OIL SPILL TRAJECTORY MODEL FOR WINYAH BAY, SOUTH CAROLINA

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INTRODUCTION

Purpose of Study

The construction of a 30,000 barrel per day oil refinery is planned for Georgetown, South Carolina to be located on the Sampit River at the upper end of Winyah Bay. With the significant increase in tanker and barge traffic in the bay, there will be an increased probability of an oil spill. The purpose of the present study was to develop an oil spill trajectory model, so that it would be available in the event that it is needed in the future. Three versions of the model are presented:

1. WBO/TRS-80 - microcomputer version
2. WBO-TI-59 - programmable calculator version
3. WBO/manual - manual version

Acknowledgements

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Previous Works

Numerous studies have been performed that relate to or resulted in the formulation of an oil spill model of various types. An excellent review of these is found in Stolzenback and others (1977). The emphasis in most of these works is on offshore oil spills. Certain portions, however, were found to be pertinent to the present study. A review compiled by Bishop (1980) was found to be helpful.

The most important recent work in this area is being performed by Jerry Galt and others at Modeling and Simulation Studies, Office of Marine Pollution Assessment, NOAA. They have developed a set of computer programs named "Streamline Analysis of Currents (SAC)" that computes the surface current vectors in regions where geographic boundaries are present, such as in an estuary like Winyah Bay. This model is described in Galt and Payton (1981) and was used to generate the surface current information for the present study.

Note on Units of Measure

It will be noticed by the user of the WBO model that there is an inconsistency of the units of measure used. In some places British Units are called for and in other places metric (SI) units are used. For example, U. S. bathymetric charts give depths in feet; NOAA Tide Tables are in hours and feet; U.S.G.S. river stages are reported in feet and discharge in cubic feet per second (cfs). The tide and river current velocities used in the model that were computed for Winyah Bay by the SAC model of NOAA are expressed in cm/sec. Wind velocity is usually measured in miles per hour. Input to the model will be in the most commonly used units and will be specified by the model so that there will be no confusion. The model itself will make the necessary conversions, thus relieving the user of this added opportunity for error.

Geographic Setting

Winyah Bay is an estuary located approximately 50 miles (80 km) northeast of Charleston, South Carolina (Fig. 1). The bay heads at the confluence of the Pee Dee and Waccamaw Rivers and extends southward for approximately 13 miles (21 km) to its outlet to the Atlantic Ocean. The area of the bay is 19.2 mi^2 (49.7 km^2). Mean tidal range varies from 3.8 ft (1.2 m) at the lighthouse (south end) and 3.3 ft (1.0 m) at the Hwy. 17 bridge (north end).

Three rivers, the Pee Dee, the Sampit, and the Waccamaw, flow into the estuary. They have a combined mean discharge of about 16,289 ft^3/s (462 m^3/s). The Pee Dee system accounts for over 92% of the total.

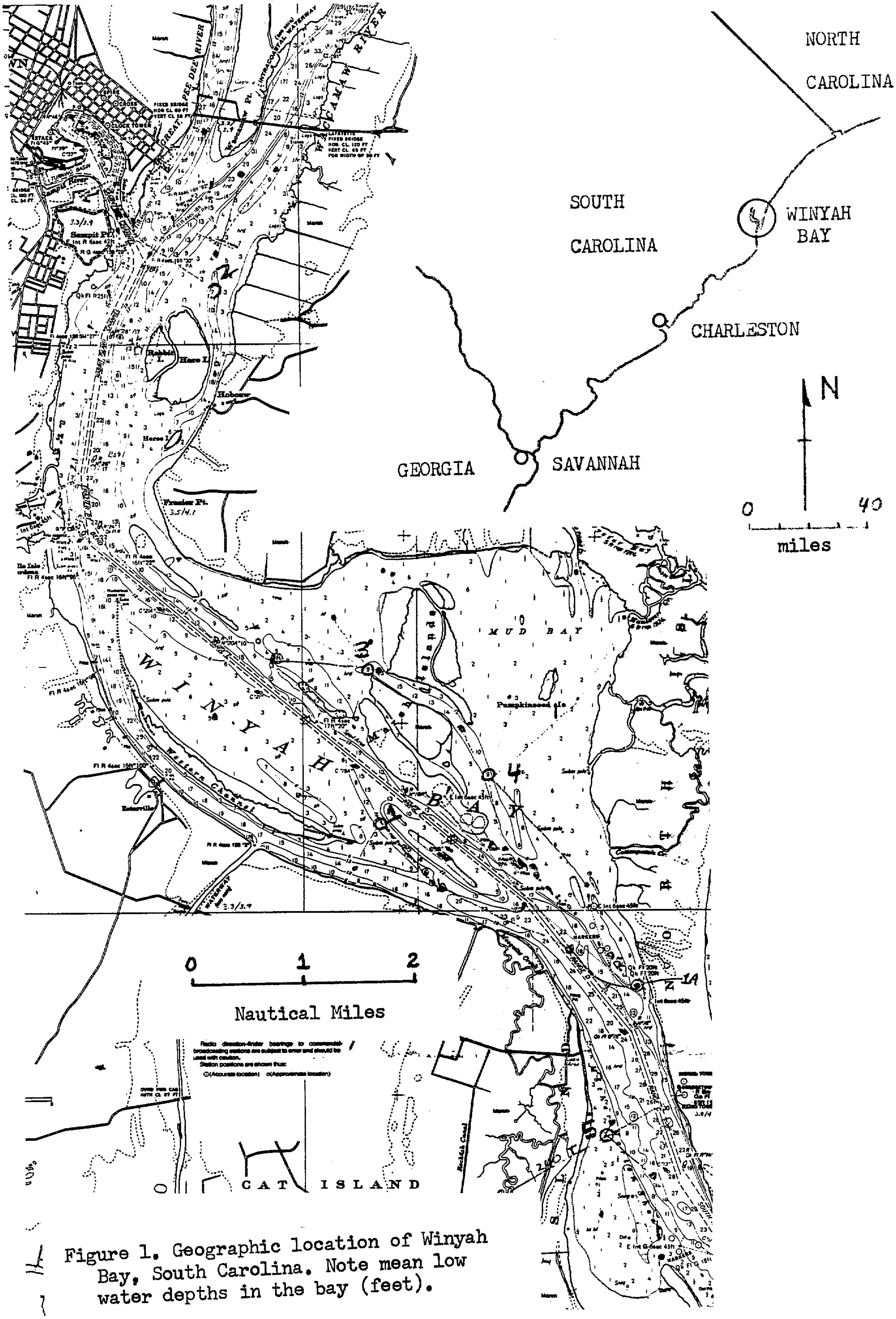


Figure 1. Geographic location of Winyah Bay, South Carolina. Note mean low water depths in the bay (feet).

MODEL DESCRIPTION

Introduction

The Winyah Bay Oil Spill (WBO) Model is based on vector addition of surface currents. It is assumed that, because of the narrow confines of the bay, spreading and aging of an oil slick are of minor significance when compared to advection, or lateral displacement, of the slick. Spreading will be important when the spill occurs very near to the shoreline. However, if this occurs, we don't need a model to indicate where the landfall may be.

There are three major types of surface currents acting simultaneously at any specified time and location in the bay: (1) Tidal currents are periodic and reversing over the 12.5 hour tidal cycle. They also vary in magnitude over the 28 day lunar cycle. (2) River currents due to the influx from the Waccamaw and Pee Dee Rivers vary with river discharge. (3) Wind-driven currents (leeway) vary with wind velocity and direction. Through the simultaneous consideration of these three types of current vectors, the path of a particle on the water surface during a specified time interval can be computed.

The WBO model determines the location of the oilspill front and computes its geographic coordinates. These coordinates are plotted on a gridded base map in order to illustrate the geographic position of the spill at any specified time. By knowing the anticipated position of the spill at a future time, informed decisions can be made concerning cleanup plans.

Three versions of the WBO model are presented: (1) microcomputer; (2) programmable calculator; and (3) manual. The microcomputer version was developed for a TRS-80. The programs are written in the BASIC language (TRS Level II BASIC). With minor modification, they can be adapted for use on other types of computer facilities. Hardware requirements include hardcopy printer and two disk drives (or equivalent, such as hard disk).

The programmable calculator version was developed using a Texas Instruments TI-59. This calculator uses magnetic cards for program and data storage. Though slower than the microcomputer version, one can still predict the successive positions of an oil spill for 15 minute increments during a complete tidal half-cycle in less than 15 minutes. The required calculator for this version costs about $200 (June 1982), or less than one-tenth the cost of a microcomputer needed for version 1. The accuracy is not significantly less than that of the microcomputer version.

The manual version of the model is slow and tedious. It should be used only under emergency circumstances when the use of versions 1 or 2 is not possible. However, with frequent practice, a technician could manually compute the successive positions of the spill using the same mathematics that the computer uses. The catch is that unless performed quickly and correctly, the spill could move as fast or faster than one could compute its location. For this reason, it should be used only as a last resort.

As with any numerical model of a continuous natural system, certain simplifying assumptions must be made in order to facilitate the mathematical formulation. These inevitably lead to minor errors.

