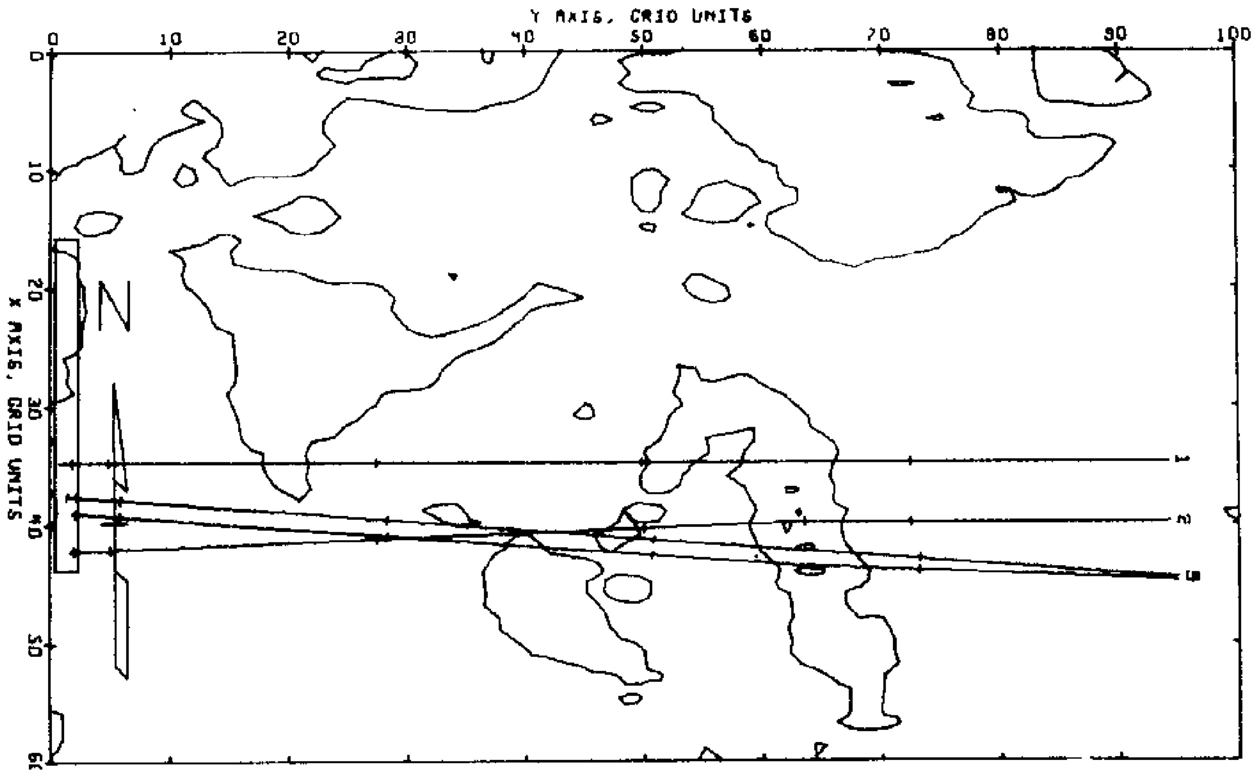
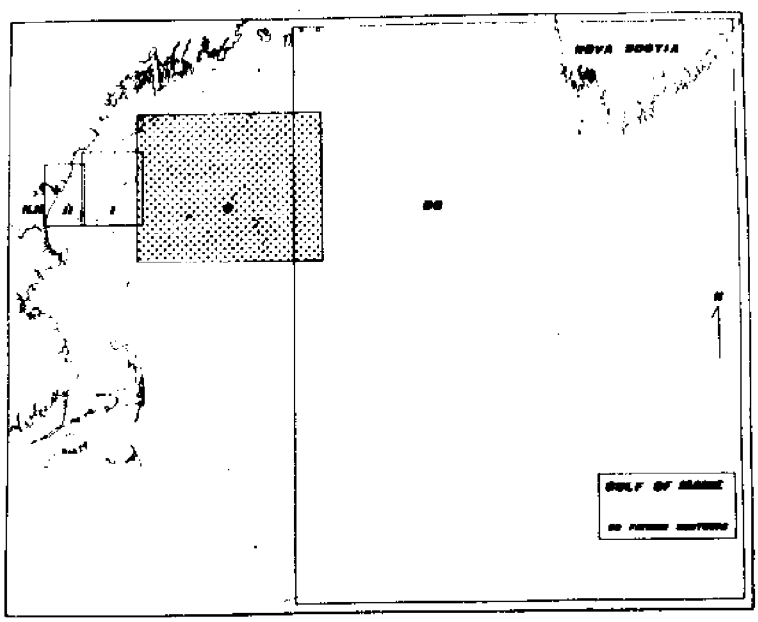


Figure 4 New Hampshire Coast

Outer Grid

T=10 sec, U=0 knots



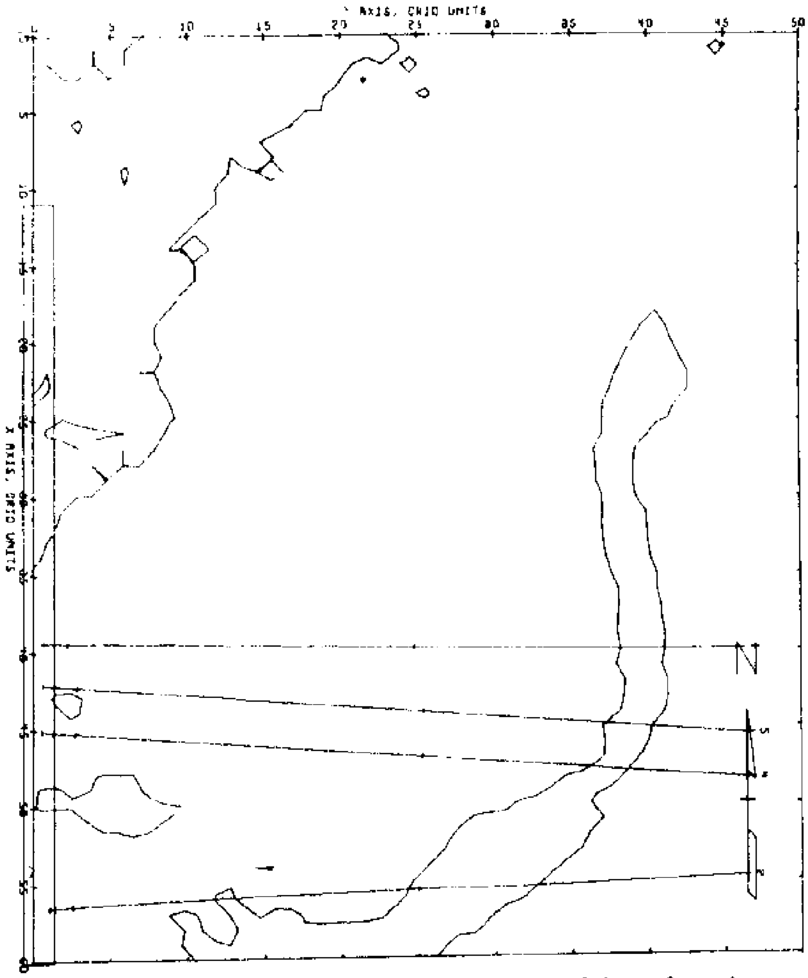
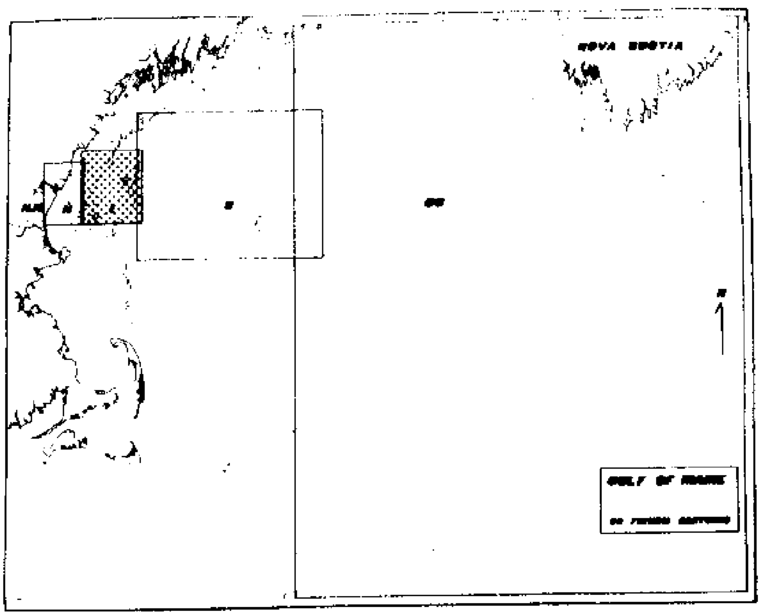


Figure 5 New Hampshire Coast

Inner Grid

T=10 sec, U=0 knots



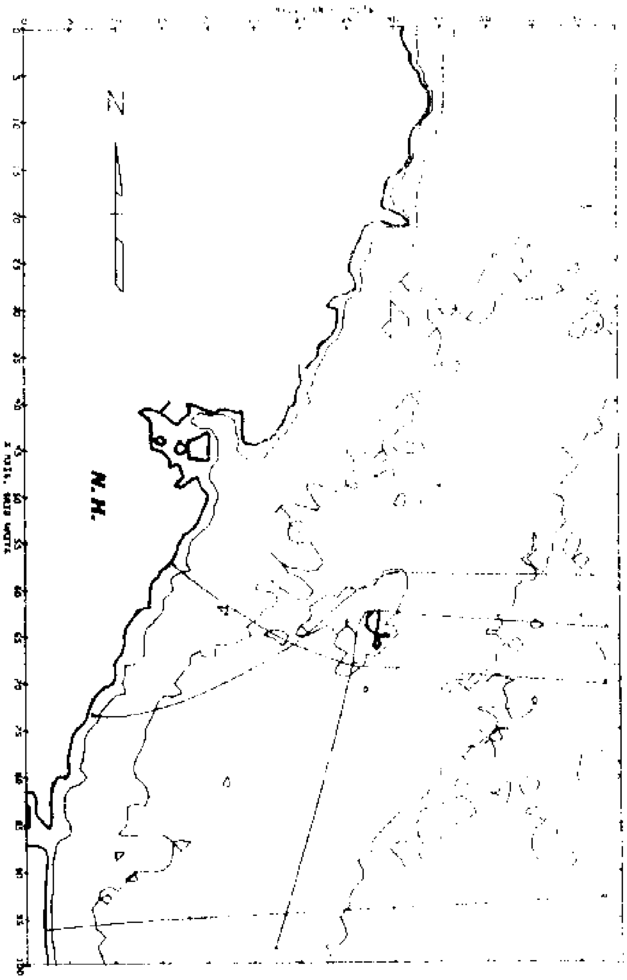
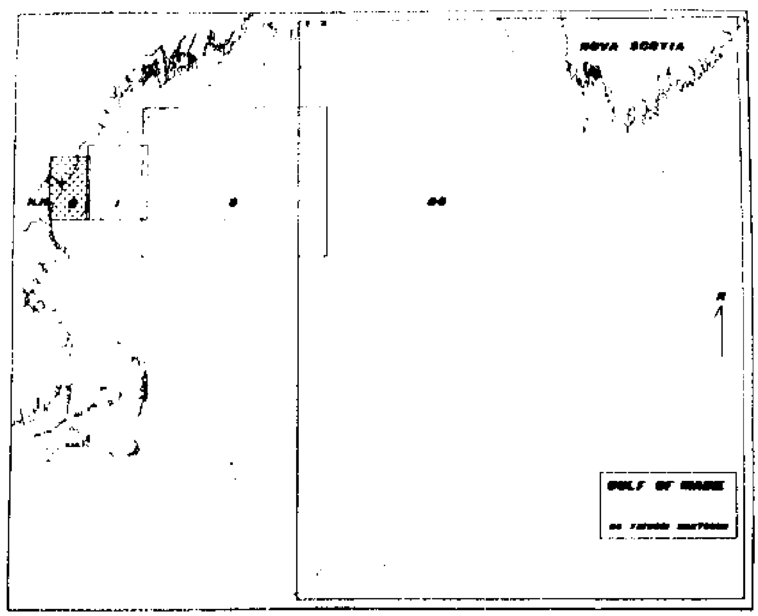


Figure 6 New Hampshire Coast

Inner Inner Grid

T=10 sec, U=0 knots



shoreward, the outer grid, Figure 4. Only the rays entering this match area in Figure 3 appear in the succeeding plot in Figure 4. Similarly, in Figure 4, only those rays entering the rectangular match area on the left edge of the grid will appear in the inner grid, Figure 5. And finally, of the rays in Figure 5, only those entering the match area on the left side of the plot are shown in Figure 6, and so are plotted from the easternmost grid to the westernmost.

The rays plotted in Figures 3-6 represent waves having a period of 10 seconds and, since wind is neglected, a windspeed of 0 knots. Figures 7-10 are plots generated by the modified program, having the same period, initial coordinates and initial direction as those in Figures 3-6, but with a 50 knot east wind. The numerical output for ray number 4 is given in Appendix C.

SUGGESTIONS FOR FURTHER WORK

To be complete, bottom friction and percolation should also be considered in the model since a significant portion of the Gulf of Maine is "shallow water," especially to longer period waves. Putnam and Johnson[17] state that the effective roughness, and therefore the damping effect on waves, is determined by the size of the ripples in the sand. Ripple size, in turn, is controlled by grain size, water depth, and wave height and period, so that bottom friction is not a static quantity. They estimate that wave height may be reduced by 30 percent by small slopes. Most of this reduction occurs in the final 20 percent of the shallow water travel of the wave. A typical friction factor of $f = .01$ is calculated for a four-foot, twelve-second wave moving in relatively shallow water over ripples having a pitch of five inches. This value has been used widely by C. Bretschneider,[18] although he used a different method to arrive at this value. Iwagaki and Kakinuma obtained a

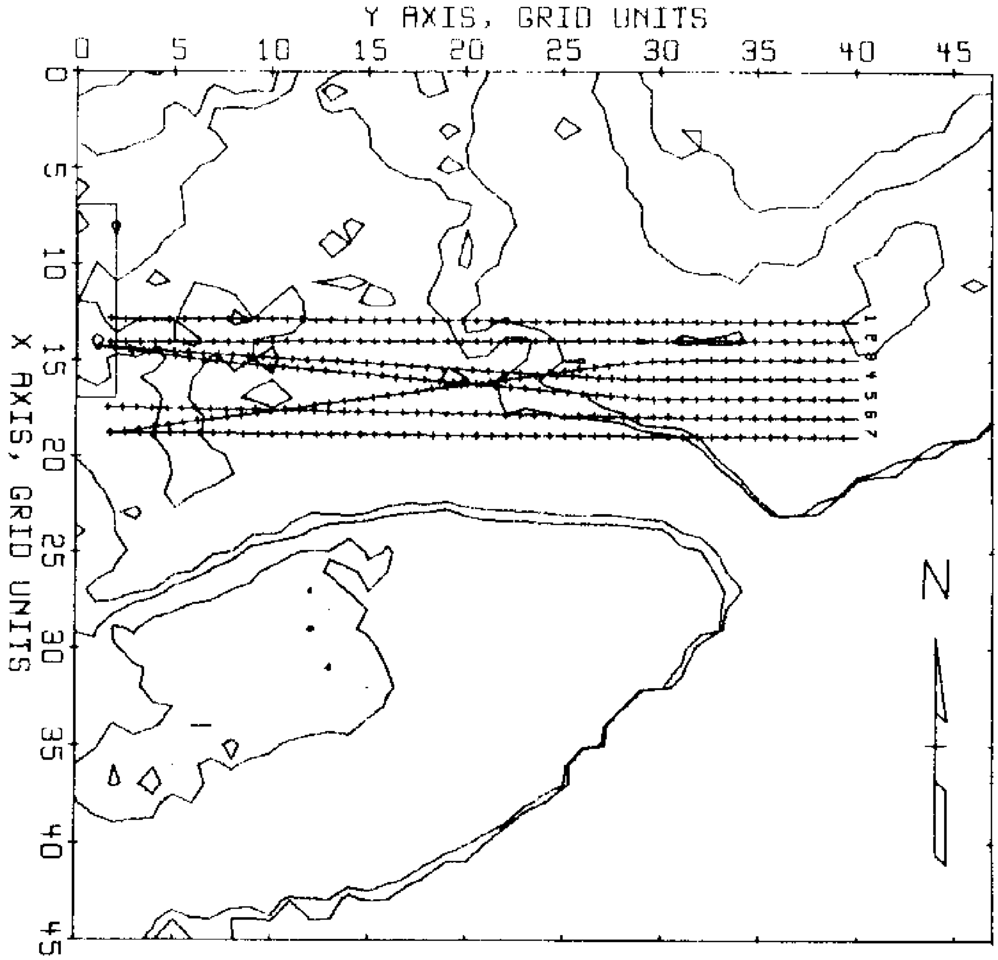
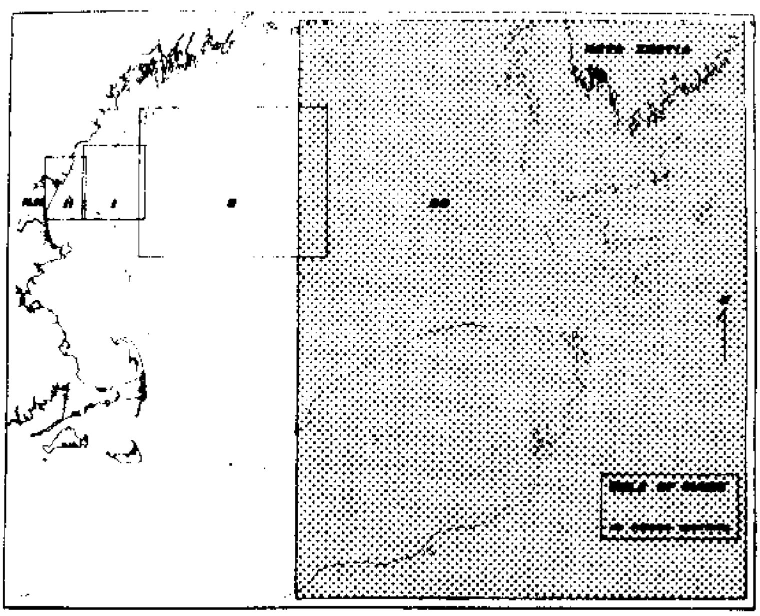


Figure 7 New Hampshire Coast

Outer Outer Grid

T=10 sec, U=50 knots



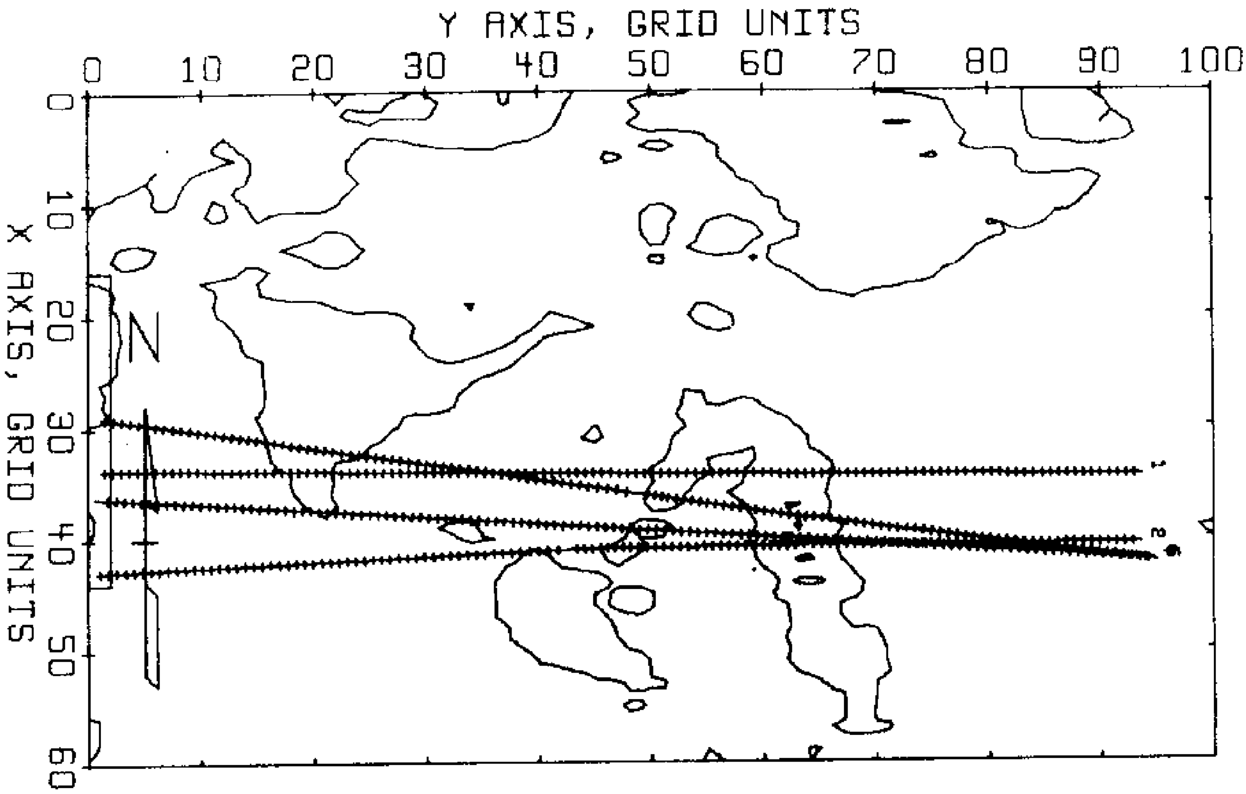
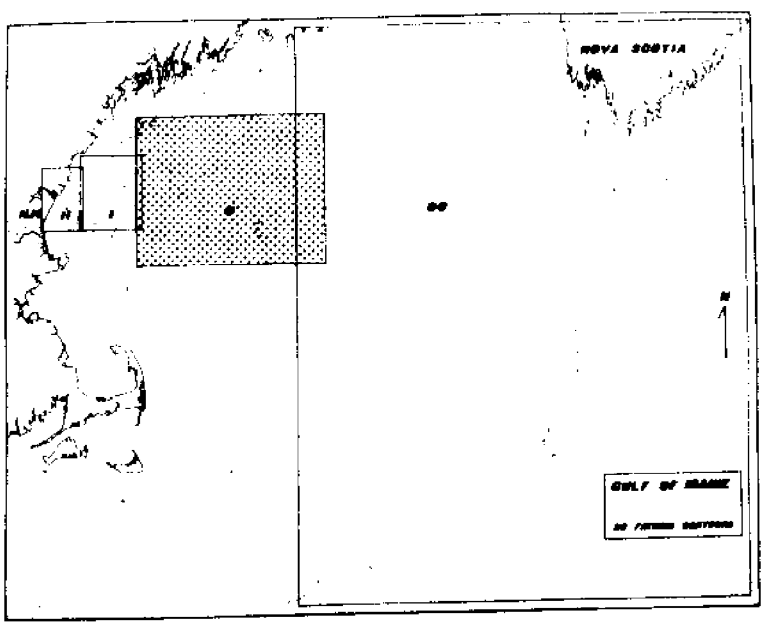


Figure 8 New Hampshire Coast

Outer Grid

T=10 sec, U=50 knots



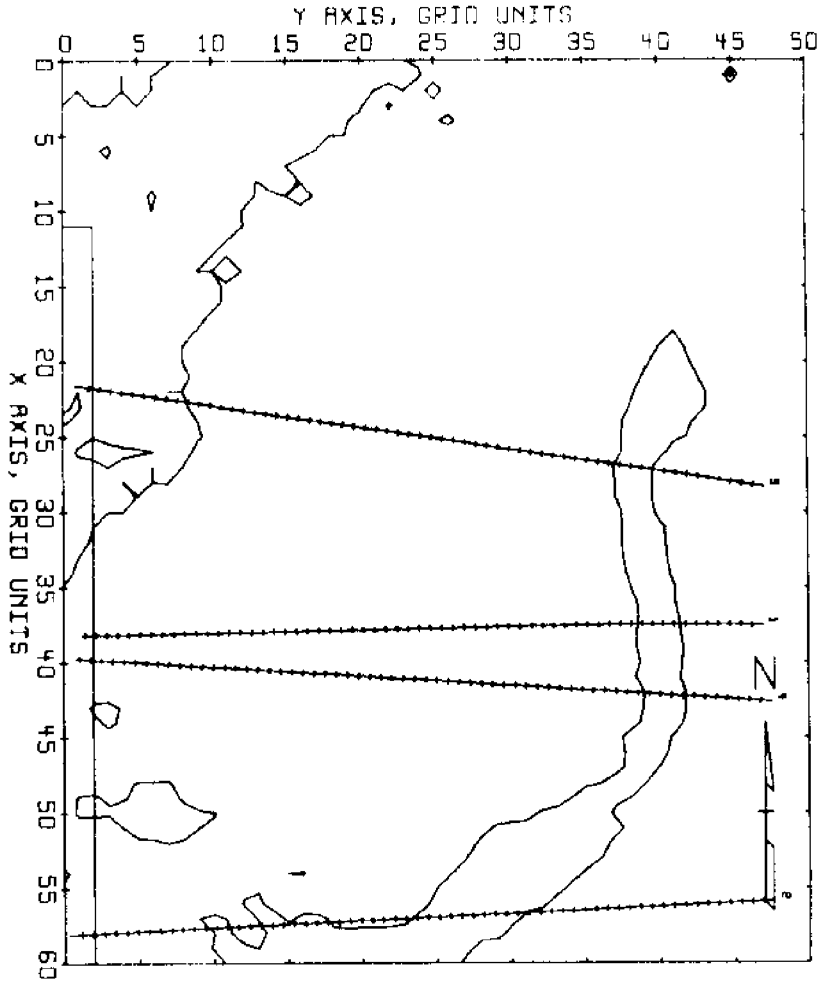
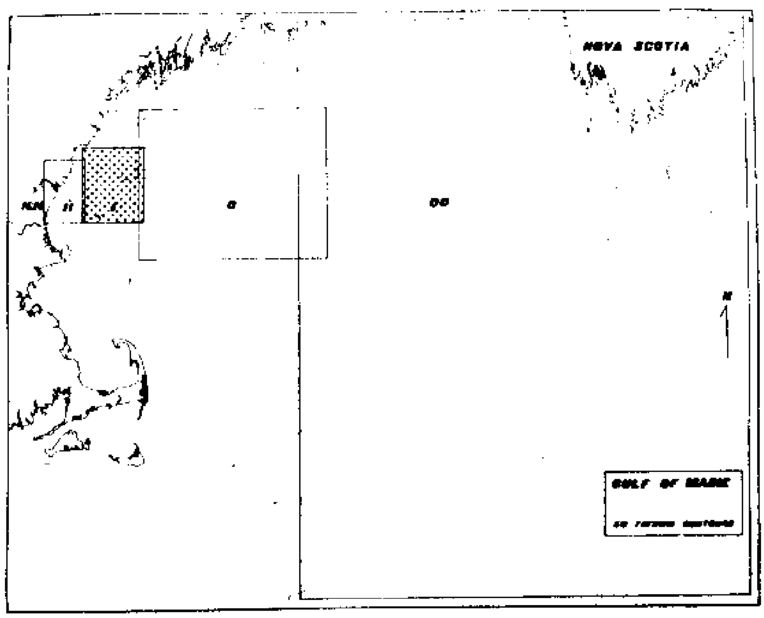


Figure 9 New Hampshire Coast

Inner Grid

T=10 sec, U=50 knots



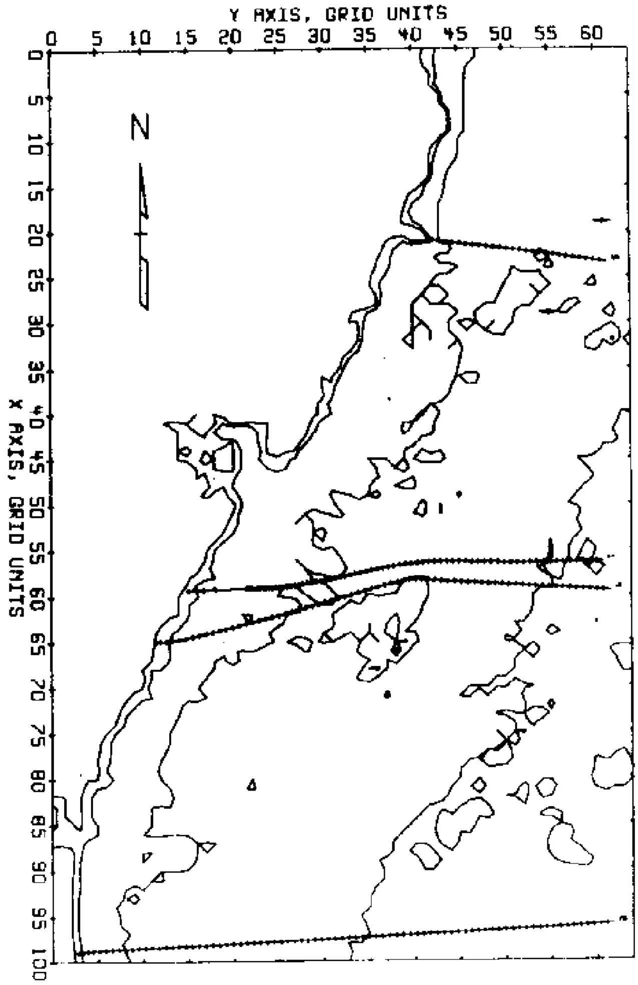
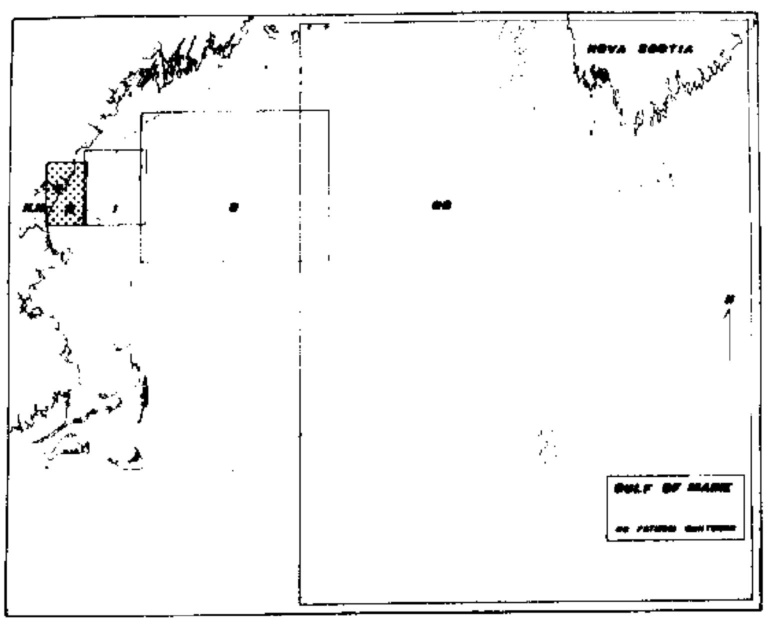


Figure 10 New Hampshire Coast

Inner Inner Grid

T=10 sec, U=50 knots



relationship between the bottom friction factor, calculated from wave observations, and the wave Reynolds number.[19]

According to Putnam,[20] energy loss by the movement of water in the permeable bottom--i.e., percolation--may amount to as much as ten percent for small slopes. Figure 4 of his paper compares the relative effects of these forms of energy dissipation on wave height.

Because water is not inviscid, wave decay occurs and should be considered. C. Bretschneider has devised a graphical method[21] for calculating wave decay in areas with no wind. A numerical method for wave decay in shallow water and appropriate computer logic has also been outlined.[22]

The assumption of a uniform wind velocity could also be improved. If the wind velocity were known as a function of space and time, matters would be simplified; but obtaining such perfect data is highly unlikely. If enough ships report barometric pressure readings so that isobars may be plotted, wind velocity could be approximated by the basic equations for gradient or geostrophic wind.[23] Equations describing the wind fields of typhoons[24] and hurricanes[25] are also available. Both Bretschneider and Wilson have attempted to compute waves generated by moving or stationary storms.[26] [27]

Another questionable assumption is that of a plane surface. As pointed out by Chao,[28] this assumption is valid for small areas, but not for areas of the size of the Gulf of Maine. He has transformed the equations governing wave refraction to account for the sphericity of the earth. These transformations should be incorporated into the refraction program.

Model studies have shown[29] that in areas of strong ray convergence, the refraction factors calculated indicate waves higher than those that actually occur. Diffraction, or energy movement parallel to the ray crest, causes this exaggeration and should therefore be included in the model.

References

1. S. W. Small, Large-Diameter Submarine Pipeline for Tanker Terminals, ASME Technical Paper 71-Unt - 1(1971), p. 6.

2. Y. Chao, Refraction of Ocean Surface Waves on the Continental Shelf, Contribution #124, Geophysical Sciences Lab., NYU, Dept. of Meteorology and Oceanography. Also 1972 OTC paper 1616, p. 1965.

3. M. St. Denis, "On Wind Generated Waves," Topics in Ocean Engineering, C. L. Bretschneider, ed., Gulf Publishing Co., Houston, Texas, (1969), p. 36.

4. R. S. Dobson, "Some Applications of a Digital Computer to Hydraulic Engineering Problems," Technical Report No. 80 (June 1967), Stanford University, Dept. of Civil Engineering.

5. T. R. Mogel, Stanford University, Dept. of Civil Engineering. Personal Communication.

6. R. S. Dobson, "Some Applications of a Digital Computer to Hydraulic Engineering Problems," Technical Report No. 80 (June 1967), Stanford University, Dept. of Civil Engineering, p. 8.