Additionally, digitization of the continuous number field of surface currents into discrete values causes local inaccuracies. Due to these considerations, extensive field measurements were made in order to calibrate and verify the model. In spite of all efforts to make the model accurate, it must be remembered that the model can only approximate the natural system and that allowances must be made for the variance between the predicted and the actual location of the oil spill front. As these variances accumulate with time, additional caution must be exercised as spill duration increases.

Time notation is different for each of the three versions of the model. For WBO/TRS-80, time is entered in hours and minutes (24 hour clock). The computer converts to fractional hours for computational purposes. For WBO/TI-59, time is entered in hours and minutes, but separated by a decimal. The calculator converts to fractional hours for computational purposes. For WBO/manual, time can be entered either as hours and minutes or as fractional hours. Tide Tables read in hours and minutes, but computation is easier in fractional hours. The user must decide which he wants to use, and then must be consistent. An example of time notation for each version of the model is given below:

Actual Time	WBO/TRS-80	WBO/TI-59	WBO/manual
9:30 AM	0930	09.30	0930 or 9.5
3:15 PM	1515	15.15	1515 or 15.25
Noon	1200	12.00	1200 or 12.00
Midnight	0000	00.00	0000 or 00.00

In order to accurately predict the path of the oil spill front from a specified location during a specified time interval, one must be able to estimate the magnitude and direction of the local tidal, river, and wind-driven surface currents. The methods used in estimating these currents are described, individually, in the following sections.

Tidal Currents

A matrix of mean maximum tidal currents was developed by J. A. Galt and Glen Watabayashi (Special Projects Office, Modeling and Simulation Studies, NOAA) for the WBO model using their computer program SAC (Streamline Analysis of Currents). SAC is a set of programs based on a finite element mathematical model that was developed especially for cases where boundary geometry exerts a significant effect on streamflow, as in the case of Winyah Bay. In order to separate the effects of tidal and river flow, the tidal model was run assuming zero river flow. River flow was run separately and is discussed later.

The results of the SAC calculations were checked and calibrated by comparison to measured data collected during a field study of the currents in the bay. The computed surface currents are given in Tables I and II. The SAC model assumes that, in the absence of river flow, the ebb and flood phases of tidal flow are equal in magnitude and reciprocal in direction.

Table I gives the ebb currents in the X (East-West) direction. Table II gives ebb currents in the Y (North-South) direction. These two current components are added vectorally to produce the net, or resultant, current for the specified location.

TABLE I. East-west component of tidal currents (cm/sec).

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
39	0	0	0	0	0	0	0	0	-6	-8	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	-6	0	-11	-6	-7	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	-11	-9	-12	-6	-7	0	0	0	0	0	0	0	0	0	0	0	0	0
36	12	12	8	-10	-17	-13	-13	-7	-7	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	6	8	-11	-17	-14	-13	-7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	-9	-15	-15	-8	-7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	-14	-22	-9	-16	-6	-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	-12	-8	-12	-25	0	-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	-12	-17	-34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	-3	-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	-9	-19	-2	19	-14	-8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	-17	-23	-16	-14	-7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	34	-12	0	-13	-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	-22	0	0	18	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	9	33	24	26	6	0	0	0	7	10	10	19	17	8	5	4	4	3	0	0	0
22	16	5	39	34	32	12	13	18	16	15	16	26	25	23	11	9	3	3	0	0	0	0
21	0	8	21	27	37	28	26	32	30	15	13	8	0	13	10	8	5	4	0	0	0	0
20	0	7	11	21	45	42	35	28	32	21	9	4	0	0	0	5	3	3	-2	0	0	0
19	0	6	7	14	43	50	50	34	27	28	2	0	0	0	0	1	1	-1	-3	0	0	0
18	0	0	10	18	21	24	39	33	27	28	0	0	0	0	0	-2	-1	0	0	0	0	0
17	0	0	8	22	11	6	27	28	29	29	18	0	0	-14	-3	-3	-1	0	0	0	0	0
16	0	0	0	21	19	6	10	12	31	31	31	25	19	25	-1	-1	0	0	0	0	0	0
15	0	0	0	0	26	13	9	5	19	21	31	26	29	34	0	0	0	2	1	0	0	0
14	0	0	0	0	0	0	19	5	4	7	32	34	38	32	33	1	0	0	3	0	0	0
13	0	0	0	0	0	0	0	0	18	15	29	26	39	33	33	31	20	20	6	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	23	49	55	54	42	35	21	9	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	56	56	84	53	15	13	12	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	36	25	14	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	38	26	15	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34	26	20	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	33	32	31	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	33	41	34	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39	33	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42	42	32
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-17	-7	37	37	30
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-17	0	30	30	26
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	24	84	69
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27	38	38	119	84

TABLE II. North-south component of tidal currents (cm/sec).

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
39	0	0	0	0	0	-23	0	-17	-16	-15	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	-12	-23	-11	-16	-15	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	-22	-22	-12	-15	-15	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	-8	-10	-22	-26	-19	-14	-14	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	-6	-8	-19	-24	-26	-18	-14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	-27	-32	-25	-25	-15	-14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	-14	-22	-33	-32	-20	-12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	-32	-35	-37	-25	-17	-11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	-32	-41	-34	0	-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	-14	-40	-46	0	0	-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	-36	-57	-47	-19	-14	-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	-45	-55	-37	-15	-14	-14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	-34	-57	-43	-14	-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	-44	-66	-46	-24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	-45	-68	-51	-25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	-44	-67	-62	-18	-8	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	-35	-45	-54	-32	-26	-3	0	0	0	7	0	0	0	0	0	0	0	0	-3	0	0	0
22	-16	-30	-48	-40	-43	-12	-7	0	0	9	3	0	0	-11	-7	-3	-5	-5	-6	0	0	0
21	0	-24	-44	-39	-44	-28	-26	-12	-17	9	4	16	0	-13	-13	-13	-5	-6	-7	0	0	0
20	0	-22	-34	-28	-29	-29	-35	-28	-23	-5	0	8	0	0	-17	-17	-7	-7	-7	0	0	0
19	0	-19	-22	-12	-22	-30	-31	-22	-27	-28	-4	0	0	0	-18	-19	-11	-11	-10	0	0	0
18	0	0	-20	-18	-14	-14	-31	-26	-27	-28	-24	0	0	0	-15	-17	-11	-12	0	0	0	0
17	0	0	-16	-22	-11	-6	-26	-24	-25	-27	-35	0	0	-14	-15	-15	-12	-13	0	0	0	0
16	0	0	0	-21	-19	-6	-10	-10	-26	-27	-24	-17	-13	-25	-17	-17	-16	-14	0	0	0	0
15	0	0	0	0	-12	-7	-9	-5	-10	-19	-24	-22	-29	-23	-28	-17	-18	-14	-4	0	0	0
14	0	0	0	0	0	0	-9	-2	-3	-5	-25	-24	-43	-32	-33	-18	-19	-14	-11	0	0	0
13	0	0	0	0	0	0	0	0	-6	-5	-9	-17	-43	-41	-42	-31	-30	-12	-23	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	-9	-20	-22	-40	-56	-35	-30	-34	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	-22	-22	-34	-76	-45	-41	-49	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-94	-100	-68	-57	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-95	-103	-70	-59	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-104	-91	-80	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-102	-101	-100	-94	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-101	-101	-127	-104	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-107	-120	-103	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-122	-116	-116	-97
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-34	-37	-101	-101	-93
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-34	-38	-83	-83	-79
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-38	-36	-29	-40	-60
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-27	0	0	0	-84

River Currents

The SAC Model was also used to estimate surface currents in Winyah Bay that result from river influx from the Pee Dee, Sampit, and Waccamaw Rivers in the north end of the estuary. The results are shown in Tables III and IV. Unlike tidal currents, river currents are always directed downstream. When added algebraically to the tidal currents, they add a downstream bias; hence, the net ebb currents are always stronger and of greater duration than the net flood currents.

The magnitude of the river currents varies with stream discharge. Tables III and IV are based on mean flow conditions. The use of this data by the WBO model requires a correction for river discharge at the time of the spill. River stages at several upstream stations are published daily and the correction for these variations can be made easily using established stage/discharge relationships. As a general rule, the stages published in the newspaper are for the previous day. Since it takes about one day for the effects measured at the station to reach the bay, it is appropriate to use the previous day values.

Table V is a compilation of rating tables for the significant rivers that enter Winyah Bay. The variation in their combined discharge affects the magnitude of river-caused currents in the bay and must be corrected for.

All three versions of the model require as input the total river discharge for the day preceding the spill. This is computed as follows:

1. From the Columbia SC newspaper, The State, note the river stage (under the heading "Stg") of the following rivers:

    a. Pee Dee (Pee Dee River at Pee Dee, SC)
    b. Effingham (Lynches River at Effingham, SC)
    c. Galivants Ferry (Little Pee Dee River at Galivants Ferry, SC)
    d. Kingstree (Black River at Kingstree, SC)

2. Use Table V to convert each stage measurement to discharge in cubic feet per second (cfs).

3. Total the four discharges and enter as Pee Dee discharge when requested by the model.

(Note that the Waccamaw River is not reported in the newspaper. The model uses the mean value for the Waccamaw. Since the Waccamaw discharge is only 7% of the total, the error introduced by this procedure is minimal.)