7. Ibid., p. 9.

8. M. St. Denis, "On Wind Generated Waves," Topics in Ocean Engineering, C. L. Bretschneider, ed., Gulf Publishing Co., Houston, Texas (1969), pp. 21-29.

9. B. Kinsman, Wind Waves, Their Generation and Propagation on the Ocean Surface, Prentice-Hall, Englewood Cliffs, N. J. (1965).

10. A. T. Ippen, ed., Estuary and Coastline Hydrodynamics, McGraw-Hill Book Co., Inc., New York (1966), pp. 139-160.

11. U. S. Army Coastal Engineering Research Center, Shore Protection, Planning, and Design, Technical Report No. 4 (1966), pp. 17-63.

12. B. Kinsman, Wind Waves, Their Generation and Propagation on the Ocean Surface, Prentice-Hall, Englewood Cliffs, N. J. (1965), p. 412.

13. B. Wilson, "Numerical Prediction of Ocean Waves in the North Atlantic for December, 1959," Deutsche Hydrographische Zeitschrift (Jahrgang 18, 1965), Heft 3, p. 126.

References, Continued

14. P. Feldhausen and S. Chakrabarti, Discussion on "Wave Forecasting for West Coast of India," Journal of the Waterways, Harbors, and Coastal Engineering Division, Proceedings of the ASCE (Feb. 1972), Vol. 28, No. WWI, pp. 141-144.

15. M. St. Denis, "On Wind Generated Waves", Topics in Ocean Engineering, C. L. Bretschneider, ed., Gulf Publishing Co., Houston, Texas (1969), p. 31.

16. Ibid., p. 35.

17. J. Putnam and J. Johnson, "The Dissipation of Wave Energy by Bottom Friction," Transactions American Geophysical Union (February 1949), Vol. 30, Number 1, p. 67.

18. A. Ippen, ed., Estuary and Coastline Hydrodynamics, McGraw-Hill Book Co., New York (1966), p. 169.

19. Y. Iwagaki and T. Kakinuma, "On the Bottom Friction Factors Off Five Japanese Coasts," Coastal Engineering in Japan (1967), Vol. 10, p. 13.

20. J. Putnam, "Loss of Wave Energy Due to Percolation in a Permeable Sea Bottom," Transactions American Geophysical Union (June 1949), Vol. 30, No. 3, p. 349.

21. U. S. Army Coastal Engineering Research Center, Shore Protection, Planning and Design, Technical Report No. 4 (1966), pp. 29-31.

22. T. Ijima and F. Tang, "Numerical Calculations of Wind Waves in Shallow Water," Proceedings of 10th Coastal Engineering Conference, Tokyo, Japan, September, 1966, ASCE, Vol. I, pp. 38-49.

23. Taylor, G., Elementary Meteorology, Prentice-Hall, Inc., New Jersey (1965), pp. 125-133.

24. T. Ijima and F. Tang, "Numerical Calculation of Wind Waves in Shallow Water," Proceedings of 10th Coastal Engineering Conference, Tokyo, Japan, September, 1966, ASCE, Vol. I, pp. 43-44.

25. C. L. Bretschneider, "A Non-Dimensional Stationary Hurricane Wave Model," Fourth Annual Offshore Technology Conference, 1972, paper CTC 1517, Vol. I, p. 52.

26. Ibid., pp. 51-68.

References, Continued

27. B. Wilson, "Deep Water Wave Generation by Moving Wind Systems," Journal of the Waterways and Harbors Division, Proceedings of the ASCE (May 1961), WW2, pp. 113-141.

28. Y. Chao, "Refraction of Ocean Surface Waves on the Continental Shelf," Fourth Annual Offshore Technology Conference, 1972, paper #OTC 1616, Vol. I, pp. 965-976.

29. R. W. Whalin, "The Limit of Applicability of Linear Wave Refraction Theory in a Convergence Zone," Texas A&M Ph.D. Dissertation, 1971.

APPENDIX A

Subroutines of Wave Refraction Program

MAIN: Reads grid data and computes grid constants. Then reads wave ray starting cards.

SUBROUTINE FRAME: Draws and labels map on which wave rays are plotted.

SUBROUTINE RAYCON: Controls each ray as it progresses across the grid. Also causes ray data to be stored temporarily when ray enters next grid.

SUBROUTINE DEPTH: Calculates the water depth at each ray point by using values from surrounding grid intersections, and also determines if wave ray has left the grid boundaries.

SUBROUTINE CURVE: Calculates local wave speed and finds the curvature of the ray at the point.

SUBROUTINE REFRAC: Solves the refraction equations to find the next point on the wave ray.

SUBROUTINE HEIGHT: Calculates the shoaling coefficient and the refraction coefficient.

SUBROUTINE WRITER: Supplies printed output showing the progress of each ray.

SUBROUTINE ERROR: Estimates error in depth as computed by SUBROUTINE DEPTH (called by WRITER).

SUBROUTINE DWIND: Increments fetch and calculates new wave parameters. Also increments elapsed time of wave ray progress across grid.

SUBROUTINE SWIND: Computes equivalent deep water fetch and new wave parameters. Also increments elapsed time.

APPENDIX B

Listing of Modified Wave Refraction Program

```
C     ...   WAVES, MK.V-UNH  OS/360 FORTRAN H WITH OUTPUT PLOTS
C     ...   A PROGRAM TO CONSTRUCT REFRACTION DIAGRAMS AND COMPUTE WAVE
C           HEIGHTS FOR WAVES MOVING INTO SHOALING WATER.
C     ...   BY R.S. DOBSON.  MODIFIED BY B. PERRY ,R. L STREET,
C     ...   AND T. R. MOGEL
C           DEPARTMENT OF CIVIL ENGINEERING,
C           STANFORD UNIVERSITY.  JULY 1968
C           MODIFIED BY D.E. THRALL,EDAL, UNIVERSITY OF NEW HAMPSHIRE
C           SEPTEMBER 1972
C     ...   ADAPTED FOR OS/360, OCTOBER 1967, BY R. L. STREET AND B. PERRY
C     ...   INPUT PARAMETERS.
C     ...   CONDITIONS FOR MARK IV,   MI .GE. MJ AND LIMNPT .LT. 1000.
C           B2      = RAY SEPARATION COEFICIENT
C           CONTP   = CONTOUR USED WHEN PUNCHING PUNCHC CARDS
C           DCON    = MULTIPLIER TO CONVERT DEPTH UNITS TO FEET. (F10.5).
C           DELTAS = MINIMUM STEP LENGTH ALONG RAY IN SHALLOW WATER. (F10.
C           DNORTH = ANGLE BETWEEN X AXIS AND NORTH(+=CCW) IN DEGREES
C           FACT    = RATIO OF COORDINATES...THIS PROG./NEXT PROG (F10.5)
C           GRID    = NUMBER OF GRID UNITS PER GRID DIVISION. (F10.5)
C           GRINC   = STEP LENGTH ALONG RAY IN DEEP WATER. (F10.5).
C           HC      = CHARACTER HEIGHT USED FOR ANNOTATION
C           HO      = INITIAL WAVE HEIGHT
C           IDNO    = RAY ID NUMBER
C           IGRCON = GRID UNIT IDENTIFER. 1 = FEET. 2 = MILES. 3 = METRES.
C           IS      = GRID IDENTIFIER(0=OUTER,1=INNER)
C           IUNITS = UNITS OF PUNCHED COORDINATED(0=OUTER,1=INNER)
C           LIMNPT = MAX. NUMBER OF RAY COMPUTATION POINTS. (I5).
C           LRAY    = END OF RAYSET IDENTIFIER(1=NO MORE RAYS)
C           MI      = MAX. VALUE FOR I SUBSCRIPT, NOT TO EXCEED 350. (I5).
C           MJ      = MAX. VALUE FOR J SUBSCRIPT, NOT TO EXCEED 350. (I5).
C           NBOX    = WHEN CARDS PUNCHED (1=WHEN ENTERING,0=WHEN LEAVING BO
C           NPLTTR = PLOTTER SIZE
C           NPRINT = FREQUENCY OF PRINTED OUTPUT FOR EACH RAY. (I5).
C           PLOTW   = PLOT WIDTH
C           PUNCHB = CARD PUNCHED AT BREAKING HEIGHT (F,NO;T,YES)
C           PUNCHN = DATA PASSED TO NEXT GRID (F,NO;T,YES)
C           PUNCHC = CARDS PUNCHED CONTP FT. CONTOUR (F,NO;T,YES)
C           RK      = REFRACTION COEFICIENT
C           SK      = SHOALING COEFICIENT
C           T       = RAY PERIOD
C           UW      = WIND VELOCITY IN KNOTS
C           TITL1...TITL5,FIRST FIVE LINES IN PLOT ID BLOCK
C           X1,X2,Y1,Y2=COORDINATES DEFINING AREA FOR CARD OUTPUT (F10.5)
C           X,Y,A   = RAY STARTING PARAMETERS(COOTDINATES AND ANGLE)
C           XCONST = DISPLACEMENT OF Y AXIS NEXT PROG UNITS (F10.5)
C           XARRO,YARRO    COORDINATES OF CENTER OF NORTH ARROW
C           YCONST = DISPLACEMENT OF X AXIS NEXT PROG UNITS (F10.5)
C
C
C     THE FOLLOWING INPUTS ARE FOR PLOTTING A REGION OF THE PROGRAM GRID:
C           XPMIN = X COR. OF LH EDGE OF REGION
C           XPMAX = X COR. OF RH EDGE OF REGION
C           YPNIM = Y COR. OF BOTTOM OF REGION
C           YPMAX = Y COR. OF TOP OF REGION
C           XARRO = X COR. OF PLOTTED ARROW
C           YARRO = Y COR. OF PLOTTED ARROW (IF COR. OF ARROW ARE OFF
C                          PLOTTED REGION, NO ARROW IS PLOTTED)
      COMMON D(12),E(6),WAR,B1,B2,CO,CXY,DCDH,DCON,DELTAS,DRC,DTGR,DXY,E
     .T,F,GRINC,HO,IGO,JGO,LIMNPT,NPRINT,NPT,PHX,PHY,RCCO,RK,MI,MJ,SIG,
     .SK,T,UW,UF,V,WL,WLO,WAD,GRID,DEP(36960)
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      COMMON /COPT/BOX,FACT,IUNITS,PDX,  TITLE(20),X1,X2,XCONST,Y1,Y2,
     .YCONST,IS,          PUNCHN,PUNCHB,PUNCHC,PLAT,IDNO,CONTP,HCID,
     .XPMAX,XPMIN,YPMAX,YPMIN
      REAL*8 UDATE
      COMMON/DATE/UDATE
      LOGICAL BOX,PUNCHN,PUNCHB,PUNCHC,PLAT,REFIND
C     ...   FOLLOWING DATA FORMAT TRUNCATED TO FOUR LETTER WORDS.
      DATA IFEET,IMILES,IMETRE/4HFEET,4HMILE,4HMETR/
   50 FORMAT(5L1,2I5,2F10.5)
   51 FORMAT(7F10.5,2I1)
   52 FORMAT(6F10.5)
   56 FORMAT(I5)
   57 FORMAT( 8A4,6F6.2)
   58 FORMAT(I1,2F6.2,F7.2,6F6.2,F7.2,4X,I5)
   59 FORMAT(6F7.2)
   60 FORMAT(1H1,9X,' STANFORD WAVE REFRACTION PROGRAM  MK V',/1H0,9X,
     .' DEVELOPED AT CIVIL ENGINEERING DEPARTMENT, STANFORD UNIVERSITY',
     ./'0',9X,' UNIVERSITY OF NEW HAMPSHIRE VERSION'////)
   71 FORMAT('1',105X,'DATE  ',A8)
   61 FORMAT(1H+,20A4/8H SET NO.,I3,10H, PERIOD =,F7.2,7H SECS.,,8H RAY
     .NO.,I5,21H, INITIAL TIME STEP =,F8.1,7H MIN. ,17H  WIND VELOCITY =
     .,F4.1,6H KNOTS//1H ,3X,5HPOINT,5X,1HX,8X,1HY,6X,5HANGLE,5X,5HDEPTH
     .,4X,7HMAX DIF,3X,6HPERIOD,3X,6HLENGTH,4X,5HSPEED,5X,6HHEIGHT,5X,2H
     .KR,8X,2HKS,8X,5HFETCH,
     .  / 130H              (GU)       (GU)      (DEG)        (FT)    (PERCENT)
     .  (SEC)      (FT)       (FPS)        (FT)          (DIMENSIONLESS)     (NM)
     .                   //1H ,I7,3F9.2,F11.2,10X,F8.2,3F10.2,20X,F10.4)
   62 FORMAT(39H0 ALL SETS COMPLETED,  NUMBER OF SETS =,I4)
   63 FORMAT(1H0,9X,  19HPROGRAM PARAMETERS.//25H  GRID LIMITS, ABSCISSA
     . =,I4,12H, ORDINATE =,I4,1H./27H  PRINTED OUTPUT INTERVAL =,I4,8H
     .POINTS./19H  GRID SIZE, UNIT =,F9.4,1X,A4,1H./31H  DEEP WATER INCR
     .EMENTAL STEP =,F7.3,12H GRID UNITS./49H  DEPTH CONVERSION, DEP(I,J
     .) TO FEET, MULTIPLY BY,F6.3)
   64 FORMAT(1H0,59HPROGRAM STOPPED, MI*MJ GREATER THAN 36960 NOT ALLOWE
     .D, MI =,I4,7H,  MJ =,I4)
   66 FORMAT('0 DATA IS PASSED WHEN RAYS ENTER'/
     .'  THE BOX DEFINED BY THE FOLLOWING POINTS:'/10X,2HX=,F7.2,
     . 5H,  Y=,F7.2  /10X,2HX=,F7.2,5H,  Y=,F7.2/10X,2HX=,F7.2,5H,  Y=,F
     .7.2/10X,2HX=,F7.2, 5H,  Y=,F7.2  /36H  GRID CONVERSION FOR PUNCHED
     . CARDS:/10X,8HXPUN=X*(,F7.2,3H)-(,F7.2,1H)/10X,8HYPUN=Y*(,F7.2,3H)
     .-(,F7.2,1H))
  666 FORMAT('0 DATA IS PASSED WHEN RAYS LEAVE'/
     .'  THE BOX DEFINED BY THE FOLLOWING POINTS:'/10X,2HX=,F7.2,
     . 5H,  Y=,F7.2  /10X,2HX=,F7.2,5H,  Y=,F7.2/10X,2HX=,F7.2,5H,  Y=,F
     .7.2/10X,2HX=,F7.2, 5H,  Y=,F7.2  /36H  GRID CONVERSION FOR PUNCHED
     . CARDS:/10X,8HXPUN=X*(,F7.2,3H)-(,F7.2,1H)/10X,8HYPUN=Y*(,F7.2,3H)
     .-(,F7.2,1H))
   67 FORMAT('1NO RAYS FOR THIS SET' /' SET NUMBER',I4)
   68 FORMAT(' INPUT CARDS FOR NEXT PROGRAM        DATE',A9,
     .29X,'0',I1)
   69 FORMAT(' CARDS PUNCHED WHEN H/D>0.78         DATE',A9,
     .29X,'1',I1)
   70 FORMAT(' CARDS PUNCHED AT',F6.2,' FT.CONTOUR  DATE',A9,
     .29X,'2',I1)
   72 FORMAT(' RAY STARTED OFF GRID OR ON LAND')
   73 FORMAT('0 CARDS ARE PUNCHED WHEN THE LOCAL WAVE HEIGHT'/
     .     '  EXCEEDS 0.78*DEPTH FOR DEEP WATER WAVE HEIGHTS FROM'/
     .     '  2.0 FEET TO 24.0 FEET IN INCREMENTS OF 2.0 FEET')
   74 FORMAT('0 CARDS ARE PUNCHED WHEN THE WAVE RAY CROSSES THE',/
     .     F7.2,' FOOT BOTTOM CONTOUR')
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  75 FORMAT('0 PLOTTING TAPE IS GENERATED. PLOT WIDTH IS',F5.2,
     .     ' INCHES',/'  AND THE CHARACTER HEIGHT IS',F5.2,' INCHES ')
  76 FORMAT('0 THE PLOTTING AREA IS REDUCED TO:'/
     .     10X,'XNIM=',F7.2,'  XMAX=',F7.2/
     .     10X,'YMIN=',F7.2,'  YMAX=',F7.2/
     .     '  AND THE NORTH ARROW IS LOCATED AT:'/
     .     10X,'XARROW=',F7.2,' YARROW=',F7.2)
 157 FORMAT(8A4,46X,'0',I1)
 158 FORMAT('1',77X,'0',I1)
      INTEGER RCNT/0/
      WRITE(6,60)
C   ...   READ BASIC DATA
      READ(20)(TITLE(I),I=1,12),MI,MJ,IGRCON,GRID,DCON,XARRO,YARRO,
     .DNORTH,IS,((DEP(I+(J-1)*MI),I=1,MI),J=1,MJ)
      IF(MI*MJ.GT.36960)GO TO 10
      MII=MI-1
      MJJ=MJ-1
      READ(5,50)PUNCHN,PUNCHB,PUNCHC,PLAT,REFIND,LIMNPT,NPRINT,DELTAS,
     .GRINC
      IF(  PUNCHN )READ(5,51)X1,X2,Y1,Y2,FACT,XCONST,YCONST,IUNITS,NBOX
      PLOTW=1.0
      HC=0.1
      IF(PUNCHC)READ(5,52)CONTP
      IF(PLAT)READ(5,52)PLOTW,HC
      HCID=0.666667*HC
      BOX=.FALSE.
      IF(NBOX.EQ.1)BOX=.TRUE.
      UNIT = GRID
      GO TO (16,17,18), IGRCON
  16  IGRCON = IFEET
      GO TO 19
  17  GRID = GRID*6080.27
      IGRCON = IMILES
      GO TO 19
  18  GRID = GRID*3.281
      IGRCON = IMETRE
  19  CONTINUE
      XPMIN=0.0
      YPMIN=0.0
      XPMAX=MII
      YPMAX=MJJ
      IF(REFIND)READ(5,52)XPMIN,XPMAX,YPMIN,YPMAX,XARRO,YARRO
      PDX=(YPMAX-YPMIN)/PLOTW
      ARROWL=PLOTW/4.0
      SCAFAC=GRID/6080.27
C  INITALIZES FRAME ROUTINE
      IF(.NOT.PLAT)GO TO 20
      CALL FRAMEI(XPMAX,XPMIN,YPMAX,YPMIN,SCAFAC,PLOTW,HC)
  20  IF(PUNCHB)WRITE(6,69)UDATE,IS
      IF(PUNCHC)WRITE(6,70)CONTP,UDATE,IS
      C
C
      WRITE(6,63) MI,MJ,NPRINT,UNIT,IGRCON,GRINC,DCON
      IF(PUNCHN.AND.BOX)WRITE(6,66)X1,Y1,X1,Y2,X2,Y2,X2,Y1,
     .         FACT,XCONST,FACT,YCONST
      IF(PUNCHN.AND..NOT.BOX)WRITE(6,666)X1,Y1,X1,Y2,X2,Y2,X2,Y1,
     .         FACT,XCONST,FACT,YCONST
      IF(PUNCHB)WRITE(6,73)
      IF(PUNCHC)WRITE(6,74)CONTP
      IF(PLAT)WRITE(6,75)PLOTW,HC
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      IF(REFIND)WRITE(6,76)XPMIN,XPMAX,YPMIN,YPMAX,XARRO,YARRO
C   ...   READ WAVE DATA
      NOSET=0
      GO TO 500
  498 WRITE(6,67)NOSET
      GO TO 500
  499 IF(PUNCHN)WRITE(7,158)IUNITS
  500 LRAY=0
      READ(5,57,END=120)(TITLE(I),I=13,20)
      NOSET=NOSET+1
  200 READ(5,58,END=121)LRAY,X,Y,A,RK,SK,B2,T,HO,UW,WAD,IDNO
      IF(LRAY.NE.0)GO TO 498
"
      IF(.NOT.PLAT)GO TO 502
      CALL FRAME(TITLE,5,NOSET,30)
      CALL ARROW(XARRO,YARRO,DNORTH,ARROWL)
      IF(.NOT.PUNCHN)GO TO 502
      IF(XPMIN.NE.0.0)GO TO 502
      CALL PLOT(90,X1,Y1)
      CALL PLOT(90,X1,Y2)
      CALL PLOT(90,X2,Y2)
      CALL PLOT(90,X2,Y1)
      CALL PLOT(91,X1,Y1)
      GO TO 502
  501 READ(5,58,END=119)LRAY,X,Y,A,RK,SK,B2,T,HO,UW,WAD,IDNO
      IF(LRAY.NE.0) GO TO 499
  502 UF=1.699669*UW
      WHMAX=(.30*UF**2)/32.174
      ET=0
      WAR=0.0174532925*WAD
      F=60710*UF**2*((1/((1-3.74116*(T/UF))**.2)-1)**3)
      HO=(0.30/32.174)*UF**2*(1-(1+.004*((32.174*F/UF**2)**.5))**(-2))
      SIG=6.28318531/T
      CO = 5.1204062*T
      WLO = CO*T
      DRC = WLO*0.6
      DTGR = GRINC/CO
      UNIT = DTGR*GRID
      B1 = B2
      NPT = 1
      CXY = CO
      FN=F/6080.27
      WL = WLO
      CALL DEPTH(X,Y)
      WRITE(6,71)UDATE
      WRITE(6,61)TITLE,NOSET,T,IDNO,UNIT,UW,NPT,X,Y,A,DXY,T,WLO,CO,HO,FN
      IF(DXY.LE.0.)GO TO 600
      CALL RAYCON(X,Y,A,WHMAX)
      GO TO 501
  600 WRITE(6,72)
      GO TO 501
  121 RCNT=RCNT+1
      IF(RCNT.LT.2) GO TO 200
      GO TO 120
  119 IF(PUNCHN)WRITE(7,158)IUNITS
  120 CONTINUE
      WRITE(6,62) NOSET
      IF(PLAT)CALL FRAMEL
      RETURN
   10 WRITE(6,64)  MI,MJ
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```
      RETURN
      END
      SUBROUTINE RAYCON(X,Y,AD,WHMAX)
      COMMON D(12),E(6),WAR,B1,B2,CO,CXY,DCDH,DCON,DELTAS,DRC,DTGR,DXY,E
     .T,F,GRINC,HO,IGO,JGO,LIMNPT,NPRINT,NPT,PHX,PHY,RCCO,RK,MI,MJ,SIG,
     .SK,T,UW,UF,V,WL,WLO,WAD,GRID,DEP(36960)
      COMMON/COMA/XP,YP
      COMMON /COPT/BOX,FACT,IUNITS,PDX,  TITLE(20),X1,X2,XCONST,Y1,Y2,
     .YCONST,IS,          PUNCHN,PUNCHB,PUNCHC,PLAT,IDNO,CONTP,HCID,
     .XPMAX,XPMIN,YPMAX,YPMIN
      LOGICAL AREA1,BOX,PUNC,PUNB,PUNCHN,PUNCHD,WRTN,WRTB,WRT3,PUNCHB,
     .PUNCHC,PLAT
      DATA XPL,YPL/0.0,0.0/
      REAL XPLOT(1300),YPLOT(1300)
   60 FORMAT('+*  ')
   61 FORMAT('+ * ')
   62 FORMAT('+  *')
   71 FORMAT(1X,2F6.2,F7.2,6F6.2,F7.2,4X,I5,6X,'0',I1)
   81 FORMAT(1X,2F6.2,F7.2,7F6.2,F7.2,I5,4X,'2',I1)
   82 FORMAT(1X,2F6.2,F7.2,7F6.2,F7.2,I5,4X,'1',I1)
      PUNCHD=.FALSE.
      PUNB=.FALSE.
      PUNC=.FALSE.
      WRTN=.FALSE.
      WRTB=.FALSE.
      WRT3=.FALSE.
      HB=24.0
      HOBL=1000.0
      DLAST=3000.0
      AI=AD
      XPLOT(1)=X
      YPLOT(1)=Y
      NPLOT=1
      AR=AD*0.0174532925
      H = HO
      IGO = 1
      COSA = COS(AR)
      SINA = SIN(AR)
   10 PX = X
      PY = Y
      X = COSA*GRINC+X
      Y = SINA*GRINC+Y
      CALL DEPTH(X,Y)
      NWRITE = 1
      IF (DXY .LE. 0.) GO TO 22
      IF (DXY .LT. DRC) GO TO 11
      CALL DWIND(AD)
      H=HO
      GO TO 300
   11 X = PX
      Y = PY
      CALL CURVE(X,Y,AR,FK)
   12 NWRITE = 1
      IF (H .GE. WHMAX) GO TO 13
      CALL SWIND(AD,H,UNIT)
      GO TO 130
   13 ET=ET+UNIT/3600.
  130 CALL REFRAC(X,Y,AR,FK,&30,&20,&21,&22,&25)
   20 NWRITE = 2
      GO TO 30
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   21 NWRITE = 3
      GO TO 30
   22 NWRITE = 4
      AD=AR*57.29577951
      NPT=NPT+1
      IF(DXY.LT.-1000.)NWRITE=5
      GO TO 910
   25 NWRITE = 7
   30 CALL HEIGHT(XP,YP,AR,H)
      AD=AR*57.29577951
C
C           CARDS PUNCHED H/DXY>0.78
C
      IF(.NOT.PUNCHB)GO TO 200
      HOB=0.78*DXY/(SK*RK)
      IF(HOB.GT.HOBL)GO TO 150
  100 IF(HOB.GT.HB)GO TO 190
      IF(PUNB) GO TO 120
      VRAD=ARCOS(PHX/((PHX*PHX+PHY*PHY)**0.5))
      IF(PHY.LT.0)VRAD=-VRAD
      ACONT=(AR-VRAD)*57.29578+180.0
      HW=H*HB
      WRITE(8,82)X,Y,AD,RK,SK,B1,T,HB,DXY,HW ,ACONT,IDNO,IS
      WRTB=.TRUE.
      PUNB=.TRUE.
  120 IF(HOB.GT.(HB-1.0))GO TO 190
      HB=HB-2.0
      PUNB=.FALSE.
      GO TO 100
  150 IF(HB.GE.24.0)GO TO 190
      IF(HOB.LT.(HB+3.0))GO TO 190
      HB=HB+2.0
      PUNB=.FALSE.
      GO TO 150
  190 HOBL=HOB
C
C           CARDS PUNCHED WHEN DXY<CONTP FEET
C
  200 IF(.NOT.PUNCHC)GO TO 300
      IF(DXY.GT.DLAST)GO TO 250
      IF(DXY.GT.CONTP.OR.PUNC)GO TO 290
      VRAD=ARCOS(PHX/((PHX*PHX+PHY*PHY)**0.5))
      IF(PHY.LT.0.)VRAD=-VRAD
      ACONT=(AR-VRAD)*57.29578+180.0
      WRITE(7,81)X,Y,AD,RK,SK,B1,T,HO,DXY,H,ACONT,IDNO,IS
      WRT3=.TRUE.
      PUNC=.TRUE.
      GO TO 290
  250 IF(DXY.GT.CONTP+5.0)PUNC=.FALSE.
  290 DLAST=DXY
C
C           CARDS PUNCHED FOR NEXT PROGRAM
C
  300 IF(.NOT.PUNCHN)GO TO 390
      IF(PUNCHD) GO TO 390
      AREA1=X.LT.X2.AND.X.GT.X1.AND.Y.LT.Y2.AND.Y.GT.Y1
      IF(((.NOT.AREA1).AND.BOX).OR.((.NOT.BOX).AND.AREA1))GO TO 390
      XPUN=X*FACT-XCONST
      YPUN=Y*FACT-YCONST
      WRITE(7,71)XPUN,YPUN,AD,RK,SK,B1,T,HO,UW,WAD,IDNO,IUNITS
```

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      PUNCHD=.TRUE.
      WRTN=.TRUE.
  390 CONTINUE
      NPT=NPT+1
      IF (NPT .GT. LIMNPT) NWRITE = 6
      NPLOT=NPLOT+1
      IF(NPLOT.GE.1297)NWRITE=8
      XPLOT(NPLOT)=X
      YPLOT(NPLOT)=Y
      IF(MOD(NPT,NPRINT).EQ.0)GO TO 915
  910 IF(WRTB.OR.WRTN.OR.WRT3.OR.NWRITE.GT.1)GO TO 915
      GO TO (10,12,990),IGO
  915 CALL WRITER(X,Y,AD ,H,NWRITE)
      IF(WRTN)WRITE(6,60)
      IF(WRTB)WRITE(6,61)
      IF(WRT3)WRITE(6,62)
      WRTN=.FALSE.
      WRTB=.FALSE.
      WRT3=.FALSE.
      DTIC=XPLOT(NPLOT)-XPLOT(NPLOT-1)
      IF(DTIC.NE.0.0)GO TO 907
      XTIC=0.03*PDX
      YTIC=0.0
      GO TO 908
  907 ATIC=ATAN((YPLOT(NPLOT)-YPLOT(NPLOT-1))/DTIC)
      XTIC=0.03*PDX*COS(ATIC+1.57079)
      YTIC=0.03*PDX*SIN(ATIC+1.57079)
  908 NPLOT=NPLOT+1
      XPLOT(NPLOT)=X+XTIC
      YPLOT(NPLOT)=Y+YTIC
      NPLOT=NPLOT+1
      XPLOT(NPLOT)=X-XTIC
      YPLOT(NPLOT)=Y-YTIC
      NPLOT=NPLOT+1
      XPLOT(NPLOT)=X
      YPLOT(NPLOT)=Y
      GO TO(10,12,990),IGO
  990 IF(.NOT.PLAT)RETURN
      WMRGN=0.2*PDX
      XPMINW=XPMIN+WMRGN
      XPMAXW=XPMAX-WMRGN
      YPMINW=YPMIN+WMRGN
      YPMAXW=YPMAX-WMRGN
      DO 920 I1=1,NPLOT
      IF(XPLOT(I1).LT.XPMINW)GO TO 920
      IF(XPLOT(I1).GT.XPMAXW)GO TO 920
      IF(YPLOT(I1).LT.YPMINW)GO TO 920
      IF(YPLOT(I1).GT.YPMAXW)GO TO 920
      GO TO 922
  920 CONTINUE
      RETURN
  922 DISP=4.5
      IF(IDNO.GE.10   )DISP=DISP-0.5
      IF(IDNO.GE.100  )DISP=DISP-0.5
      IF(IDNO.GE.1000 )DISP=DISP-0.5
      IF(IDNO.GE.10000)DISP=DISP-0.5
      XI=XPLOT(I1)-DISP*PDX*HCID
      DISP=0.66667
      IF(YPLOT(I1+1).GT.YPLOT(I1))DISP=-2.33333
      YI=YPLOT(I1)+DISP*PDX*HCID
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      DO 924 IL=I1,NPLOT
      IF(XPLOT(IL).GT.XPMAX)GO TO 926
      IF(XPLOT(IL).LT.XPMIN)GO TO 926
      IF(YPLOT(IL).GT.YPMAX)GO TO 926
      IF(YPLOT(IL).LT.YPMIN)GO TO 926
      IF(IL.EQ.NPLOT)GO TO 927
  924 CONTINUE
  926 IL=IL-1
  927 IL=IL-1
      DF=(XPLOT(I1)-XPL)**2+(YPLOT(I1)-YPL)**2
      DL=(XPLOT(IL)-XPL)**2+(YPLOT(IL)-YPL)**2
      IF(DF.GT.DL)GO TO 950
      CALL PLOT(91,XI,YI)
      WRITE(4,9930)IDNO
 9930 FORMAT(I5,100X)
      CALL CHAR(HCID,0)
      DO 930 I=I1,IL
  930 CALL PLOT(90,XPLOT(I),YPLOT(I))
      XPL=XPLOT(IL+1)
      YPL=YPLOT(IL+1)
      CALL PLOT(91,XPL,YPL)
      RETURN
  950 CONTINUE
      DO 960 I=I1,IL
      II=IL-I+I1+1
  960 CALL PLOT(90,XPLOT(II),YPLOT(II))
      XPL=XPLOT(I1)
      YPL=YPLOT(I1)
      CALL PLOT(91,XPL,YPL)
      CALL PLOT(91,XI,YI)
      WRITE(4,9930)IDNO
      CALL CHAR(HCID,0)
      RETURN
      END
      SUBROUTINE WRITER(X,Y,ANG,H,NWRITE)
      COMMON D(12),E(6),WAR,B1,B2,CO,CXY,DCDH,DCON,DELTAS,DRC,DTGR,DXY,E
     .T,F,GRINC,HO,IGO,JGO,LIMNPT,NPRINT,NPT,PHX,PHY,RCCO,RK,MI,MJ,SIG,
     .SK,T,UW,UF,V,WL,WLO,WAD,GRID,DEP(36960)
      IF(NWRITE.EQ.5)DXY=DXY+10000.
      CALL ERROR(FIT,DIFMAX)
      FN=F/6080.
      WRITE(6,62) NPT,X,Y,ANG,DXY,DIFMAX,T,WL,CXY,H,RK,SK,FN
   62 FORMAT(1H ,I7,3F9.2,F11.2,F10.2,F8.2,3F10.2,3F10.4)
      GO TO (11,20,21,22,23,24,25,26), NWRITE
   20 WRITE(6,61) NPT
   61 FORMAT(29H  CURVATURE AVERAGED AT POINT, I4)
      GO TO 11
   21 WRITE(6,63)
   63 FORMAT(1H ,42HRAY STOPPED, NO CONVERGENCE FOR CURVATURE.)
      GO TO 12
   22 WRITE(6,64) X,Y,ET
   64 FORMAT(1H ,32HRAY STOPPED, REACHED SHORE.  X =,F7.2,6H,   Y=,F7.2,1
     .7H,  ELAPSED TIME =,F15.2,9H  HOURS  )
      GO TO 12
   23 WRITE(6,65) X,Y,ET
   65 FORMAT(1H ,35HRAY STOPPED, REACHED BOUNDARY.  X =,F7.2,6H,  Y =,
     .F7.2,17H,  ELAPSED TIME =,F15.2,9H  HOURS  )
      GO TO 12
   24 WRITE(6,66) LIMNPT,X,Y
   66 FORMAT(1H ,55HRAY STOPPED, NUMBER OF POINTS EXCEEDS MAXIMUM.  LIMI
```