If, for some reason, it is not possible to determine the river discharge, the mean value of 15,066 cfs for the Pee Dee River should be used. In time of river flood or extreme drought, some adjustment may be estimated. A telephone call to the USGS/WRD Office in Columbia (765-5966) should provided the needed information.

TABLE III. East-west component of river currents (cm/sec).

FILE R5

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
39	0	0	0	0	0	0	0	0	-2	-2	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	-2	0	-3	-2	-2	-2	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	-3	-2	-3	-2	-2	0	0	0	0	0	0	0	0	0	0	0	0	0
36	1	1	1	-2	-4	-3	-3	-2	-2	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	1	1	-2	-4	-3	-3	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	-2	-3	-3	-2	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	-3	-4	-2	-3	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	-1	-2	-1	-2	-5	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	-1	-2	-3	-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	-1	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	-1	-3	-0	3	-2	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	-3	-4	-2	-2	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	5	-2	0	-2	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	-3	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	1	4	3	3	1	1	0	0	1	1	2	2	2	1	1	0	0	0	0	0	0
22	2	1	5	4	4	1	2	2	2	2	2	3	2	2	1	1	0	0	0	0	0	0
21	0	1	2	3	4	3	3	3	3	2	1	1	0	1	1	1	1	0	0	0	0	0
20	0	1	1	2	5	5	4	3	3	2	1	0	0	0	0	1	0	0	-0	0	0	0
19	0	1	1	2	5	5	5	4	3	3	0	0	0	0	0	0	0	-0	-0	0	0	0
18	0	0	1	2	2	3	4	3	3	3	0	0	0	0	0	-0	-0	0	-0	0	0	0
17	0	0	1	2	1	1	3	3	3	3	2	0	0	-1	-0	-0	-0	0	0	0	0	0
16	0	0	0	2	2	1	1	1	3	3	3	2	2	2	-0	-0	0	0	0	0	0	0
15	0	0	0	0	3	1	1	1	2	2	3	2	3	3	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	2	2	2	1	3	3	4	3	3	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	3	3	3	2	4	3	3	3	2	2	1	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	2	4	5	5	4	3	2	1	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	5	7	7	2	1	1	1	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	3	2	1	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	3	3	1	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	2	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	2	2	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	2	2	2
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	2	2	2
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	4	4
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	4	6	4

TABLE IV. North-south component of river currents (cm/sec).

FILE R6

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
39	0	0	0	0	0	-7	0	-5	-5	-4	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	-3	-6	-3	-5	-5	-4	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	-5	-5	-3	-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	-1	-2	-5	-6	-5	-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	-1	-1	-4	-5	-6	-4	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	-5	-6	-5	-5	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	-3	-4	-6	-6	-4	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	-6	-6	-6	-7	-5	-3	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	-5	-5	-7	-6	0	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	-2	-6	-8	0	0	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	-5	-9	-7	-3	-2	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	-7	-8	-6	-2	-2	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	-5	-8	-6	-2	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	-6	-9	-6	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	-6	-9	-7	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	-6	-9	-8	-2	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	-5	-6	-7	-4	-3	-0	-0	0	0	1	0	0	0	0	0	0	0	0	-0	0	0	0
22	-2	-4	-6	-5	-5	-1	-1	0	0	1	0	0	0	-1	-1	-0	-1	-1	-1	0	0	0
21	0	-3	-5	-5	-5	-3	-3	-1	-2	1	0	2	0	-1	-1	-1	-1	-1	-1	0	0	0
20	0	-3	-4	-3	-3	-3	-4	-3	-2	-1	0	1	0	0	-2	-2	-1	-1	-1	0	0	0
19	0	-2	-3	-1	-2	-3	-3	-2	-3	-3	-0	0	0	0	-2	-2	-1	-1	-1	0	0	0
18	0	0	-2	-2	-2	-2	-3	-3	-3	-3	-2	0	0	0	-1	-2	-1	-1	-1	0	0	0
17	0	0	-2	-2	-1	-1	-3	-2	-3	-3	-4	0	0	-1	-1	-1	-1	-1	0	0	0	0
16	0	0	0	-2	-2	-1	-1	-1	-3	-3	-2	-2	-1	-2	-2	-2	-2	-2	0	0	0	0
15	0	0	0	0	-1	-1	-1	-1	-2	-2	-2	-2	-3	-2	-3	-2	-2	-1	-0	0	0	0
14	0	0	0	0	0	0	-1	-1	-1	-1	-2	-2	-4	-3	-3	-2	-2	-1	-1	0	0	0
13	0	0	0	0	0	0	0	0	-1	-1	-1	-2	-4	-4	-4	-3	-3	-1	-2	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	-1	-2	-2	-4	-5	-3	-3	-3	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	-3	-3	-3	-3	-4	-4	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-8	-8	-6	-5	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-8	-9	-8	-6	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-8	-7	-6	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-7	-7	-7	-7	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-7	-9	-7	-7	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-9	-7	-7	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-7	-6	-6	-7
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-3	-6	-6	-6	-6
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	-4	-5	-5	-5
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-3	-3	-4	-3	-4
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	-4

TABLE V. Rating tables for rivers entering Winyah Bay.

STAGE (feet)	River Discharge (cfs) Waccamaw at Longs	Pee Dee at Pee Dee	Lynches at Effingham	Little Pee Dee at Galivants	Black at Kingstree
0					
1	44	830			
2	109	1240	170		38
3	191	1750	305	250	98
4	290	2350	461	450	185
5	406	3030	654	729	294
6	555	3750	882	1200	430
7	754	4480	1136	2000	630
8	1010	5240	1445	3400	940
9	1350	6013	1830	5378	1460
10	2210	6800	2320	8000	2300
11	3720	7641	2820	11920	3718
12	5647	8500	3420	17030	6750
13	8290	9533	4170	23520	9394
14	11500	10600	5120		14800
15	17000	12010	6400		
16		13500	8100		
17		15290	10000		
18		17200	12500		
19		19740			
20		22500			
21		26070			
22		30000			
23		35580			
24		41890			
25		49000			
26		59050			
27		70660			
28		84000			
29		102000			
30		125000			
Mean	1223	9852	1035	3243	942

Wind-driven currents

Surface currents caused by wind shear stress (leeway) are complex and not fully understood. It is believed that the wind-driven surface water current can be expressed as a percentage of wind velocity and is closely related to wind direction. The most commonly used leeway value is 3% of wind velocity and a deflection angle of either 0 or +15 degrees (15 degrees to the right of wind direction in the northern hemisphere) (Bishop, 1980). The WBO model uses 3% at 0 degrees deflection. Zero deflection is used because it is felt that due to the variability and short fetch of winds on the bay, deflection due to Coriolis effect is insignificant. A more critical factor is the need for accurate information on wind velocity and direction at the time and location of the spill. This may vary somewhat from the local airport or Coast Guard Station. The extent of that variation will cause some amount of error to be introduced.

Leeway may be the most critical factor regarding the path of the oil spill. Tide and river currents follow the geometric boundaries of the bay and, in the absence of wind, will tend to flush the spill from the bay in several tidal cycles, depending on the spill origin, lunar phase, and river discharge. However, the presence of even a slight wind will probably cause the spill to make leeway and impinge on the bay boundary (generally, the bordering salt marsh) before the spill can be flushed from the system. For this reason, wind information should be as accurate and up-to-the-minute as possible.

As a general rule, one can figure on about 25 feet/minute of leeway for each 10 miles/hour of wind speed. For example, in a 20 miles/

hour wind, one can expect the oil spill to travel downwind at a rate of 50 feet/minute. It is easily seen that this is a critical factor within a narrow bay.

Another effect of the wind is the generation of waves. There is a small, but finite, mass transport of water in the down wave direction. This effect is not important within a small bay due to the absence of swell. That is, the only waves are of the type termed "seas", due to the present effect of wind sheer. The waves tend to be small because of limited fetch and shallow depths; hence, leeway far outweighs the effects of mass transport due to the presence of waves.

Geometry of Winyah Bay

For the purpose of computerization the Winyah Bay region was divided into a rectangular grid (Fig. 2) measuring 22 by 40 grid spaces (East-West and North-South, respectively). Each grid square measures 484 m on a side. The grid squares are numbered according to a right-hand Cartesian system (zero is in the lower-left corner). A point on the grid can be located by giving its (X,Y) coordinates, where X refers to the East-West direction and Y refers to the North-South direction. Tables I - IV, giving surface currents in the X and Y directions for both tides and river flow, are keyed to the grid. That is, the various current components for a specified grid location can be read easily from the tables.