```
  .T =,I4,13H POINTS.  X =,F7.2,6H,  Y =,F7.2)
   GO TO 12
25 WRITE(6,67) DELTAS,X,Y
67 FORMAT(1H ,51HRAY STOPPED, INCREMENT DISTANCE ALONG RAY LESS THAN,
  .F6.3,17H GRID UNITS.  X =,F7.2,6H,  Y =,F7.2)
   GO TO 12
26 WRITE(6,68)
68 FORMAT(' RAY STOPPED,PLOTTING ARRAY FILLED')
12 IGO = 3
11 RETURN
   END
   SUBROUTINE REFRAC(X,Y,A,FK,*,*,*,*,*)
   COMMON D(12),E(6),WAR,B1,B2,CO,CXY,DCDH,DCON,DELTAS,DRC,DTGR,DXY,E
  .T,F,GRINC,HO,IGO,JGO,LIMNPT,NPRINT,NPT,PHX,PHY,RCCO,RK,MI,MJ,SIG,
  .SK,T,UW,UF,V,WL,WLO,WAD,GRID,DEP(36960)
   NCUR = 1
   GO TO (11,12,10), IGO
11 FKM = FK
   IGO = 2
12 DS = CXY*DTGR
   IF (DS .LT. DELTAS) RETURN 5
   RESMAX = 0.00005/DS
13 DO 110 I=1,20
   DELA = FKM*DS
   AA = A+DELA
   AM = DELA*0.5+A
   XX = COS(AM)*DS+X
   YY = SIN(AM)*DS+Y
   CALL CURVE(XX,YY,AA,FKK)
   IF (DXY .LE. 0.) RETURN 4
   GO TO (111,16), NCUR
111 FKM = (FK+FKK)*0.5
   IF (I .EQ. 1) GO TO 110
   IF (RESMAX .GT. ABS(FKP-FKM)) GO TO 16
   IF (I .EQ. 18) FK18 = FKM
110 FKP = FKM
   IF (RESMAX .GT. ABS(FK18-FKM)) GO TO 15
   RETURN 3
15 FKM = (FKM+FK18)*0.5
   NCUR = 2
   GO TO 13
16 X = XX
   Y = YY
   A = AA
   FK = FKK
   IF (NCUR .EQ. 2) RETURN 2
10 RETURN 1
   END
   SUBROUTINE CURVE(X,Y,A,FK)
   COMMON D(12),E(6),WAR,B1,B2,CO,CXY,DCDH,DCON,DELTAS,DRC,DTGR,DXY,E
  .T,F,GRINC,HO,IGO,JGO,LIMNPT,NPRINT,NPT,PHX,PHY,RCCO,RK,MI,MJ,SIG,
  .SK,T,UW,UF,V,WL,WLO,WAD,GRID,DEP(36960)
   COMMON/COMA/XP,YP
   GO TO (10,11), IGO
11 CALL DEPTH(X,Y)
   IF (DXY*200. .GT. WL) GO TO 10
   IF (DXY .LE. 0.) RETURN
   JGO = 2
   ARG = 32.1725*DXY
   CXY = SQRT(ARG)
```

```
      DCDH = 16.08625/CXY
      GO TO 14
   10 CI = CXY
      JGO = 1
      DO 120 I=1,50
      ARG = (DXY*SIG)/CI
      CXY = CO*TANH(ARG)
      RESID = CXY-CI
      IF (ABS(RESID) .LT. 0.001) GO TO 13
  120 CI = (CXY+CI)*0.5
   13 RCCO = CXY/CO
      SCMC = (1.-RCCO*RCCO)*SIG
      V = SCMC*DXY+RCCO*CXY
      DCDH = CXY*SCMC/V
   14 PHX = E(4)*2.*XP+E(5)*YP+E(2)
      PHY = E(6)*2.*YP+E(5)*XP+E(3)
      FK = (SIN(A)*PHX-COS(A)*PHY)*DCDH*DCON/CXY
      RETURN
      END
      SUBROUTINE DEPTH(X,Y)
      COMMON D(12),E(6),WAR,B1,B2,CO,CXY,DCDH,DCON,DELTAS,DRC,DTGR,DXY,E
     .T,F,GRINC,HO,IGO,JGO,LIMNPT,NPRINT,NPT,PHX,PHY,RCCO,RK,MI,MJ,SIG,
     .SK,T,UW,UF,V,WL,WLO,WAD,GRID,DEP(36960)
      COMMON/COMA/XP,YP
      DIMENSION SXY(12,6)
      DATA   SXY                         /0.30861241,0.23684207,0.21770331,
     .0.23684207,-0.08492823,2*-0.05143541,-0.08492823,0.00598086,2*0.13
     .038277,0.00598086,0.05322964,0.19677030,0.14413872,0.10586122,0.09
     .031100,-0.06758374,-0.03349283,0.03349282,-0.18241626,-0.34031099,
     .-0.12440190,0.12440190,0.05322964,0.10586122,0.14413872,0.19677030
     .,0.03349282,-0.03349283,-0.06758374,0.09031099,0.12440190,-0.12440
     .191,-0.34031099,-0.18241625,4*-0.12499998,2*0.125,2*0.,2*0.1249999
     .9,2*-0.,0.05263157,-0.05263157,0.05263158,-0.05263157,-0.15789473,
     .2*0.15789474,2*-0.15789473,2*0.15789473,-0.15789473,4*-0.12499998,
     .2*0.,2*0.125,2*-0.,2*0.12499999/
      I = X+1.
      J = Y+1.
      XP = AMOD(X,1.)
      YP = AMOD(Y,1.)
      IF (NPT .EQ. 1) GO TO 11
      IF (IP .NE. I) GO TO 11
      IF (JP .EQ. J) GO TO 14
   11 IP = I
      JP = J
      IF(I.LT.2.OR.I.GT.(MI-2).OR.J.LT.2.OR.J.GT.(MJ-2))GO TO 200
      LCNT=I+J*MI
      D(1) = DEP(LCNT-MI)
      D(2) = DEP(LCNT+1-MI)
      D(3) = DEP(LCNT+1)
      D(4) = DEP(LCNT)
      D(5) = DEP(LCNT+2-MI)
      D(6) = DEP(LCNT+2)
      D(7) = DEP(LCNT+1+MI)
      D(8) = DEP(LCNT+MI)
      D(9) = DEP(LCNT-1)
      D(10)= DEP(LCNT-1-MI)
      D(11)= DEP(LCNT-MI-MI)
      D(12)= DEP(LCNT+1-MI-MI)
      DO 110 K=1,6
      E(K) = 0.
```

```
      DO 110 L=1,12
  110 E(K) = E(K)+D(L)*SXY(L,K)
   14 DXY = (E(1)+E(2)*XP+E(3)*YP+E(4)*XP*XP+E(5)*XP*YP+E(6)*YP*YP)*DCON
      RETURN
  200 DXY=DXY-10000.
      RETURN
      END
      SUBROUTINE HEIGHT(X,Y,A,H)
      COMMON D(12),E(6),WAR,B1,B2,CO,CXY,DCDH,DCON,DELTAS,DRC,DTGR,DXY,E
     .T,F,GRINC,HO,IGO,JGO,LIMNPT,NPRINT,NPT,PHX,PHY,RCCO,RK,MI,MJ,SIG,
     .SK,T,UW,UF,V,WL,WLO,WAD,GRID,DEP(36960)
      WL = WLO*RCCO
      GN = 12.5663706144*DXY/WL
      IF (GN .GT. 174.62)  GN = 174.62
      CG = (1.+GN/SINH(GN))*CXY
      SKI=SQRT(CO/CG)
      IF (CG .LT. 0.) RETURN
      RKI=ABS(1./B2)
      RKI=SQRT(RKI)
      H=HO*(1+((RKI*SKI-RK*SK)/RK*SK))
      RK=RKI
      SK=SKI
      GO TO (11,12), JGO
   11 U = -2.*SIG*RCCO*CXY/(V*V)
      GO TO 10
   12 U = -0.5/DXY
   10 U = U*DCON
      DCDH = DCDH*DCON
      COSA = COS(A)
      SINA = SIN(A)
      P = -(COSA*PHX+SINA*PHY)*DCDH*DTGR*2.
      Q = ((E(4)*2.+U*PHX*PHX)*SINA*SINA-(E(5)+U*PHX*PHY)*2.*SINA*COSA
     .      +(E(6)*2.+U*PHY*PHY)*COSA*COSA)*DCDH*CXY*DTGR*DTGR*2.
      B3 = ((P-2.)*B1+(4.-Q)*B2)/(P+2.)
      B1 = B2
      B2 = B3
      RETURN
      END
      SUBROUTINE ERROR(FIT,DIFMAX)
      COMMON D(12),E(6),WAR,B1,B2,CO,CXY,DCDH,DCON,DELTAS,DRC,DTGR,DXY,E
     .T,F,GRINC,HO,IGO,JGO,LIMNPT,NPRINT,NPT,PHX,PHY,RCCO,RK,MI,MJ,SIG,
     .SK,T,UW,UF,V,WL,WLO,WAD,GRID,DEP(36960)
      DIMENSION DP(4)
      IF (NPT .LT. 3) GO TO 11
      IF (EP .EQ. E(5)) GO TO 12
   11 DP(1) = E(1)
      DP(2) = E(1)+E(2)+E(4)
      DP(3) = E(1)+E(2)+E(3)+E(4)+E(5)+E(6)
      DP(4) = E(1)+E(3)+E(6)
      DIFMAY = 0.
      SUM = 0.
      DO 110 I=1,4
      DIF = ABS(D(I)-DP(I))
      DIFMAY = AMAX1(DIF,DIFMAY)
  110 SUM = DIF*DIF+SUM
      DIFMAY = DIFMAY*DCON
      SUM = SUM*0.25
      FIT = SQRT(SUM)
      EP = E(5)
   12 DIFMAX = DIFMAY/DXY*100.
```

```
      RETURN
      END
      SUBROUTINE FRAMEI(XMAX,XMIN,YMAX,YMIN,SCFAC,PLOTW,HC)
C
C     INITIALIZES PLOTTING ROUTINES
C
      LOGICAL STD,LABELD
      REAL*8 UDATE
      COMMON/DATE/UDATE
      INTEGER AXISN
      REAL ARROWA(15),ARROWL(15),ARROWX(15),ARROWY(15),TITLP(4),
     .   TITLE(1),XLABEL(1),YLABEL(1),SUNT(1),XPLT(600),YPLT(600)
      DATA ARROWA    /0.,5.902,0.,0.,1.5708,4.7124,0.,3.1416,3.225,3.36,
     .3.1416,0.077,0.0605,-0.077,-0.0605/,ARROWL /.1522,.1174,.4783,0.,
     ..04348,.04348,0.,.4783,.5235,.2004,.1522,.653,.825,.653,.825/
      I=HC*10.0+0.5
      HC=I/10.0
      XDELT=XMAX-XMIN
      YDELT=YMAX-YMIN
      PDX=YDELT*HC/PLOTW
      XMAXF=XMAX+(21.4+3.67/HC)*PDX
      XD=XMAXF-XMIN
      XL=XD*PLOTW/YDELT
      CALL PLOT(201,XMIN,XMAXF,XL,XD,YMIN,YMAX,PLOTW,YDELT)
      CALL DATER(UDATE)
      K=1
      MJJ=YDELT
   10 IF((MJJ/(2*K)).LE.12)GO TO 12
      IF((MJJ/(5*K)).LE.12)GO TO 15
      IF((MJJ/(10*K)).LE.12)GO TO 16
      IF((MJJ/(15*K)).LE.12)GO TO 17
      K=K*10
      GO TO 10
   12 AXISN=2*K
      GO TO 90
   15 AXISN=5*K
      GO TO 90
   16 AXISN=10*K
      GO TO 90
   17 AXISN=15*K
   90 CONTINUE
      PDXHC=PDX/HC
      SCALE=SCFAC*PDXHC
      TIC=0.05*PDXHC
      NX=XDELT/AXISN+1
      NMIN=XMIN
      NXMIN=NMIN/AXISN
      IF(MOD(NMIN,AXISN).EQ.0)GO TO 95
      NX=NX-1
      NXMIN=NXMIN+1
   95 CONTINUE
      N1X=NXMIN*AXISN
      XNUMY=-1.666*PDX+YMIN
      XAXSLX=(XMAX+XMIN)/2.0-(9.0)*PDX
      XAXSLY=-3.333*PDX+YMIN
      NY=YDELT/AXISN+1
      NMIN=YMIN
      NYMIN=NMIN/AXISN
      IF(MOD(NMIN,AXISN).EQ.0)GO TO 98
      NY=NY-1
```

```
      NYMIN=NYMIN+1
   98 CONTINUE
      N1Y=NYMIN*AXISN
      YNUMX=-0.666*PDX+XMIN
      YAXSLX=-2.333*PDX+XMIN
      YAXSLY=(YMAX+YMIN)/2.0-(9.0)*PDX
      XS=(XL-2.0)*PDXHC+XMIN
      XLS=3.2*PDX+XMAX
      RETURN
      ENTRY FRAME(TITLE,NL,NSET,NUNITR)
C
C     DRAWS PLOTTING FRAME
C
      IF(NUNITR.GT.0)REWIND NUNITR
      CALL PLOT(90,XS,YMAX)
      CALL PLOT(91,XS,YMIN)
      CALL PLOT(7)
      CALL PLOT(201,XMIN,XMAXF,XL,XD,YMIN,YMAX,PLOTW,YDELT)
C
C     DRAW X AXIS
C
      LABELD=.FALSE.
      DISP=-2.3*PDX
      DO 1010 I=1,NX
      NUM=N1X+(I-1)*AXISN
      IF(NUM.GE.10 )DISP=-2.0*PDX
      IF(NUM.GE.100)DISP=-1.5*PDX
      XNUMX=NUM+DISP
      IF(LABELD.OR.XNUMX.LT.XAXSLX)GO TO 1005
      LABELD=.TRUE.
      CALL PLOT(91,XAXSLX,XAXSLY)
      WRITE(4,9010)
      CALL CHAR(HC,0)
 9010 FORMAT('X AXIS, GRID UNITS',100X)
 1005 CALL PLOT(91,XNUMX,XNUMY)
      WRITE(4,9011)NUM
 9011 FORMAT(I3,100X)
 1010 CALL CHAR(HC,0)
      CALL PLOT(90,XMAX,YMIN)
      DO 1020 I=1,NX
      X=(NX-I)*AXISN+N1X
      CALL PLOT(90,X,YMIN)
      CALL PLOT(90,X,YMIN+TIC)
      CALL PLOT(90,X,YMIN-TIC)
 1020 CALL PLOT(90,X,YMIN)
      CALL PLOT(91,XMIN,YMIN)
C
C     DRAW Y AXIS
C
      LABELD=.FALSE.
      DISP=-2.3*PDX
      DO 1030 I=1,NY
      NUM=N1Y+(I-1)*AXISN
      IF(NUM.GE.10 )DISP=-2.0*PDX
      IF(NUM.GE.100)DISP=-1.5*PDX
      YNUMY=NUM+DISP
      IF(LABELD.OR.YNUMY.LT.YAXSLY)GO TO 1025
      LABELD=.TRUE.
      CALL PLOT(91,YAXSLX,YAXSLY)
      WRITE(4,9030)
```

```
      CALL CHAR(HC,1)
 9030 FORMAT('Y AXIS, GRID UNITS',100X)
 1025 CALL PLOT(91,YNUMX,YNUMY)
      WRITE(4,9011)NUM
 1030 CALL CHAR(HC,1)
      CALL PLOT(90,XMIN,YMAX)
      DO 1040 I=1,NY
      Y=(NY-I)*AXISN+N1Y
      CALL PLOT(90,XMIN,Y)
      CALL PLOT(90,XMIN+TIC,Y)
      CALL PLOT(90,XMIN-TIC,Y)
 1040 CALL PLOT(90,XMIN,Y)
      CALL PLOT(91,XMIN,YMIN)
C
C     DRAW TOP OF FRAME
C
      CALL PLOT(90,XMIN,YMAX)
      DO 1050 I=1,NX
      X=(I-1)*AXISN+N1X
      CALL PLOT(90,X,YMAX)
      CALL PLOT(90,X,YMAX-TIC)
 1050 CALL PLOT(90,X,YMAX)
      CALL PLOT(91,XMAX,YMAX)
C
C     FILL ID BOX
C
      YLS=YMAX-PDX
      DO 1070 I=1,NL
      DO 1060 J=1,4
 1060 TITLP(J)=TITLE(4*(I-1)+J)
      YLS=YLS-1.5*PDX
      CALL PLOT(91,XLS,YLS)
      WRITE(4,9060)TITLP
 9060 FORMAT(4A4,100X)
 1070 CALL CHAR(HC,0)
      YLS=YLS-1.5*PDX
      CALL PLOT(91,XLS,YLS)
      WRITE(4,9070)SCALE
      CALL CHAR(HC,0)
 9070 FORMAT('1 IN.=',F5.2,'N.M.',100X)
      IF(NSET.LE.0)GO TO 1080
      YLS=YLS-1.5*PDX
      CALL PLOT(91,XLS,YLS)
      WRITE(4,9075)NSET
      CALL CHAR(HC,0)
 9075 FORMAT(' SET NUMBER',I4,100X)
 1080 CALL PLOT(91,XLS,YLS-1.5*PDX)
      WRITE(4,9080) UDATE
      CALL CHAR(HC,0)
 9080 FORMAT(4X,A8,100X)
      X=XMAX+21.4*PDX
      Y=YLS-2.5*PDX
      CALL PLOT(90,XMAX,Y)
      CALL PLOT(90,X,Y)
      CALL PLOT(90,X,YMAX)
      CALL PLOT(90,XMAX,YMAX)
C
C     DRAW RIGHT SIDE OF FRAME
C
      DO 1090 I=1,NY
```

```
      Y=(NY-I)*AXISN+N1Y
      CALL PLOT(90,XMAX,Y)
      CALL PLOT(90,XMAX-TIC,Y)
 1090 CALL PLOT(90,XMAX,Y)
      CALL PLOT(91,XMAX,YMIN)
      IF(NUNITR.LE.0)RETURN
      XPL=XMAX
      YPL=YMIN
  100 READ(NUNITR,END=120)CONT,NPLT,(XPLT(I),YPLT(I),I=1,NPLT)
      DO 105 I=1,NPLT
      IF(XPLT(I).GT.XMAX)XPLT(I)=XMAX
      IF(XPLT(I).LT.XMIN)XPLT(I)=XMIN
      IF(YPLT(I).GT.YMAX)YPLT(I)=YMAX
  105 IF(YPLT(I).LT.YMIN)YPLT(I)=YMIN
      NPLT1=NPLT-1
      DF=(XPLT(1)-XPL)**2+(YPLT(1)-YPL)**2
      DL=(XPLT(NPLT)-XPL)**2+(YPLT(NPLT)-YPL)**2
      IF(DF.GT.DL)GO TO 115
      DO 110 I=1,NPLT1
  110 CALL PLOT(90,XPLT(I),YPLT(I))
      XPL=XPLT(NPLT)
      YPL=YPLT(NPLT)
      CALL PLOT(91,XPL,YPL)
      GO TO 100
  115 DO 116 I=1,NPLT1
      II=NPLT-I+1
  116 CALL PLOT(90,XPLT(II),YPLT(II))
      XPL=XPLT(1)
      YPL=YPLT(1)
      CALL PLOT(91,XPL,YPL)
      GO TO 100
  120 CONTINUE
      RETURN
      ENTRY ARROW(XA,YA,DARROW,ALTH)
C
C     DRAWS NORTH ARROW
C
      IF(XA.LE.XMIN)RETURN
      IF(XA.GT.XMAX)RETURN
      IF(YA.LE.YMIN)RETURN
      IF(YA.GT.YMAX)RETURN
      IF(ALTH.LE.0.0)RETURN
      AARROW=DARROW*0.017453295
      DO 5 I=1,15
      ARROWX(I)=ARROWL(I)*COS(ARROWA(I)+AARROW)*ALTH*PDXHC+XA
    5 ARROWY(I)=ARROWL(I)*SIN(ARROWA(I)+AARROW)*ALTH*PDXHC+YA
      DO 60 I=1,14
      IF(I.EQ.12)CALL PLOT(99)
   60 CALL PLOT(90,ARROWX(I),ARROWY(I))
      CALL PLOT(91,ARROWX(15),ARROWY(15))
      RETURN
      ENTRY FRAMEL
C
C     CLOSES PLOTTING ROUTINES
C
      CALL PLOT(90,XS,YMAX)
      CALL PLOT(91,XS,YMIN)
      CALL PLOT(100)
      RETURN
      END
```