Date__________

TS__________

X__________

Y__________

HP__________

TP__________

HN__________

TN__________

Q__________

WV__________

WD__________

Tide Changes:

HN__________

TN__________

HN__________

TN__________

HN__________

TN__________

Wind changes:

WV__________

WD__________

WV__________

WD__________

WV__________

WD__________

WV__________

WD__________

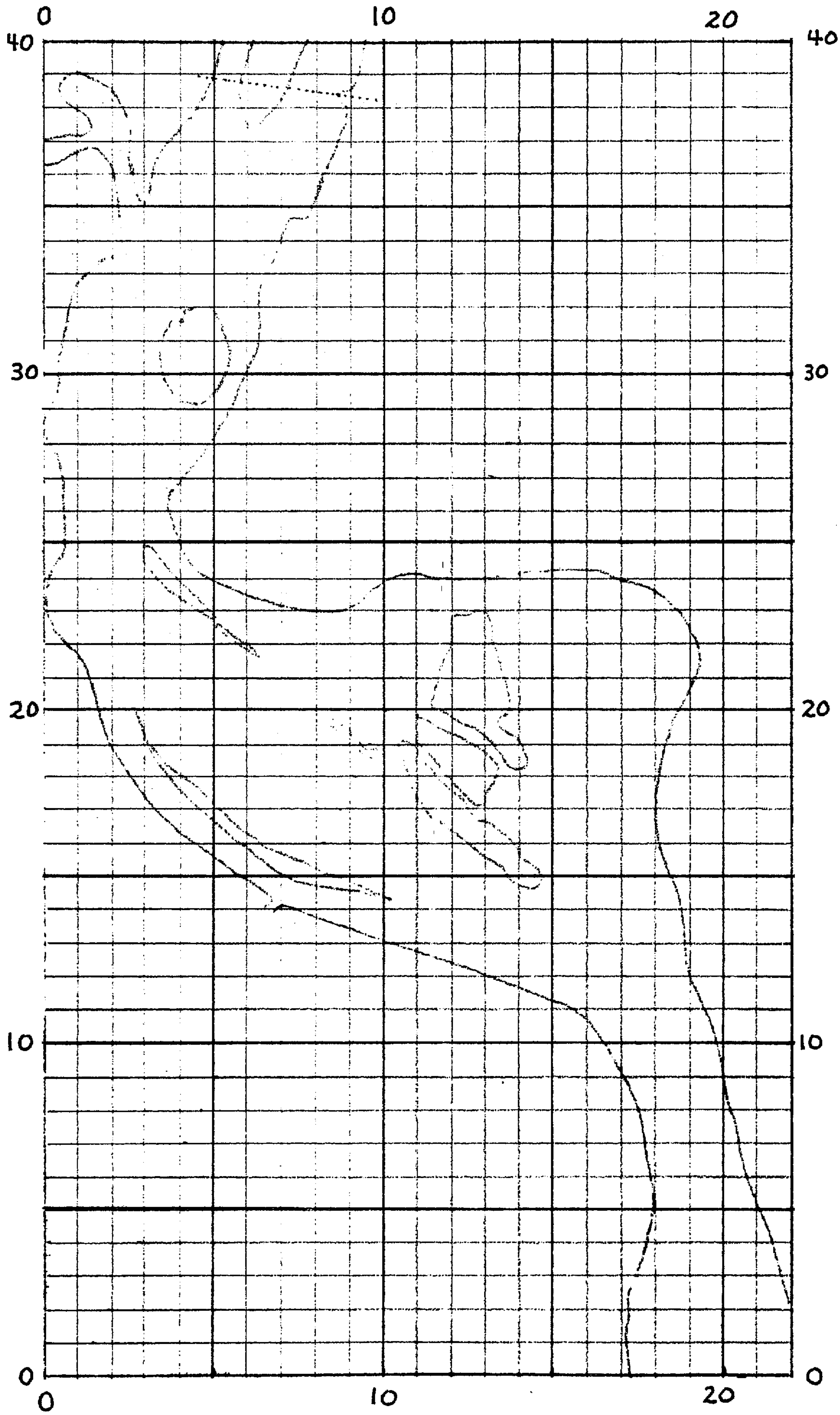


Figure 2. Winyah Bay shorelines superposed onto a 22 by 40 grid. Each grid square measures 484 m on a side.

Field Study

In order to be able to develop and verify a computer model of a natural system, such as the Winyah Bay Estuary, actual field observations are required to which computer predicted values can be compared. Model refinement and calibration are continued until agreement between predicted and actual values is reached. For this reason, a field study was performed in order to measure the necessary parameters by the modeling process.

The field study consisted of surface current and wind measurements at numerous locations (Fig. 3) around the bay at various phases of the tidal cycle. Surface currents were measured by a Price Current Meter or by the use of drogues. Current velocity and direction was noted. Wind velocity was measured at a point 1.5 m above the water surface with a hand-held Dwyer Wind Meter. A bearing compass was used to measure direction. Also noted were wave height and direction, water depth, time (tidal phase), and any significant meterological or hydrological anomalies.

Additional surface current data derived from recording current meter deployments of several days duration were provided by the South Carolina Marine Resources Research Institute. These four stations are also indicated in Fig. 3. Other sources of field data include the NOAA Tide Currents Tables (1981), U. S. Geological Survey stream flow records reported in their Water Resources Data for South Carolina (1981), and a published study of Georgetown Harbor by the Waterways Experiment Station, U. S. Army Corps of Engineers (Trawle, 1978).

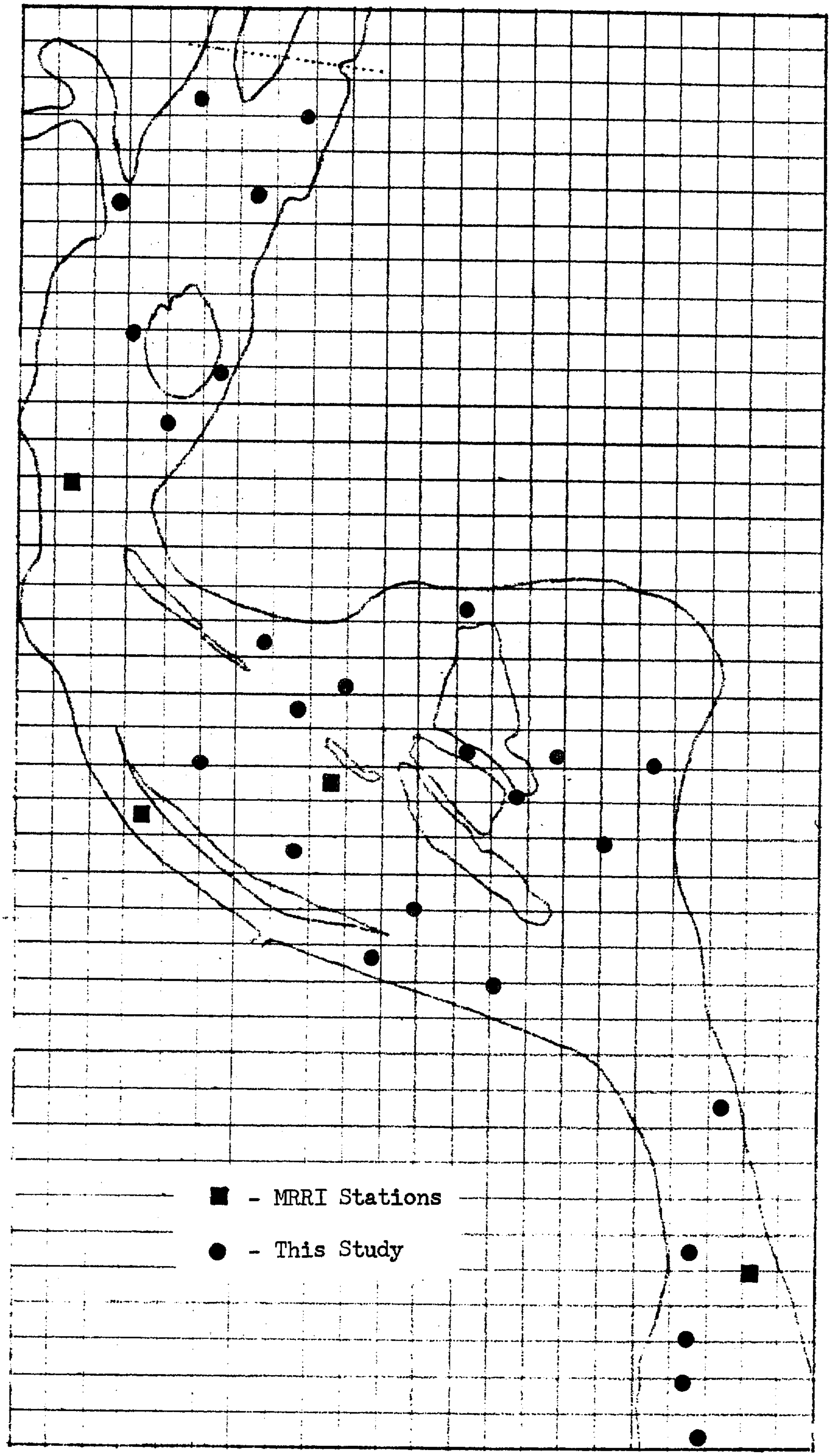


Figure 3. Map showing location of field study stations.

WBO/TRS-80

WBO/TRS-80 is a microcomputer version of the Winyah Bay Oil Spill model. The model was designed and developed for a Radio Shack TRS-80 microcomputer and was written in the "Level II BASIC" language. A complete listing of the computer program is given in Fig. 4. The program could be used on an Apple or other similar microcomputer, as well as on a mini or main frame computer, with minimal adaptation.