```
      SUBROUTINE DWIND(A)
      COMMON D(12),E(6),WAR,B1,B2,CO,CXY,DCDH,DCON,DELTAS,DRC,DTGR,DXY,E
     .T,F,GRINC,HO,IGO,JGO,LIMNPT,NPRINT,NPT,PHX,PHY,RCCO,RK,MI,MJ,SIG,
     .SK,T,UW,UF,V,WL,WLO,WAD,GRID,DEP(36960)
      AR=A*0.0174532925
      UP=UF*COS(WAR-AR)
      F=F+GRINC*GRID
      T=8.60*(UP/32.174)*(1-1/(1+.008*(32.174*F/UP**2)**.333)**5)
      HO=(0.30/32.174)*UP**2*(1-1/(1+.004*(32.174*F/UP**2)**.5)**2)
      SIG=6.28318531/T
      CO=5.1204062*T
      WLO=CO*T
      DRC=WLO*0.6
      DTGR=GRINC/CO
      NUNIT=DTGR*GRID
      ET=ET+((UNIT+NUNIT)/7200.)
      UNIT=NUNIT
      CXY=CO
      WL=WLO
      RETURN
      END
      SUBROUTINE SWIND(A,H,UNIT)
      COMMON D(12),E(6),WAR,B1,B2,CO,CXY,DCDH,DCON,DELTAS,DRC,DTGR,DXY,E
     .T,F,GRINC,HO,IGO,JGO,LIMNPT,NPRINT,NPT,PHX,PHY,RCCO,RK,MI,MJ,SIG,
     .SK,T,UW,UF,V,WL,WLO,WAD,GRID,DEP(36960)
      AR=A*0.0174532925
      UP=UF*COS(WAR-AR)
      COSW=COS(WAR-AR)
      F=1942.56231*UP**2*(((1/(1-107.24666*H/UP**2)**.5)-1)**2)
      F=F+CXY*DTGR
      T=8.60*(UP/32.174)*(1-1/(1+.008*(32.174*F/UP**2)**.333)**5)
      HO=(0.30/32.174)*UP**2*(1-1/(1+.004*(32.174*F/UP**2)**.5)**2)
      SIG=6.28318531/T
      CO=5.1204062*T
      WLO=CO*T
      DRC=WLO*0.6
      DTGR=GRINC/CO
      NUNIT=DTGR*GRID
      ET=ET+((UNIT+NUNIT)/7200.)
      UNIT=NUNIT
      RETURN
      END
```

APPENDIX C

Numerical Computer Output for Ray No. 4

T=10 Seconds, U=50 Knots

NEW HAMPSHIRE COAST OUTER OUTER RAYS IN U = 50 KNOTS DATE 2/23/73
SFT NO. 1, PERIOD = 10.00 SECS., RAY NO. 4, INITIAL TIME STEP = 445.3 MIN. , WIND VELOCITY =50.0 KNOTS

POINT	X (GU)	Y (GU)	ANGLE (DEG)	DEPTH (FT)	MAX DIF (PERCENT)	PERIOD (SEC)	LENGTH (FT)	SPEED (FPS)	HEIGHT (FT)	KR (DIMENSIONLESS)	KS (DIMENSIONLESS)	FETCH (NM)
1	16.00	40.00	-90.00	322.13		10.00	512.04	51.20	23.64			134.3344
2	16.00	39.25	-90.00	323.85	2.07	10.04	516.66	51.43	23.87	1.0000	1.0000	138.0905
3	16.00	38.50	-90.00	323.91	1.47	10.11	523.10	51.75	24.10	1.0000	1.0000	141.8407
4	16.00	37.75	-90.00	321.88	5.15	10.17	529.42	52.07	24.32	1.0000	1.0000	145.5908
5	16.00	37.00	-90.00	334.57	4.95	10.23	535.64	52.37	24.54	1.0000	1.0000	149.3410
6	16.00	36.25	-90.00	341.76	5.85	10.29	541.76	52.67	24.76	1.0000	1.0000	153.0912
7	16.00	35.50	-90.00	342.00	4.91	10.34	547.78	52.96	24.97	1.0000	1.0000	156.8413
8	16.00	34.75	-90.00	332.01	5.48	10.40	553.70	53.25	25.18	1.0000	1.0000	160.5915
9	16.00	34.00	-89.98	317.83	5.72	10.40	552.89	53.17	25.07	1.0000	0.9955	160.5893
10	16.00	33.25	-89.97	309.60	4.24	10.37	549.53	53.00	25.05	0.9999	0.9949	158.5305
11	16.00	32.50	-89.96	285.72	4.92	10.36	548.42	52.92	24.98	0.9997	0.9922	158.2421
12	16.00	31.75	-89.94	253.63	5.14	10.34	544.72	52.66	24.82	0.9993	0.9864	156.8965
13	16.00	31.00	-89.99	227.80	5.73	10.30	538.26	52.24	24.66	0.9996	0.9797	154.2075
14	16.00	30.26	-90.17	205.68	5.38	10.26	530.82	51.74	24.50	1.0006	0.9720	151.4171
15	16.00	29.52	-90.47	157.00	33.20	10.22	512.21	50.14	23.98	1.0037	0.9469	148.6149
16	15.99	28.79	-90.87	143.77	33.72	10.07	493.55	48.99	24.60	1.0391	0.9412	139.8108
17	15.97	28.09	-91.42	157.05	30.87	10.24	514.50	50.23	26.60	1.1282	0.9464	150.3310
18	15.95	27.40	-92.12	190.99	18.65	10.78	576.43	53.50	30.58	1.3042	0.9556	188.4928
19	15.93	26.74	-92.62	295.65	36.85	11.82	708.07	59.90	39.49	1.6799	0.9786	289.2395
20	15.90	26.12	-93.01	346.81	31.41	14.10	992.68	70.42	67.41	2.9719	0.9615	715.2747
21	15.85	25.39	-93.39	421.45	25.56	14.10	1007.07	71.44	36.78	2.7024	0.9788	715.2747
22	15.81	24.61	-93.50	435.52	14.38	13.41	916.26	68.32	22.63	1.6024	0.9876	546.5825
23	15.74	23.58	-93.53	513.30	12.03	9.71	482.69	49.71	17.95	1.2473	1.0000	119.8745
24	15.69	22.71	-93.53	590.52	8.50	8.37	359.13	42.88	15.20	1.0564	1.0000	65.2315
25	15.64	21.88	-93.53	629.69	8.32	7.54	291.07	38.61	13.42	0.9327	1.0000	43.2087
26	15.59	21.07	-93.53	638.53	8.20	6.97	248.82	35.69	12.15	0.8443	1.0000	32.0563
27	15.54	20.28	-93.53	617.77	7.42	6.55	219.53	33.53	11.18	0.7771	1.0000	25.3752
28	15.49	19.49	-93.53	584.87	9.59	6.21	197.78	31.82	10.41	0.7237	1.0000	20.9663
29	15.44	18.70	-93.53	599.65	7.36	5.94	180.86	30.43	9.79	0.6800	1.0000	17.8043
30	15.40	17.93	-93.53	649.57	3.78	5.72	167.25	29.26	9.26	0.6433	1.0000	15.4639
31	15.35	17.15	-93.53	679.47	3.61	5.52	156.01	28.26	8.81	0.6120	1.0000	13.6558
32	15.30	16.38	-93.53	700.00	2.94	5.35	146.53	27.39	8.42	0.5849	1.0000	12.2184
33	15.25	15.61	-93.53	677.11	4.82	5.20	138.41	26.62	8.07	0.5611	1.0000	11.0491
34	15.20	14.84	-93.53	667.73	10.88	5.07	131.36	25.94	7.77	0.5400	1.0000	10.0801
35	15.16	14.07	-93.53	661.71	10.98	4.94	125.17	25.32	7.50	0.5211	1.0000	9.2643
36	15.11	13.31	-93.53	673.30	9.14	4.83	119.68	24.76	7.25	0.5040	1.0000	8.5684
37	15.06	12.54	-93.53	687.60	7.29	4.73	114.77	24.24	7.03	0.4886	1.0000	7.9679
38	15.02	11.78	-93.53	681.36	6.63	4.64	110.36	23.77	6.83	0.4744	1.0000	7.4448
39	14.97	11.02	-93.53	650.39	3.18	4.56	106.35	23.34	6.64	0.4615	1.0000	6.9848
40	14.92	10.26	-93.53	621.06	5.31	4.48	102.70	22.93	6.47	0.4495	1.0000	6.5776
41	14.87	9.49	-93.53	608.57	6.80	4.40	99.35	22.55	6.31	0.4384	1.0000	6.2145
42	14.83	8.73	-93.53	557.97	10.06	4.34	96.27	22.20	6.16	0.4281	1.0000	5.8886
43	14.78	7.97	-93.53	540.07	14.76	4.27	93.42	21.87	6.02	0.4185	1.0000	5.5940
44	14.73	7.21	-93.53	530.73	15.01	4.21	90.79	21.56	5.89	0.4095	1.0000	5.3285
45	14.69	6.46	-93.53	580.13	13.54	4.15	88.33	21.27	5.77	0.4011	1.0000	5.0858
46	14.64	5.70	-93.53	575.03	15.71	4.10	86.04	20.99	5.66	0.3932	1.0000	4.8639
47	14.59	4.94	-93.53	592.80	10.88	4.05	83.90	20.73	5.55	0.3857	1.0000	4.6604
48	14.55	4.18	-93.53	591.58	10.90	4.00	81.88	20.48	5.45	0.3786	1.0000	4.4730
49	14.50	3.42	-93.53	568.81	18.50	3.95	79.99	20.24	5.35	0.3719	1.0000	4.2999
50	14.45	2.67	-93.53	534.93	16.26	3.91	78.21	20.01	5.26	0.3656	1.0000	4.1395
51	14.41	1.91	-93.53	595.10	12.32	3.87	76.52	19.79	5.17	0.3595	1.0000	3.9905
52	14.36	1.15	-93.53	584.59	12.54	3.83	74.95	19.59	5.09	0.3538	1.0000	3.8516
53	14.36	1.15	-93.53	584.59	12.54	3.79	74.95	19.59	5.09	0.3538	1.0000	3.7219

RAY STOPPED, REACHED BOUNDARY. X = 14.36, Y = 1.15, ELAPSED TIME = 10.26 HOURS

NEW HAMPSHIRE COAST OUTER RAYS IN U = 50 KNOTS DATE 2/23/73
SET NO. 1, PERIOD = 3.87 SECS., RAY NO. 4, INITIAL TIME STEP = 230.1 MIN. , WIND VELOCITY =50.0 KNOTS

POINT	X (GU)	Y (GU)	ANGLE (DEG)	DEPTH (FT)	MAX DIF (PERCENT)	PERIOD (SEC)	LENGTH (FT)	SPEED (FPS)	HEIGHT (FT)	KR (DIMENSIONLESS)	KS (DIMENSIONLESS)	FETCH (NM)
1	42.03	94.55	-93.53	494.57		3.87	76.69	19.82	5.26			3.9757
2	41.98	93.80	-93.53	524.20	7.91	4.06	84.59	20.81	5.69	0.3600	1.0000	4.7260
3	41.94	93.05	-93.53	540.14	7.68	4.24	92.26	21.73	6.10	0.3600	1.0000	5.4760
4	41.89	92.30	-93.53	554.36	6.35	4.41	99.46	22.57	6.47	0.3600	1.0000	6.2260
5	41.85	91.56	-93.53	575.48	3.22	4.56	106.27	23.33	6.82	0.3600	1.0000	6.9761
6	41.80	90.81	-93.53	584.97	2.16	4.69	112.75	24.03	7.15	0.3600	1.0000	7.7261
7	41.75	90.06	-93.53	593.28	2.13	4.82	118.94	24.68	7.46	0.3600	1.0000	8.4761
8	41.71	89.31	-93.53	598.59	2.34	4.94	124.88	25.29	7.76	0.3600	1.0000	9.2261
9	41.66	88.56	-93.53	612.05	3.30	5.05	130.59	25.86	8.04	0.3600	1.0000	9.9762
10	41.61	87.81	-93.53	622.51	8.41	5.16	136.10	26.40	8.30	0.3600	1.0000	10.7262
11	41.57	87.06	-93.53	604.40	8.66	5.26	141.43	26.91	8.56	0.3600	1.0000	11.4762
12	41.52	86.32	-93.53	562.81	11.14	5.35	146.58	27.40	8.81	0.3600	1.0000	12.2263
13	41.48	85.57	-93.53	503.30	2.27	5.44	151.59	27.86	9.05	0.3600	1.0000	12.9763
14	41.43	84.82	-93.53	486.06	3.16	5.53	156.46	28.30	9.28	0.3600	1.0000	13.7263
15	41.38	84.07	-93.53	492.36	3.12	5.61	161.19	28.73	9.50	0.3600	1.0000	14.4764
16	41.34	83.32	-93.53	529.91	5.73	5.69	165.81	29.14	9.72	0.3600	1.0000	15.2264
17	41.29	82.57	-93.53	565.42	4.51	5.77	170.32	29.53	9.93	0.3600	1.0000	15.9764
18	41.24	81.82	-93.53	587.75	2.40	5.84	174.71	29.91	10.13	0.3600	1.0000	16.7265
19	41.20	81.08	-93.53	610.44	2.31	5.91	179.01	30.28	10.33	0.3600	1.0000	17.4765
20	41.15	80.33	-93.53	625.87	0.73	5.98	183.22	30.63	10.52	0.3600	1.0000	18.2265
21	41.11	79.58	-93.53	641.71	0.64	6.05	187.34	30.97	10.71	0.3600	1.0000	18.9765
22	41.06	78.83	-93.53	653.80	2.22	6.11	191.38	31.30	10.89	0.3600	1.0000	19.7266
23	41.01	78.08	-93.53	672.18	2.15	6.18	195.34	31.63	11.07	0.3600	1.0000	20.4766
24	40.97	77.33	-93.53	688.80	1.45	6.24	199.22	31.94	11.25	0.3600	1.0000	21.2266
25	40.92	76.58	-93.53	718.03	0.73	6.30	203.04	32.24	11.42	0.3600	1.0000	21.9767
26	40.88	75.84	-93.53	740.39	2.12	6.35	206.79	32.54	11.59	0.3600	1.0000	22.7267
27	40.83	75.09	-93.53	748.68	2.10	6.41	210.47	32.83	11.75	0.3600	1.0000	23.4767
28	40.78	74.34	-93.53	753.47	2.48	6.47	214.09	33.11	11.91	0.3600	1.0000	24.2268
29	40.74	73.59	-93.53	733.48	2.84	6.52	217.66	33.38	12.07	0.3600	1.0000	24.9768
30	40.69	72.84	-93.53	697.73	1.80	6.57	221.16	33.65	12.22	0.3600	1.0000	25.7268
31	40.64	72.09	-93.53	665.31	1.89	6.62	224.62	33.91	12.37	0.3600	1.0000	26.4769
32	40.60	71.34	-93.53	627.28	4.85	6.67	228.02	34.17	12.52	0.3600	1.0000	27.2269
33	40.55	70.60	-93.53	596.99	5.05	6.72	231.37	34.42	12.67	0.3600	1.0000	27.9769
34	40.51	69.85	-93.52	576.63	3.34	6.77	234.68	34.66	12.81	0.3600	1.0000	28.7269
35	40.46	69.10	-93.53	553.07	3.48	6.82	237.94	34.90	12.95	0.3600	1.0000	29.4770
36	40.41	68.35	-93.53	530.63	3.37	6.86	241.15	35.14	13.09	0.3600	1.0000	30.2270
37	40.37	67.60	-93.53	511.21	3.58	6.91	244.32	35.37	13.23	0.3600	1.0000	30.9770
38	40.32	66.85	-93.53	484.56	2.93	6.95	247.46	35.60	13.36	0.3600	1.0000	31.7271
39	40.27	66.10	-93.53	447.76	3.17	7.00	250.55	35.82	13.50	0.3600	1.0000	32.4771
40	40.23	65.36	-93.53	404.30	3.20	7.04	253.60	36.04	13.63	0.3600	1.0000	33.2271
41	40.18	64.61	-93.53	336.36	18.47	7.08	256.61	36.25	13.76	0.3600	1.0000	33.9772
42	40.14	63.86	-93.53	311.00	25.71	7.12	259.59	36.46	13.88	0.3600	1.0000	34.7272
43	40.09	63.11	-93.53	231.47	34.54	7.16	262.54	36.66	14.01	0.3600	1.0000	35.4772
44	40.04	62.36	-93.53	183.12	56.11	7.20	265.45	36.87	14.13	0.3600	1.0000	36.2272
45	40.00	61.61	-93.53	219.31	53.76	7.24	268.33	37.07	14.25	0.3600	1.0000	36.9773
46	39.95	60.86	-93.53	288.75	8.84	7.28	271.17	37.26	14.37	0.3600	1.0000	37.7273
47	39.91	60.12	-93.53	370.81	6.88	7.31	273.99	37.46	14.49	0.3600	1.0000	38.4773
48	39.86	59.37	-93.53	423.95	7.39	7.35	276.76	37.65	14.61	0.3600	1.0000	39.2274
49	39.81	58.62	-93.53	461.05	5.96	7.39	279.52	37.83	14.72	0.3600	1.0000	39.9774
50	39.77	57.87	-93.53	529.11	6.60	7.42	282.25	38.02	14.84	0.3600	1.0000	40.7274
51	39.72	57.12	-93.53	583.48	5.99	7.46	284.94	38.20	14.95	0.3600	1.0000	41.4775
52	39.67	56.37	-93.53	635.07	2.87	7.49	287.62	38.38	15.06	0.3600	1.0000	42.2275
53	39.63	55.62	-93.53	622.20	4.61	7.53	290.26	38.55	15.17	0.3600	1.0000	42.9775
54	39.58	54.88	-93.53	586.35	2.54	7.56	292.87	38.73	15.28	0.3600	1.0000	43.7276

55	39.54	54.13	-93.53	560.49	2.65	7.60	295.47	38.90	15.38	0.3600	1.0000	44.4776
56	39.49	53.38	-93.53	538.25	1.22	7.63	298.04	39.07	15.49	0.3600	1.0000	45.2276
57	39.44	52.63	-93.53	522.68	3.93	7.66	300.58	39.23	15.59	0.3600	1.0000	45.9777
58	39.40	51.88	-93.53	466.77	14.45	7.69	303.10	39.40	15.70	0.3600	1.0000	46.7277
59	39.35	51.13	-93.53	427.18	15.79	7.73	305.60	39.56	15.80	0.3600	1.0000	47.4777
60	39.30	50.38	-93.53	366.61	19.71	7.76	308.08	39.72	15.90	0.3600	1.0000	48.2278
61	39.26	49.64	-93.53	370.99	21.78	7.79	310.53	39.88	16.00	0.3600	1.0000	48.9778
62	39.21	48.89	-93.53	396.06	12.68	7.82	312.96	40.03	16.10	0.3600	1.0000	49.7278
63	39.17	48.14	-93.53	435.95	11.52	7.85	315.37	40.19	16.20	0.3600	1.0000	50.4778
64	39.12	47.39	-93.53	500.53	4.72	7.88	317.77	40.34	16.30	0.3600	1.0000	51.2279
65	39.07	46.64	-93.53	588.51	5.46	7.91	320.14	40.49	16.39	0.3600	1.0000	51.9779
66	39.03	45.89	-93.53	619.26	5.52	7.94	322.49	40.64	16.49	0.3600	1.0000	52.7279
67	38.98	45.14	-93.53	615.42	6.29	7.96	324.82	40.78	16.58	0.3600	1.0000	53.4780
68	38.94	44.40	-93.53	559.29	1.54	7.99	327.13	40.93	16.67	0.3600	1.0000	54.2280
69	38.89	43.65	-93.53	535.04	1.68	8.02	329.43	41.07	16.77	0.3600	1.0000	54.9780
70	38.84	42.90	-93.53	518.86	1.36	8.05	331.71	41.21	16.86	0.3600	1.0000	55.7281
71	38.80	42.15	-93.53	514.27	1.37	8.08	333.97	41.35	16.95	0.3600	1.0000	56.4781
72	38.75	41.40	-93.53	520.97	2.70	8.10	336.21	41.49	17.04	0.3600	1.0000	57.2281
73	38.70	40.65	-93.53	523.59	2.96	8.13	338.43	41.63	17.13	0.3600	1.0000	57.9781
74	38.66	39.90	-93.53	516.97	3.69	8.16	340.64	41.76	17.22	0.3600	1.0000	58.7282
75	38.61	39.15	-93.53	525.34	3.63	8.18	342.83	41.90	17.30	0.3600	1.0000	59.4782
76	38.57	38.41	-93.53	542.02	5.51	8.21	345.01	42.03	17.39	0.3600	1.0000	60.2282
77	38.52	37.66	-93.53	567.97	3.71	8.23	347.17	42.16	17.48	0.3600	1.0000	60.9783
78	38.47	36.91	-93.53	555.15	2.55	8.26	349.31	42.29	17.56	0.3600	1.0000	61.7283
79	38.43	36.16	-93.53	538.41	2.63	8.28	351.44	42.42	17.65	0.3600	1.0000	62.4783
80	38.38	35.41	-93.53	503.68	0.90	8.31	353.55	42.55	17.73	0.3600	1.0000	63.2284
81	38.33	34.66	-93.53	472.85	2.46	8.33	355.65	42.67	17.81	0.3600	1.0000	63.9784
82	38.29	33.91	-93.53	453.68	4.54	8.36	357.74	42.80	17.89	0.3600	1.0000	64.7284
83	38.24	33.17	-93.53	446.62	4.61	8.38	359.81	42.92	17.98	0.3600	1.0000	65.4785
84	38.20	32.42	-93.53	449.35	4.09	8.41	361.87	43.05	18.06	0.3600	1.0000	66.2285
85	38.15	31.67	-93.53	448.37	3.66	8.43	363.91	43.17	18.14	0.3600	1.0000	66.9785
86	38.10	30.92	-93.53	448.73	3.59	8.45	365.94	43.29	18.22	0.3600	1.0000	67.7285
87	38.06	30.17	-93.53	452.05	3.56	8.48	367.95	43.41	18.30	0.3600	1.0000	68.4786
88	38.01	29.42	-93.53	463.54	3.28	8.50	369.96	43.52	18.37	0.3600	1.0000	69.2286
89	37.97	28.67	-93.53	485.63	1.60	8.52	371.94	43.64	18.45	0.3600	1.0000	69.9786
90	37.92	27.93	-93.53	522.37	1.81	8.55	373.92	43.76	18.53	0.3600	1.0000	70.7287
91	37.87	27.18	-93.53	537.57	1.76	8.57	375.88	43.87	18.61	0.3600	1.0000	71.4787
92	37.83	26.43	-93.53	537.42	3.72	8.59	377.84	43.98	18.68	0.3600	1.0000	72.2287
93	37.78	25.68	-93.53	515.56	2.76	8.61	379.78	44.10	18.76	0.3600	1.0000	72.9788
94	37.73	24.93	-93.53	503.74	1.37	8.63	381.70	44.21	18.83	0.3600	1.0000	73.7288
95	37.69	24.18	-93.53	490.26	1.41	8.66	383.62	44.32	18.91	0.3600	1.0000	74.4788
96	37.64	23.43	-93.53	483.90	1.51	8.68	385.52	44.43	18.98	0.3600	1.0000	75.2289
97	37.60	22.69	-93.53	473.31	2.36	8.70	387.42	44.54	19.05	0.3600	1.0000	75.9789
98	37.55	21.94	-93.53	456.61	2.98	8.72	389.30	44.65	19.13	0.3600	1.0000	76.7289
99	37.50	21.19	-93.53	447.92	3.04	8.74	391.17	44.75	19.20	0.3600	1.0000	77.4789
100	37.46	20.44	-93.53	447.61	4.17	8.76	393.03	44.86	19.27	0.3600	1.0000	78.2290
101	37.41	19.69	-93.53	461.14	3.46	8.78	394.88	44.97	19.34	0.3600	1.0000	78.9790
102	37.36	18.94	-93.53	473.22	1.42	8.80	396.72	45.07	19.41	0.3600	1.0000	79.7290
103	37.32	18.19	-93.53	490.50	1.37	8.82	398.54	45.17	19.48	0.3600	1.0000	80.4791
104	37.27	17.45	-93.53	509.06	1.38	8.84	400.37	45.28	19.55	0.3600	1.0000	81.2291
105	37.23	16.70	-93.53	530.75	4.08	8.86	402.17	45.38	19.62	0.3600	1.0000	81.9791
106	37.18	15.95	-93.53	545.75	4.11	8.88	403.97	45.48	19.69	0.3600	1.0000	82.7292
107	37.13	15.20	-93.53	557.13	4.03	8.90	405.75	45.58	19.76	0.3600	1.0000	83.4792
108	37.09	14.45	-93.53	565.69	3.78	8.92	407.53	45.68	19.83	0.3600	1.0000	84.2292
109	37.04	13.70	-93.53	577.59	1.72	8.94	409.30	45.78	19.89	0.3600	1.0000	84.9793
110	37.00	12.95	-93.53	601.19	0.55	8.96	411.06	45.88	19.96	0.3600	1.0000	85.7293
111	36.95	12.21	-93.53	627.39	0.53	8.98	412.81	45.98	20.03	0.3600	1.0000	86.4793
112	36.90	11.46	-93.53	647.95	1.26	9.00	414.55	46.07	20.09	0.3600	1.0000	87.2294
113	36.86	10.71	-93.53	674.59	1.60	9.02	416.28	46.17	20.16	0.3600	1.0000	87.9794
114	36.81	9.96	-93.53	695.38	0.43	9.04	418.00	46.26	20.22	0.3600	1.0000	88.7294

	115	36.76	9.21	-93.53	709.09	0.42	9.05	419.71	46.36	20.29	0.3600	1.0000	89.4794
	116	36.72	8.46	-93.53	717.26	0.33	9.07	421.42	46.45	20.35	0.3600	1.0000	90.2295
	117	36.67	7.71	-93.53	727.56	0.33	9.09	423.11	46.55	20.42	0.3600	1.0000	90.9795
	118	36.63	6.97	-93.53	738.20	0.33	9.11	424.80	46.64	20.48	0.3600	1.0000	91.7295
	119	36.58	6.22	-93.53	747.37	0.33	9.13	426.47	46.73	20.54	0.3600	1.0000	92.4796
	120	36.53	5.47	-93.53	757.10	1.01	9.14	428.14	46.82	20.61	0.3600	1.0000	93.2296
	121	36.49	4.72	-93.53	744.02	2.28	9.16	429.80	46.91	20.67	0.3600	1.0000	93.9796
	122	36.44	3.97	-93.53	716.16	1.78	9.18	431.46	47.00	20.73	0.3600	1.0000	94.7297
	123	36.40	3.22	-93.53	688.89	1.86	9.20	433.10	47.09	20.79	0.3600	1.0000	95.4797
	124	36.35	2.47	-93.53	665.94	2.46	9.21	434.74	47.18	20.85	0.3600	1.0000	96.2297
*	125	36.30	1.73	-93.53	632.64	0.81	9.23	436.37	47.27	20.91	0.3600	1.0000	96.9798
	126	36.26	0.98	-93.53	632.64	0.81	9.23	436.37	47.27	20.91	0.3600	1.0000	96.9798

RAY STOPPED, REACHED BOUNDARY. X = 36.26, Y = 0.98, ELAPSED TIME = 4.20 HOURS

NEW HAMPSHIRE COAST INNER RAYS IN U = 50 KNOTS DATE 2/23/73
SET NO. 1, PERIOD = 9.23 SECS., RAY NO. 4, INITIAL TIME STEP = 48.2 MIN., WIND VELOCITY =50.0 KNOTS

POINT	X (GU)	Y (GU)	ANGLE (DEG)	DEPTH (FT)	MAX DIF (PERCENT)	PERIOD (SEC)	LENGTH (FT)	SPEED (FPS)	HEIGHT (FT)	KR (DIMENSIONLESS)	KS (DIMENSIONLESS)	FETCH (NM)
1	42.61	47.45	-93.53	633.64		9.23	436.22	47.26	20.87			95.7602
2	42.56	46.70	-93.53	610.42	0.99	9.21	434.54	47.17	20.85	0.3600	1.0000	96.1395
3	42.52	45.95	-93.53	577.82	1.41	9.22	435.36	47.21	20.88	0.3600	1.0000	96.5145
4	42.47	45.20	-93.53	542.77	1.50	9.23	436.17	47.26	20.91	0.3600	1.0000	96.8895
5	42.43	44.46	-93.53	505.76	10.47	9.24	436.99	47.30	20.94	0.3600	1.0000	97.2645
6	42.38	43.71	-93.53	432.60	13.85	9.25	437.79	47.35	20.97	0.3600	1.0000	97.6395
7	42.33	42.96	-93.53	341.93	1.34	9.26	438.60	47.39	21.00	0.3600	1.0000	98.0145
8	42.29	42.21	-93.53	273.59	1.68	9.26	439.40	47.43	21.03	0.3600	1.0000	98.3895
9	42.24	41.46	-93.50	228.21	0.76	9.26	438.14	47.30	20.83	0.3594	0.9922	98.3880
10	42.20	40.71	-93.44	191.04	5.45	9.21	430.83	46.79	20.65	0.3595	0.9832	95.9384
11	42.15	39.97	-93.44	184.18	3.07	9.16	425.62	46.48	20.64	0.3599	0.9814	93.7474
12	42.11	39.22	-93.50	209.67	2.70	9.15	427.11	46.67	20.80	0.3600	0.9894	93.5513
13	42.06	38.48	-93.54	287.22	11.58	9.20	433.10	47.08	20.98	0.3599	0.9982	95.5678
14	42.01	37.74	-93.55	364.88	5.42	9.25	437.96	47.35	20.99	0.3596	0.9997	97.7364
15	41.97	36.99	-93.55	383.37	12.47	9.25	438.46	47.38	20.98	0.3594	0.9998	97.9629
16	41.92	36.24	-93.55	403.56	11.85	9.25	438.15	47.37	20.97	0.3592	0.9999	97.8160
17	41.87	35.49	-93.55	401.67	10.72	9.25	437.82	47.35	20.96	0.3589	0.9999	97.6604
18	41.83	34.74	-93.55	429.71	6.16	9.24	437.44	47.33	20.94	0.3587	1.0000	97.4860
19	41.78	33.99	-93.55	461.00	7.96	9.24	437.10	47.31	20.93	0.3584	1.0000	97.3263
20	41.73	33.24	-93.55	485.23	7.56	9.24	436.74	47.29	20.92	0.3582	1.0000	97.1604
21	41.69	32.50	-93.55	501.33	6.49	9.23	436.38	47.27	20.90	0.3580	1.0000	96.9902
22	41.64	31.75	-93.55	530.19	3.34	9.23	436.01	47.25	20.89	0.3577	1.0000	96.8191
23	41.59	31.00	-93.55	559.69	1.88	9.22	435.64	47.23	20.87	0.3575	1.0000	96.6482
24	41.55	30.25	-93.55	577.77	1.82	9.22	435.26	47.21	20.86	0.3573	1.0000	96.4775
25	41.50	29.50	-93.55	594.24	3.05	9.22	434.89	47.19	20.85	0.3570	1.0000	96.3069
26	41.46	28.75	-93.55	593.47	2.97	9.21	434.52	47.17	20.83	0.3568	1.0000	96.1366
27	41.41	28.00	-93.55	599.23	2.94	9.21	434.15	47.15	20.82	0.3566	1.0000	95.9662
28	41.36	27.25	-93.55	588.98	1.69	9.20	433.78	47.13	20.80	0.3563	1.0000	95.7970
29	41.32	26.50	-93.55	597.50	2.04	9.20	433.42	47.11	20.79	0.3561	1.0000	95.6280
30	41.27	25.76	-93.55	597.86	1.35	9.20	433.05	47.09	20.78	0.3559	1.0000	95.4599
31	41.22	25.01	-93.55	595.71	1.36	9.19	432.68	47.07	20.76	0.3556	1.0000	95.2921
32	41.18	24.26	-93.55	582.02	0.89	9.19	432.31	47.05	20.75	0.3554	1.0000	95.1252
33	41.13	23.51	-93.55	574.70	2.43	9.18	431.95	47.03	20.74	0.3552	1.0000	94.9585
34	41.08	22.76	-93.55	563.18	3.08	9.18	431.58	47.01	20.72	0.3549	1.0000	94.7928
35	41.04	22.01	-93.55	564.23	3.07	9.18	431.22	46.99	20.71	0.3547	1.0000	94.6273
36	40.99	21.26	-93.55	569.51	2.99	9.17	430.86	46.97	20.69	0.3545	1.0000	94.4628
37	40.94	20.51	-93.55	553.80	2.45	9.17	430.49	46.95	20.68	0.3542	1.0000	94.2984
38	40.90	19.76	-93.55	540.28	2.05	9.17	430.13	46.93	20.67	0.3540	1.0000	94.1351
39	40.85	19.02	-93.55	521.83	2.12	9.16	429.77	46.91	20.65	0.3538	1.0000	93.9719
40	40.80	18.27	-93.55	505.27	1.74	9.16	429.41	46.89	20.64	0.3536	1.0000	93.8089
41	40.76	17.52	-93.55	485.20	0.92	9.15	429.05	46.87	20.63	0.3533	1.0000	93.6460
42	40.71	16.77	-93.55	477.14	1.13	9.15	428.69	46.85	20.61	0.3531	1.0000	93.4832
43	40.66	16.02	-93.55	467.98	1.16	9.15	428.33	46.83	20.60	0.3529	1.0000	93.3215
44	40.62	15.27	-93.55	460.19	1.53	9.14	427.98	46.81	20.59	0.3526	1.0000	93.1597
45	40.57	14.52	-93.55	446.51	2.36	9.14	427.62	46.79	20.57	0.3524	1.0000	92.9993
46	40.53	13.77	-93.55	431.11	3.83	9.13	427.26	46.77	20.56	0.3522	1.0000	92.8390
47	40.48	13.02	-93.55	426.45	3.88	9.13	426.90	46.75	20.55	0.3520	1.0000	92.6750
48	40.43	12.28	-93.55	434.35	5.96	9.13	426.54	46.73	20.53	0.3517	1.0000	92.5158
49	40.39	11.53	-93.55	433.72	2.79	9.12	426.19	46.71	20.52	0.3515	1.0000	92.3573
50	40.34	10.78	-93.55	406.63	1.59	9.12	425.84	46.69	20.51	0.3513	0.9999	92.2012
51	40.29	10.03	-93.55	389.15	1.66	9.12	425.46	46.67	20.49	0.3511	0.9999	92.0345
52	40.25	9.28	-93.55	368.93	1.33	9.11	425.08	46.65	20.48	0.3508	0.9998	91.8570
53	40.20	8.53	-93.55	357.50	1.45	9.11	424.68	46.63	20.46	0.3506	0.9998	91.6907
54	40.15	7.78	-93.55	343.23	1.44	9.10	424.27	46.61	20.45	0.3504	0.9996	91.5141

	55	40.11	7.03	-93.55	330.93	1.50	9.10	423.84	46.58	20.43	0.3502	0.9995	91.3308
	56	40.06	6.29	-93.55	316.43	1.25	9.09	423.39	46.56	20.41	0.3499	0.9993	91.1422
	57	40.01	5.54	-93.55	304.87	1.87	9.09	422.90	46.53	20.39	0.3497	0.9991	90.9345
	58	39.97	4.79	-93.55	303.19	2.84	9.08	422.43	46.50	20.38	0.3495	0.9990	90.7262
	59	39.92	4.04	-93.55	301.33	2.86	9.08	422.07	46.48	20.37	0.3493	0.9990	90.5731
	60	39.87	3.29	-93.55	302.43	0.89	9.08	421.73	46.46	20.36	0.3491	0.9990	90.4185
	61	39.83	2.54	-93.55	303.32	1.02	9.07	421.43	46.45	20.34	0.3489	0.9991	90.2823
*	62	39.78	1.79	-93.55	283.49	9.31	9.07	421.03	46.42	20.32	0.3486	0.9984	90.1411
	63	39.74	1.04	-93.55	279.66	9.44	9.06	420.32	46.38	20.30	0.3484	0.9983	89.8393
	64	39.74	1.04	-93.55	279.67	9.44	9.06	420.32	46.38	20.30	0.3484	0.9983	89.6550

RAY STOPPED, REACHED BOUNDARY. X = 39.74, Y = 1.04, ELAPSED TIME = 0.84 HOURS

NEW HAMPSHIRE COAST INNER INNER RAYS IN U = 50 KNOTS DATE 2/23/73
SET NO. 1, PERIOD = 9.07 SECS., RAY NO. 4, INITIAL TIME STEP = 24.5 MIN. , WIND VELOCITY =50.0 KNOTS

POINT	X (GU)	Y (GU)	ANGLE (DEG)	DEPTH (FT)	MAX DIF (PERCENT)	PERIOD (SEC)	LENGTH (FT)	SPEED (FPS)	HEIGHT (FT)	KR (DIMENSIONLESS)	KS (DIMENSIONLESS)	FETCH (NM)
1	59.56	61.59	-93.55	294.49		9.07	421.23	46.44	20.30			89.0869
2	59.51	60.84	-93.55	283.21	2.75	9.05	419.25	46.33	20.27	0.3500	1.0000	89.2784
3	59.47	60.09	-93.55	276.66	2.81	9.05	419.68	46.36	20.29	0.3500	1.0000	89.4659
4	59.42	59.34	-93.55	276.64	2.99	9.06	420.10	46.38	20.30	0.3500	1.0000	89.6534
5	59.37	58.60	-93.55	281.81	1.13	9.06	420.52	46.40	20.32	0.3500	1.0000	89.8409
6	59.33	57.85	-93.55	280.71	1.51	9.07	420.95	46.43	20.33	0.3500	1.0000	90.0284
7	59.28	57.10	-93.55	277.12	1.53	9.07	421.38	46.45	20.35	0.3500	1.0000	90.2159
8	59.23	56.35	-93.55	269.04	2.14	9.08	421.80	46.47	20.37	0.3500	1.0000	90.4034
9	59.19	55.60	-93.55	257.34	4.52	9.08	422.23	46.50	20.38	0.3500	1.0000	90.5909
10	59.14	54.85	-93.55	251.37	5.14	9.08	421.75	46.44	20.23	0.3486	0.9964	90.5898
11	59.10	54.10	-93.56	244.37	5.29	9.04	417.56	46.21	20.22	0.3486	0.9960	88.7774
12	59.05	53.35	-93.57	241.40	3.28	9.03	417.27	46.19	20.21	0.3485	0.9957	88.6702
13	59.00	52.61	-93.57	228.87	4.25	9.03	416.82	46.15	20.18	0.3485	0.9941	88.5869
14	58.96	51.86	-93.56	226.35	6.72	9.02	415.88	46.10	20.17	0.3485	0.9938	88.2038
15	58.91	51.11	-93.54	223.35	6.81	9.02	415.62	46.08	20.16	0.3485	0.9934	88.1235
16	58.86	50.36	-93.50	213.00	7.91	9.02	414.97	46.02	20.12	0.3484	0.9915	87.9852
17	58.82	49.62	-93.44	209.28	6.03	9.00	413.75	45.95	20.09	0.3481	0.9909	87.5014
18	58.77	48.87	-93.42	202.20	4.37	9.00	412.61	45.87	20.08	0.3476	0.9893	87.1306
19	58.73	48.12	-93.42	196.71	4.49	8.98	410.81	45.75	19.98	0.3472	0.9881	86.4623
20	58.68	47.38	-93.42	197.40	6.62	8.97	409.66	45.69	19.97	0.3469	0.9884	85.9336
21	58.64	46.63	-93.46	189.70	7.05	8.96	408.94	45.63	19.92	0.3467	0.9862	85.8313
22	58.59	45.89	-93.56	171.25	6.79	8.95	405.88	45.36	19.77	0.3465	0.9795	85.2372
23	58.55	45.14	-93.70	156.94	7.41	8.91	400.28	44.95	19.63	0.3461	0.9731	83.6391
24	58.50	44.40	-93.93	136.77	10.29	8.87	392.48	44.27	19.38	0.3457	0.9612	82.1293
25	58.44	43.67	-94.28	139.98	17.17	8.79	387.64	44.08	19.54	0.3474	0.9650	79.5183
26	58.39	42.94	-94.77	132.49	13.67	8.84	389.21	44.03	19.55	0.3499	0.9587	81.2951
27	58.32	42.21	-95.16	118.73	15.26	8.85	384.47	43.46	19.44	0.3518	0.9477	81.6220
28	58.26	41.49	-94.54	88.03	6.51	8.82	362.12	41.08	19.07	0.3535	0.9235	80.5934
29	58.22	40.80	-92.17	74.22	11.81	8.71	340.95	39.16	18.97	0.3540	0.9163	76.5056
30	58.22	40.14	-87.99	70.08	12.51	8.67	333.69	38.48	18.79	0.3506	0.9148	74.8451
31	58.27	39.49	-82.85	63.63	34.91	8.62	321.86	37.34	18.31	0.3403	0.9132	73.0429
32	58.37	38.85	-79.07	86.99	36.94	8.49	340.67	40.11	17.86	0.3253	0.9277	69.8346
33	58.52	38.17	-77.10	97.90	32.82	8.39	341.08	40.67	17.11	0.3055	0.9396	67.7823
34	58.69	37.46	-76.12	116.03	14.73	8.18	333.79	40.82	16.44	0.2854	0.9609	62.1569
35	58.87	36.73	-75.63	105.43	8.70	7.98	316.25	39.64	15.36	0.2665	0.9563	56.8391
36	59.06	36.00	-75.18	95.58	5.95	7.65	290.21	37.94	14.47	0.2499	0.9550	48.3442
37	59.26	35.27	-74.72	90.20	6.31	7.37	269.86	36.62	13.74	0.2356	0.9566	41.9847
38	59.46	34.56	-74.39	88.98	7.00	7.14	254.38	35.65	13.13	0.2230	0.9616	37.2445
39	59.66	33.82	-74.16	88.73	2.24	6.94	241.65	34.83	12.59	0.2121	0.9667	33.5554
40	59.87	33.09	-74.00	87.47	2.28	6.76	230.16	34.04	12.10	0.2024	0.9702	30.4921
41	60.08	32.37	-73.91	86.32	4.10	6.59	219.40	33.28	11.64	0.1937	0.9734	27.7721
42	60.29	31.64	-73.88	84.51	3.24	6.44	209.54	32.55	11.21	0.1857	0.9757	25.4291
43	60.50	30.91	-73.93	74.35	16.19	6.29	198.75	31.61	10.73	0.1785	0.9686	23.3002
44	60.71	30.18	-74.12	74.59	16.14	6.11	188.73	30.87	10.44	0.1725	0.9739	21.0072
45	60.91	29.46	-74.40	78.20	14.89	6.01	183.10	30.48	10.19	0.1671	0.9804	19.6748
46	61.11	28.73	-74.57	91.36	11.93	5.92	178.70	30.20	10.01	0.1622	0.9913	18.5695
47	61.31	28.00	-74.63	89.44	12.19	5.85	174.66	29.86	9.74	0.1576	0.9914	17.7886
48	61.51	27.27	-74.71	80.40	15.69	5.75	168.31	29.28	9.44	0.1534	0.9879	16.6775
49	61.71	26.54	-74.85	71.22	17.33	5.64	161.48	28.64	9.16	0.1495	0.9828	15.5469
50	61.91	25.80	-75.17	65.74	19.59	5.53	155.12	28.05	8.93	0.1460	0.9798	14.4980
51	62.10	25.07	-75.62	68.76	6.90	5.44	150.63	27.68	8.80	0.1431	0.9852	13.6428
52	62.28	24.34	-75.98	62.44	23.25	5.39	147.28	27.33	8.55	0.1395	0.9798	13.1395
53	62.47	23.61	-76.15	58.96	20.11	5.29	141.65	26.79	8.35	0.1363	0.9784	12.2515
54	62.65	22.88	-76.18	74.01	22.80	5.21	138.59	26.61	8.32	0.1338	0.9931	11.6007

55	62.83	22.15	-76.12	72.07	23.41	5.20	137.87	26.53	8.16	0.1313	0.9923	11.4998
56	63.01	21.41	-75.97	65.26	30.15	5.13	134.39	26.17	7.98	0.1289	0.9889	11.0290
57	63.19	20.68	-75.82	63.65	33.47	5.07	130.80	25.82	7.84	0.1265	0.9889	10.5244
58	63.38	19.95	-75.79	60.20	9.81	5.01	127.81	25.51	7.69	0.1242	0.9871	10.1312
59	63.56	19.22	-75.86	59.76	9.88	4.95	124.76	25.21	7.57	0.1222	0.9881	9.7050
60	63.75	18.48	-76.10	53.38	14.01	4.90	121.99	24.89	7.42	0.1204	0.9822	9.3806
61	63.92	17.75	-76.58	50.65	13.68	4.84	118.69	24.54	7.30	0.1187	0.9804	8.9462
62	64.10	17.02	-77.05	53.02	15.46	4.79	116.54	24.35	7.22	0.1167	0.9849	8.5965
63	64.26	16.29	-77.45	51.25	8.90	4.75	114.64	24.14	7.07	0.1144	0.9838	8.3404
64	64.42	15.55	-77.96	45.05	9.17	4.69	111.14	23.71	6.87	0.1118	0.9761	7.9532
65	64.57	14.81	-78.72	38.62	7.03	4.60	106.05	23.06	6.62	0.1088	0.9659	7.4181
66	64.71	14.07	-80.03	30.82	8.81	4.49	99.18	22.09	6.31	0.1052	0.9484	6.8098
67	64.83	13.34	-81.99	21.33	9.42	4.35	88.13	20.25	5.93	0.1009	0.9231	6.0768
68	64.91	12.63	-84.73	13.72	21.02	4.18	73.71	17.64	5.65	0.0964	0.9131	5.2525
69	64.95	12.00	-89.03	6.71	46.85	4.05	54.50	13.46	5.65	0.0920	0.9549	4.6824
70	64.93	11.51	-95.40	2.18	144.48	4.04	32.89	8.14	6.49	0.0883	1.1588	4.6236
71	64.93	11.51	-95.40	-0.20	-1593.71	4.42	32.89	8.14	6.49	0.0883	1.1588	6.3049

RAY STOPPED, REACHED SHORE. X = 64.93, Y=, 11.51, ELAPSED TIME = 0.64 HOURS