The program is completely interactive and user-oriented. That is, once the program is begun, it asks the user specific questions which are entered through the keyboard. For input, the following items of information are required:

1. Date of spill
2. Time of spill
3. Grid coordinates of spill origin (from Fig. 2)
4. Height (feet) of previous tide
5. Time of previous tide
6. Height of next tide
7. Time of next tide
8. River discharge (see section on river currents)
9. Wind speed (mph)
10. Wind direction

(Items 4–7: From NOAA Tide Tables for Charleston, SC corrected for Winyah Bay)

The computer will then determine the successive positions of the leading edge of the spill for 15 minute intervals until the time of the next tide change is reached. During the processing the computer will ask if the wind has changed. If "yes", then items 9 and 10 are re-entered. At the time of the next tide, the computer will ask for items 6 and 7 for the second tidal half-cycle and so on. Processing will continue until the spill makes landfall or exits the mouth of the bay. The program prints out the location of both the downstream and the upstream ends of the spill. Both ends must be monitored in order

```
10 'WBO/TRS-80: OIL SPILL MODEL FOR WINYAH BAY
20 DIM TU(22,40),TV(22,40),RU(22,40),RV(22,40)
30 DEFINT I-N
40 TI=15: 'TI IS TIME STEP INCREMENT IN MINUTES
50 RM=5.2: 'RM IS MEAN TIDE RANGE AT CHARLESTON
60 KK=1
70 RD=0.0174533: 'RD IS RADIANS/DEGREE
80 CLS:PRINT"WINYAH BAY OIL SPILL MODEL : WBO/TRS-80"
90 PRINT"        WRITTEN BY"
100 PRINT"JAMES P. MAY, PH.D."
110 PRINT"DEPARTMENT OF CHEMISTRY AND GEOLOGY"
120 PRINT"THE CITADEL"
130 PRINT"CHARLESTON, SOUTH CAROLINA  29409"
140 PRINT"------------------------------------------------------------"
150 PRINT"  "
160 GX=484:GY=484:NX=22:NY=40
170 GOSUB1430
180 INPUT"ENTER DATE OF SPILL (YR/MO/DA)";DA$
190 LPRINT"DATE- ";DA$
200 PRINT
210 PRINT"ENTER TIME OF OIL SPILL.  TIME IS BASED ON A"
220 INPUT"24-HOUR CLOCK (9:30 AM = 0930;3:15 PM = 1515)";T
230 T1=T
240 GOSUB1340 :T5=T
250 PRINT
260 INPUT"ENTER SPILL COORDINATES (X,Y).  SEE BASE MAP";X,Y
270 XS=X:YS=Y:XD=X:YD=Y:XU=X:YU=Y
280 PRINT
290 PRINT"REFER TO NOAA TIDE TABLES FOR CHARLESTON,SC"
300 INPUT"ENTER HEIGHT OF PREVIOUS TIDE AT CHARLESTON";HP
310 PRINT:PRINT"TIMES OF TIDES MUST BE CORRECTED FOR WINYAH BAY"
320 PRINT"TO THE TIME OF PREVIOUS TIDE AT CHARLESTON"
330 PRINT"      IF HIGH TIDE ADD ONE HOUR.."
340 PRINT"      IF LOW TIDE ADD TWO HOURS.."
350 PRINT"IF DAYLIGHT SAVINGS TIME, ADD ANOTHER HOUR"
360 INPUT"ENTER TIME OF PREVIOUS TIDE AT WINYAH BAY";T
```

Figure 4. Program printout for WBO/TRS-80.

```
370 GOSUB1340 :TP=T:PRINT
380 PRINT"SPILL TIME WAS ";T1
390 PRINT"CHECK TO SEE WHETHER CORRECTED PREVIOUS TIME"
400 PRINT"IS STILL PRIOR TO SPILL TIME. IF YES, ENTER 'Y'"
410 INPUT"IF NOT, ENTER 'N'";Y$
420 IF Y$="N" THEN GOTO300
430 PRINT
440 INPUT"ENTER HEIGHT OF NEXT TIDE AT CHARLESTON";HN
450 PRINT
460 PRINT"ENTER TIME OF NEXT TIDE AT WINYAH BAY"
470 INPUT"CORRECTED AS INSTRUCTED PREVIOUSLY. ";T
480 GOSUB1340 :TN=T
490 HR=HN-HP:PRINT"TIDAL RANGE IS ";HR;" FT"
500 TT=TN-TP:IF TT<0 THEN TT=TT+24
510 PRINT"TIDAL HALF-PERIOD IS ";TT;" HOURS"
520 IF HR>0 THEN PRINT"FLOOD PHASE" ELSE PRINT"EBB PHASE"
530 FOR II=1TO200:NEXT
540 PRINT
550 CP=ABS(HR/RM)
560 IF HR>0 THEN PH=-1 ELSE PH=1
570 IF KK>1 THEN GOTO720
580 PRINT"COMPUTE PEE DEE RIVER DISCHARGE AS PER INSTRUCTIONS"
590 PRINT"IF UNABLE TO COMPUTE DISCHARGE, ENTER 0"
600 INPUT"OTHERWISE ENTER COMPUTED DISCHARGE (CFS)";SP
610 IF SP = 0 THEN SP=15066
620 RC=SP/15066
630 PRINT
640 INPUT"ENTER WIND VELOCITY (MPH)";W
650 WV=W*5280*30.48/3600
660 PRINT"WIND VELOCITY IS ";W;" MPH = ";WV/100;" M/SEC"
670 PRINT
680 PRINT"ENTER DIRECTION FROM WHICH WIND IS COMING"
690 INPUT"DEGREES CLOCKWISE FROM NORTH";WD
700 PRINT"WIND COMING FROM ";WD
710 PRINT
720 PRINT"INITIAL INPUT DATA COMPLETE"
```

Figure 4. (cont.)

```
730 GOSUB1140 :'PRINT HEADINGS AND INITIAL CONDITIONS
740 GOSUB 1300 :'PRINT INITIAL COORDINATES
750 'LUNAR CYCLE CORRECTION TO MEAN CONDITIONS
760 TS=TS+TI/60
770 IF TS>24 THEN TS=TS-24
780 GOSUB1380 :'COMPUTE TIDAL HALF-PERIODS AND PHASE ANGLE
790 IF A>TT THEN TP=TN:HP=HN:KK=2:TS=TS-TI/60:GOTO440
800 IF KK=1 THEN 810  ELSE 840
810 IF PH=-1 THEN GOTO830
820 X=XD:Y=YD:GOSUB860  :XD=X:YD=Y:XU=XS:YU=YS:GOTO1070 :'EBB
830 X=XU:Y=YU:GOSUB860  :XU=X:YU=Y:XD=XS:YD=YS:GOTO1070 :'FLOOD
840 KK=3:X=XD:Y=YD:GOSUB860  :XD=X:YD=Y
850 X=XU:Y=YU:GOSUB860  :XU=X:YU=Y:GOTO1070
860 'TIDAL PHASE CORRECTION TO TIDAL CURRENT DISPLACEMENT
870 TX=CP*SIN(T)*TU(X,Y)*TI*PH*60/(GX*100)
880 TY=CP*SIN(T)*TV(X,Y)*TI*PH*60/(GY*100)
890 IF TU(X,Y)=0 AND TV(X,Y)=0 THEN 900  ELSE 920
900 PRINT"LANDFALL AT ";:PRINTUSING"####.#";X,Y
910 LPRINT"LANDFALL AT ";:LPRINTUSING"#####.#";X,Y:GOTO1120
920 'WIND EFFECT
930 WX=-0.03*WV*SIN(WD*RD)*TI*60/(GX*100)
940 WY=-0.03*WV*COS(WD*RD)*TI*60/(GY*100)
950 'RIVER EFFECT
960 RX=RU(X,Y)*RC*TI*60/(GX*100)
970 RY=RV(X,Y)*RC*TI*60/(GY*100)
980 'NET DISPLACEMENT
990 DX=TX+WX+RX:DY=TY+WY+RY
1000 IF ABS(DX)<.001 THEN DX=0: IF ABS(DY)<.001 THEN DY=0
1010 X=X+DX : Y=Y+DY
1020 IF X<0 OR X>NX OR Y<0 OR Y>NY THEN 1030 ELSE 1050
1030 PRINT"SPILL EXITED GRID BOUNDARY AT ";:PRINTUSING"####.#";X,Y
1040 LPRINT"SPILL EXITED GRID BOUNDARY AT ";:LPRINTUSING"#####.#";X,Y:GOTO1120
1050 RETURN
1060 TC=TS:GOSUB1360
1070 TC=TS:GOSUB1360 :PRINT TC;TAB(10);XD;TAB(20);YD;TAB(30);XU;TAB(40);YU
1080 LPRINTUSING"############";TC;
1090 LPRINT USING "##########.#";XD;YD;XU;YU
1100 INPUT"HAS WIND CHANGED (Y OR N)";Y$
1110 IF Y$="Y" THEN 640  ELSE 760
1120 LPRINT"END OF RUN":KK=1:CLS:GOTO180
```

Figure 4. (cont.)

```
1140 'PRINTOUT ROUTINE
1150 FOR II=1TO100:NEXT:CLS
1160 PRINT"DATE- ";DA$
1170 TC=TS:GOSUB1360
1180 PRINT"SPILL TIME- ";TC
1190 TC=TP:GOSUB1360
1200 LPRINT"PREVIOUS TIDE      TIME= ";TC;"  HEIGHT=";HP
1210 TC=TN:GOSUB1360
1220 LPRINT"NEXT TIDE          TIME= ";TC;"  HEIGHT=";HN
1230 IF PH=1 THEN LPRINT"EBB PHASE" ELSE LPRINT"FLOOD PHASE"
1240 LPRINT"RIVER DISCHARGE IS ";SP;" CFS"
1250 LPRINT"WIND AT ";W;" MPH FROM ";WD;" DEGREES"
1260 PRINT"COORDINATES OF OIL SPILL FRONTS"
1270 LPRINT"TIME AND COORDINATES OF SPILL FRONTS (D=DOWNSTREAM: U=UPSTREAM)"
1280 PRINT"TIME";TAB(10);"XD";TAB(20);"YD";TAB(30);"XU";TAB(40);"YU"
1290 LPRINT"        TIME          XD          YD          XU          YU":RETURN
1300 TC=TS:GOSUB1360 :PRINT TC;TAB(10);XD;TAB(20);YD;TAB(30);XU;TAB(40);YU
1310 LPRINTUSING"############";TC;
1320 LPRINTUSING"##########.#";XD;YD;XU;YU
1330 RETURN
1340 'SUBROUTINE TO CONVERT HRS:MIN TO FRACTIONAL HRS
1350 T=INT(T/100)+((T/100-INT(T/100))*100)/60:RETURN
1360 'SUBROUTINE TO CONVERT FRACTIONAL HOURS TO HRS & MIN
1370 TC=100*INT(TC)+60*(TC-INT(TC)):RETURN
1380 'SUBROUTINE TO COMPUTE PHASE ANGLE
1390 ' TIME TP=PREVIOUS TIDE, TT=TIDE PERIOD, TS=SPILL TIME
1400 A=TS-TP-(TT/120): IF A<0 THEN A=A+24
1410 T=3.1416*A/TT
1420 RETURN
1430 'SUBROUTINE TO LOAD CURRENT DATA ARRAYS
1440 TU$="TU":TV$="TV": RU$="RU":RV$="RV"
1450 PRINT"LOADING SURFACE CURRENT DATA FILES"
1460 PRINT"PLEASE STAND BY....."
1470 OPEN"I",1,TU$
1480 FORJ=0TONY-1:FOR I=0TONX-1:INPUT#1,TU(I,J):NEXT:NEXT:CLOSE
1490 OPEN"I",1,TV$
1500 FORJ=0TONY-1:FOR I=0TONX-1:INPUT#1,TV(I,J):NEXT:NEXT:CLOSE
1510 OPEN"I",1,RU$
1520 FORJ=0TONY-1:FOR I=0TONX-1:INPUT#1,RU(I,J):NEXT:NEXT:CLOSE
1530 OPEN"I",1,RV$
1540 FORJ=0TONY-1:FOR I=0TONX-1:INPUT#1,RV(I,J):NEXT:NEXT:CLOSE
1550 RETURN
```

Figure 4. (cont.)

to know where and when to dispatch clean-up equipment.

The program and the current data are permanently stored on a 5.25" floppy disk and output is printed on both the video screen and a hard copy printer. The coordinates printed out can then be hand plotted on the map grid and the progress of the spill illustrated. This step could also be computerized with the addition of a plotter to the microcomputer. A copy of the disk can be obtained from the author by sending a blank disk and a stamped, self-addressed envelope.

User instructions for WBO/TRS-80.

1. Load "WBO" from the disk and enter "RUN".

2. Surface current data files will be loaded from disk at this time.

3. Enter data of oil spill:_______________.

4. Enter time of oil spill:_______________.
   (Note that time is based on 24 hour clock. 9:30 AM = 0930; 3:15 PM = 1515.)

5. Enter oil spill coordinates: X = ________, Y = ________

6. Refer to NOAA Tide Tables for Charleston tide data. Times must be corrected for Winyah Bay by adding 1 hour to time of high tide and 2 hours to time of low tide. Also add another hour for Daylight Saving Time.

   Enter height of previous tide:____________ ft.

   Enter time of previous tide :____________

   Enter height of next tide :____________ ft.

   Enter time of next tide :____________

7. Enter river discharge:___________ cfs. (See section on river currents.) If unable to compute discharge, enter "Ø".

8. Enter wind velocity _________ mph at location near oil spill.

9. Enter direction __________ (degrees clockwise from north) from which wind is coming.

10. New, X,Y coordinates (at both ends of the oil spill) will be printed out for 15 minute intervals of time. The new coordinates reflect the displacements due to tide, river, and wind. If the wind has changed, you may re-enter items 8 and 9. If clock time has reached the time of the next tide, you will be directed to enter the height and time of the following tide and processing will continue until a landfall of the oil spill occurs.

WBO/TI-59

WBO/TI-59 is a version of the Winyah Bay Oil Spill model designed for use on a programmable calculator. The model was developed on a Texas Instruments TI-59 programmable calculator that uses magnetic cards for program and data storage. A complete listing of the program is given in Fig. 5. The program could be adapted for use on other similar calculators; however, extensive re-writing may be required. A copy of the program can be obtained from the author by sending a blank mag card and a self-addressed envelope.

The basic input data and the output data from WBO/TI-59 are nearly the same as that from WBO/TRS-80. The grid coordinates of the oil spill front are computed for 15 minute intervals for the duration of the half-tidal cycle. These coordinates are then plotted on the map grid as previously discussed.

The main difference in WBO/TI-59 is that additional input information is required for each 15 minute iteration. Specifically, current and wind data must be entered for the present location of the spill front for each iteration. This makes processing somewhat slower than that using the microcomputer, but the accuracy is not significantly affected.

In the event of a continuous oil spill, the spill will possess an upstream and a downstream end. Either end could make landfall first depending on tidal phase, river discharge, and wind. If the spill occurs during ebb, it is the downstream end that is initially monitored. This should be continued until it makes landfall. One should then return to the time of first tidal reversal (in this case, the commencement of the first flood tide) and run the model starting at the point

```
000  01  1
001  42  STO
002  00  00
003  07  7
004  32  X:T
005  43  RCL
006  00  00
007  91  R/S
008  88  DMS
009  85  +
010  93  .
011  01  1
012  02  2
013  05  5
014  95  =
015  72  ST*
016  00  00
017  01  1
018  44  SUM
019  00  00
020  43  RCL
021  00  00
022  77  GE
023  12  B
024  91  R/S
025  61  GTO
026  00  00
027  15  15
028  76  LBL
029  12  B
030  07  7
031  42  STO
032  00  00
033  01  1
034  01  1
035  32  X:T
036  43  RCL
037  00  00
038  91  R/S
039  88  DMS
040  72  ST*
041  00  00
042  01  1
043  44  SUM
044  00  00
045  43  RCL
046  00  00
047  91  R/S
048  72  ST*
049  00  00
050  01  1
051  44  SUM
052  00  00
053  43  RCL
054  00  00
055  77  GE
056  11  A
057  91  R/S
058  61  GTO
059  00  00
060  39  39
061  76  LBL
062  11  A
063  00  0
064  32  X:T
065  43  RCL
066  09  09
067  75  -
068  43  RCL
069  07  07
070  95  =
071  42  STO
072  20  20
073  00  0
074  32  X:T
075  43  RCL
076  20  20
077  77  GE
078  22  INV
079  02  2
080  04  4
081  85  +
082  43  RCL
083  20  20
084  95  =
085  42  STO
086  20  20
087  76  LBL
088  22  INV
089  66  PAU
090  43  RCL
091  10  10
092  75  -
093  43  RCL
094  08  08
095  95  =
096  94  +/-
097  42  STO
098  21  21
099  66  PAU
100  76  LBL
101  13  C
102  43  RCL
103  00  00
104  91  R/S
105  42  STO
106  11  11
107  01  1
108  44  SUM
109  00  00
110  43  RCL
111  00  00
112  91  R/S
113  42  STO
114  12  12
115  09  9
116  55  ÷
117  43  RCL
118  04  04
119  95  =
120  42  STO
121  22  22
122  43  RCL
123  01  01
124  75  -
125  43  RCL
126  07  07
127  95  =
128  42  STO
129  17  17
130  00  0
131  32  X:T
132  43  RCL
133  17  17
134  77  GE
135  23  LNX
136  02  2
137  04  4
138  85  +
139  43  RCL
140  17  17
141  95  =
142  42  STO
143  17  17
144  76  LBL
145  23  LNX
146  43  RCL
147  17  17
148  55  ÷
149  43  RCL
```

Figure 5. Listing of WBO/TI-59.

150	20	20
151	95	=
152	42	STO
153	18	18
154	65	×
155	89	π
156	95	=
157	42	STO
158	19	19
159	70	RAD
160	38	SIN
161	42	STO
162	23	23
163	43	RCL
164	21	21
165	55	÷
166	43	RCL
167	05	05
168	95	=
169	42	STO
170	24	24
171	43	RCL
172	11	11
173	65	×
174	43	RCL
175	23	23
176	65	×
177	43	RCL
178	22	22
179	65	×
180	43	RCL
181	24	24
182	95	=
183	42	STO
184	25	25
185	66	PAU
186	43	RCL
187	12	12
188	65	×
189	43	RCL
190	23	23
191	65	×
192	43	RCL
193	22	22
194	65	×
195	43	RCL
196	24	24
197	95	=
198	42	STO
199	26	26
200	66	PAU
201	01	1
202	44	SUM
203	00	00
204	43	RCL
205	00	00
206	90	LST
207	76	LBL
208	14	D
209	42	STO
210	13	13
211	01	1
212	40	IND
213	00	0
214	43	RCL
215	00	00
216	91	R/S
217	42	STO
218	14	14
219	43	RCL
220	06	06
221	55	÷
222	01	1
223	05	5
224	00	0
225	06	6
226	06	6
227	65	×
228	23	LNX
229	14	D
230	65	×
231	43	RCL
232	22	22
233	95	=
234	42	STO
235	27	27
236	66	PAU
237	23	LNX
238	07	7
239	55	÷
240	01	1
241	05	5
242	00	0
243	06	6
244	06	6
245	65	×
246	43	RCL
247	14	14
248	65	×
249	43	RCL
250	22	22
251	95	=
252	42	STO
253	28	28
254	66	PAU
255	01	1
256	44	SUM
257	00	00
258	43	RCL
259	00	00
260	91	R/S
261	76	LBL
262	15	E
263	65	×
264	04	4
265	04	4
266	93	.
267	07	7
268	95	=
269	42	STO
270	15	15
271	01	1
272	44	SUM
273	00	00
274	43	RCL
275	00	00
276	91	R/S
277	60	DEG
278	42	STO
279	16	16
280	38	SIN
281	65	×
282	43	RCL
283	15	15
284	65	×
285	93	.
286	00	0
287	03	3
288	65	×
289	43	RCL
290	22	22
291	95	=
292	94	+/-
293	42	STO
294	29	29
295	66	PAU
296	43	RCL
297	16	16
298	39	COS
299	65	×

Figure 5. (cont.)

300	43	RCL
301	15	15
302	65	×
303	93	.
304	00	0
305	03	3
306	65	×
307	43	RCL
308	22	22
309	95	=
310	94	+/-
311	42	STO
312	30	30
313	66	PAU
314	43	RCL
315	01	01
316	85	+
317	93	.
318	01	1
319	02	2
320	05	5
321	95	=
322	22	INV
323	88	DMS
324	91	R/S
325	43	RCL
326	02	02
327	85	+
328	43	RCL
329	25	25
330	85	+
331	43	RCL
332	27	27
333	85	+
334	43	RCL
335	29	29
336	95	=
337	42	STO
338	02	02
339	91	R/S
340	43	RCL
341	03	03
342	85	+
343	43	RCL
344	26	26
345	85	+
346	43	RCL
347	28	28
348	85	+
349	43	RCL
350	30	30
351	95	=
352	42	STO
353	03	03
354	91	R/S
355	93	.
356	02	2
357	05	5
358	44	SUM
359	01	01
360	02	2
361	04	4
362	32	X⇌T
363	43	RCL
364	01	01
365	22	INV
366	77	GE
367	24	CE
368	43	RCL
369	01	01
370	75	-
371	02	2
372	04	4
373	95	=
374	42	STO
375	01	01
376	76	LBL
377	24	CE
378	93	.
379	02	2
380	05	5
381	44	SUM
382	17	17
383	43	RCL
384	20	20
385	32	X⇌T
386	43	RCL
387	17	17
388	77	GE
389	12	B
390	01	1
391	01	1
392	42	STO
393	00	00
394	61	GTO
395	13	C
396	91	R/S

Figure 5. (cont.)

of origin of the spill and continue until the upstream end makes landfall. The procedure is the same when the spill begins during flood... first monitor the upstream end, and then monitor the downstream end. Information on the location of both ends of the spill at all times is necessary in order to decide where and when to dispatch clean-up equipment.

User Instructions for WBO/TI-59

1. Load program onto TI-59; Turn on TI-59; enter "1", "INV 2nd Write", then insert mag card (printed side up); enter (2), "INV 2nd Write" and insert mag card (rotated 180°, printed side up). The program is now loaded.

2. Enter "CLR", "2nd Fix 2" to clear and set two decimal places in the display.

3. Enter "R/S" to start the program running. After each entry, enter "R/S":

Display	Item
1.00	- Enter time of spill (9:45 AM = 9.45; 3:30 PM = 15.30)
2.00	- Enter X coordinate of spill (refer to map grid)
3.00	- Enter Y coordinate of spill
4.00	- Enter map grid dimension (484 m for Winyah Bay)
5.00	- Enter mean tidal range for Charleston Tide Tables (5.2 ft)
6.00	- Enter river discharge computed from previous day stages (in unknown, enter 15066 for Winyah Bay)
7.00	- Enter time of previous tide } Refer to NOAA Tide Tables,
8.00	- Enter height of previous tide } On Charleston: add 1 hr for
9.00	- Enter time of next tide } high, add 2 hrs for low.
10.00	- Enter height of next tide } Add another hr for DST.
11.00	- Enter UT = tide current velocity in X direction (Table I)
12.00	- Enter VT = tide current velocity in Y direction (Table II)
	- X and Y displacement due to tide will flash on display
13.00	- Enter UR - river current velocity in X direction (Table III)
14.00	- Enter VR = river current velocity in Y direction (Table IV)
	- X and Y displacement due to river will flash on display
15.00	- Enter WV = wind velocity (mph) near spill
16.00	- Enter WD = wind direction from which wind is coming (degrees from north in a clockwise direction)
	- X and Y displacement due to wind will flash on display

4. Display will show time after 15 minute interval. Record and enter "R/S"

5. Display will show new X coordinate. Record and enter "R/S"

6. Display will show new Y coordinate. Record and enter "R/S"

7. Program will cycle back to item 11.00 (enter UT) or back to item 7.00 if a new tidal half-cycle has been entered.

8. A plot of the coordinates should be maintained so that time and location of a landfall can be determined.

I. Date ____________________ Technician ______________________________

II. Initial Conditions:

1. TS(HH.mm) ____.____
2. X ____________
3. Y ____________
4. Grid (484)
5. MTR (5.2)
6. Discharge ____________ *

* if unknown = 15066

III. Tidal Cycle Data

	(1)	(2)**	(3)	(4)	(5)
7. TP	.	.	.	.	.
8. HP					
9. TN	.	.	.	.	.
10. HN					

** TP&HP = TN&HN of previous cycle

IV. 15 Minute Increments

INPUT						OUTPUT		
11. UT	12. VT	13. UR	14. VR	15. WV	16. WD	Time	X	Y

WBO/manual

The WBO/manual version was developed so that one could, in an emergency situation when microcomputer and programmable calculator were not available, use the model to predict the trajectory of an oil spill using only pencil and paper, with either trig tables, slide rule, or scientific calculator. As emphasized earlier, this method is tedious, slow, and fraught with the potential of user error. It should only be used as a last resort.

The accompanying "User Form" takes the user through the model step by step. As with the other versions of the model, tide data for Charleston must be corrected for Winyah Bay. River discharge should be computed based on upstream stage data; however, the mean discharge may be used. A separate form is used for calcuation of displacement due to the wind. This does not have to be re-calculated for each 15 minute iteration, but only when there occurs a change in wind velocity or direction.

Output from the model is the set of coordinates of the location of the oil spill front after each 15 minute interval. These coordinates should be plotted immediately to monitor the spill and ascertain when a landfall will occur.

In the case of a continuous oil spill, a separate run should be performed for the opposite end of the spill. If the spill occurs during tidal ebb, the downstream end of the spill is initially monitored. A separate run beginning with the commencement of the flood phase at the piont of origin of the spill will monitor the upstream end of the spill. Either end could make landfall first. If the original spill occurs during flood, the procedure is the same...that is, first monitor the upstream end, and then monitor the downstream end.

WBO/manual user form

1. Date ____________________ Technician ____________________________

2. Time of spill (24 hour clock) __________________

3. Grid coordinates of spill: X = ___________, Y = ___________

4. Tidal heights (See NOAA Tide Tables for Charleston):

   (a) Height of previous tide _________ ft.
   (b) Height of next tide _________ ft.
   (c) Tidal range factor = ((4a) - (4b))/5.2 = _________

5. Tidal times (See NOAA Tide Tables for Charleston):

   (a) Time of previous tide_____ = _____ hrs. (if high, add 1 hr; if low, add
   (b) Time of next tide _____ = _____ hrs. 2 hrs; if on DST add another 1 hr.)***
   (c) Period of half-cycle = (5a) - (5b) (if less than 0, add 24) = _____ hrs.

6. River discharge factor:

   (a) Compute river discharge from upstream stations _________ cfs.
   (b) ÷ mean discharge (15066 cfs) = ____________
   (If (6a) is unobtainable, enter 1.0 in (6b).)

7. Grid coordinates at 15 minute time intervals:

(a) Time*						
(b) - (5a) =						
(c) - 0.125 =						
(d) ÷ (5c) = phase angle						
(e) Table VI factor						
(f) Table VII DXT						
(g) X(4c)X(7e) ÷ 100 =						
(h) Table IX DXR						
(i) X (6b) ÷ 100 =						
(j) Wind DXW						
(k) Total (g+i+j) =						
(l) New X						
(m) Table VIII DYT						
(n) X(4c)X(7e) ÷ 100 =						
(o) Table X DYR						
(p) X (6b) ÷ 100 =						
(q) Wind DYW						
(r) Total (n+p+q) =						
(s) New Y						

* Note time conventions: 9:30 AM = 0930 = 9.50 hrs
3:15 PM = 1515 = 15.25 hrs

*** Note spill time after correcting times of Charleston tides to Winyah Bay. It may be found that the "previous tide" is no longer previous, in which case the tide before that should be used.

When "Time" passes time of next tide, one should return to item 4 and begin a new tidal cycle on a new sheet.

Wind Factor Calculation

(to be re-calculated for each change in wind velocity or direction)

1. Enter wind velocity:____________ mph.

2. Multiply by .025: WV = ___________ grids/15 minutes.

3. Enter wind direction: WB = ________ degrees clockwise from north. (Direction from which wind is coming)

4. DXW = -WV sin WD = ____________

   DYW = -WV cos WD = ____________

PHASE ANGLE	CORRECTION FACTOR	PHASE ANGLE	CORRECTION FACTOR
0.00	0.00	0.50	1.00
0.01	0.03	0.51	1.00
0.02	0.06	0.52	1.00
0.03	0.09	0.53	1.00
0.04	0.13	0.54	0.99
0.05	0.16	0.55	0.99
0.06	0.19	0.56	0.98
0.07	0.22	0.57	0.98
0.08	0.25	0.58	0.97
0.09	0.28	0.59	0.96
0.10	0.31	0.60	0.95
0.11	0.34	0.61	0.94
0.12	0.37	0.62	0.93
0.13	0.40	0.63	0.92
0.14	0.43	0.64	0.90
0.15	0.45	0.65	0.89
0.16	0.48	0.66	0.88
0.17	0.51	0.67	0.86
0.18	0.54	0.68	0.84
0.19	0.56	0.69	0.83
0.20	0.59	0.70	0.81
0.21	0.61	0.71	0.79
0.22	0.64	0.72	0.77
0.23	0.66	0.73	0.75
0.24	0.68	0.74	0.73
0.25	0.71	0.75	0.71
0.26	0.73	0.76	0.68
0.27	0.75	0.77	0.66
0.28	0.77	0.78	0.64
0.29	0.79	0.79	0.61
0.30	0.81	0.80	0.59
0.31	0.83	0.81	0.56
0.32	0.84	0.82	0.54
0.33	0.86	0.83	0.51
0.34	0.88	0.84	0.48
0.35	0.89	0.85	0.45
0.36	0.90	0.86	0.43
0.37	0.92	0.87	0.40
0.38	0.93	0.88	0.37
0.39	0.94	0.89	0.34
0.40	0.95	0.90	0.31
0.41	0.96	0.91	0.28
0.42	0.97	0.92	0.25
0.43	0.98	0.93	0.22
0.44	0.98	0.94	0.19
0.45	0.99	0.95	0.16
0.46	0.99	0.96	0.13
0.47	1.00	0.97	0.09
0.48	1.00	0.98	0.06
0.49	1.00	0.99	0.03

TABLE VII. DXT (X displacement due to tidal currents) per 15 minutes.

FILE T5

39	0	0	0	0	0	0	0	0	-11	-15	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	-11	0	-20	-11	-13	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	-20	-17	-22	-11	-13	0	0	0	0	0	0	0	0	0	0	0	0	0
36	22	22	15	-19	-32	-24	-24	-13	-13	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	11	15	-20	-32	-26	-24	-13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	-17	-28	-28	-15	-13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	-26	-41	-17	-30	-11	-11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	-22	-15	-22	-46	0	-11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	-22	-32	-63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	-6	-30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	-17	-35	-4	35	-26	-15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	-32	-43	-30	-26	-13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	63	-22	0	-24	-30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	-41	0	0	33	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	17	61	54	48	11	0	0	0	13	19	33	35	32	15	9	7	7	6	0	0	0
22	30	9	73	63	73	22	24	33	30	28	30	48	46	43	20	17	6	6	0	0	0	0
21	0	15	39	50	69	52	48	60	56	28	24	15	0	24	19	15	9	7	0	0	0	0
20	0	13	20	39	84	78	65	52	60	39	17	7	0	0	0	9	6	6	-4	0	0	0
19	0	11	13	26	80	93	93	63	50	52	0	0	0	0	0	2	2	-2	-6	0	0	0
18	0	0	19	33	39	45	73	61	50	52	0	0	0	0	0	-4	-2	0	0	0	0	0
17	0	0	15	41	20	11	50	52	54	54	0	0	0	-26	-6	-6	-2	0	0	0	0	0
16	0	0	0	39	35	11	19	22	58	58	58	46	35	46	-2	-2	0	0	0	0	0	0
15	0	0	0	0	48	24	17	9	35	39	58	48	54	63	0	0	0	4	2	0	0	0
14	0	0	0	0	0	0	35	9	7	13	60	63	71	60	61	2	0	0	6	0	0	0
13	0	0	0	0	0	0	0	0	33	28	54	48	73	61	61	58	37	37	11	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	43	91	78	87	78	65	39	17	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	104	104	156	99	28	24	22	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	89	67	46	26	0	0
9	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	91	71	48	28	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	63	48	37	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	61	61	60	58	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	61	61	76	63	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	73	61	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	78	78	60
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-32	-13	69	69	56
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-32	0	56	56	48
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	45	156	128
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	50	71	71	221	156

TABLE VIII. DYT (Y displacement due to tidal currents) per 15 minutes.

FILE 76.

39	0	0	0	0	0	-43	0	-32	-30	-28	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	-22	-43	-20	-30	-28	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	-41	-41	-22	-28	-28	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	-15	-19	-41	-48	-35	-26	-26	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	-11	-15	-35	-45	-48	-33	-26	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	-50	-60	-46	-46	-28	-26	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	-26	-41	-61	-60	-37	-22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	-60	-65	-69	-46	-32	-20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	-60	-76	-63	0	-33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	-26	-74	-86	0	0	-33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	-67	-106	-87	-35	-26	-30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	-84	-102	-69	-28	-26	-26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	-63	-106	-80	-25	-30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	-82	-123	-86	-45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	-84	-126	-95	-46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	-82	-125	-115	-33	-15	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	-65	-84	-100	-54	-48	-6	0	0	0	13	0	0	0	0	0	0	0	0	-6	0	0	0
22	-30	-56	-89	-74	-73	-22	-13	0	0	17	6	0	0	-20	-13	-6	-9	-9	-11	0	0	0
21	0	-45	-82	-73	-82	-52	-48	-22	-32	17	7	30	0	-24	-24	-24	-9	-11	-13	0	0	0
20	0	-41	-63	-52	-54	-54	-65	-52	-43	-9	0	15	0	0	-32	-32	-13	-13	-13	0	0	0
19	0	-35	-41	-22	-41	-56	-58	-41	-50	-52	-9	0	0	0	-33	-35	-20	-20	-19	0	0	0
18	0	0	-37	-33	-26	-26	-58	-48	-50	-52	-45	0	0	0	-28	-32	-20	-22	0	0	0	0
17	0	0	-30	-41	-20	-11	-48	-45	-46	-50	-74	0	0	-26	-28	-28	-22	-24	0	0	0	0
16	0	0	0	-39	-35	-11	-19	-19	-48	-50	-45	-32	-24	-46	-32	-32	-30	-26	0	0	0	0
15	0	0	0	0	-22	-13	-17	-9	-33	-35	-45	-41	-54	-43	-52	-32	-33	-26	-7	0	0	0
14	0	0	0	0	0	0	-17	-4	-6	-9	-46	-45	-80	-60	-61	-33	-35	-26	-20	0	0	0
13	0	0	0	0	0	0	0	0	-11	-9	-17	-32	-80	-76	-78	-58	-56	-22	-43	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	-17	-37	-78	-89	-104	-65	-56	-63	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	-41	-41	-63	-141	-84	-76	-91	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-175	-186	-126	-106	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-177	-192	-130	-110	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-193	-169	-149	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-190	-180	-186	-175	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-180	-180	-236	-193	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-199	-223	-192	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-227	-216	-216	-180
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-63	-69	-180	-180	-173
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-63	-71	-154	-154	-147
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-71	-67	-54	-91	-128
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-50	0	0	0	-156

TABLE IX. DXR (X displacement due to river currents) per 15 minutes.

FILE R5

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
39	0	0	0	0	0	0	0	0	-4	-4	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	-3	0	-6	-4	-4	-4	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	-5	-4	-6	-3	-4	0	0	0	0	0	0	0	0	0	0	0	0	0
36	2	2	1	-4	-7	-5	-6	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	1	3	-4	-7	-6	-5	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	-3	-6	-6	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	-5	-8	-3	-6	-2	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	-3	-4	-3	-4	-9	0	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	-3	-4	-5	-11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	-1	-5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	-3	-5	-1	6	-4	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	-5	-7	-4	-4	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	9	-3	0	-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	-5	0	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	2	7	5	6	1	1	0	0	1	2	3	3	3	1	1	1	1	1	0	0	0
22	4	1	9	7	7	3	3	4	3	3	3	5	4	4	2	1	1	1	0	0	0	0
21	0	2	4	6	8	6	5	6	6	3	3	1	0	2	2	1	1	1	0	0	0	0
20	0	1	2	4	9	9	7	5	6	4	2	1	0	0	0	1	1	1	-0	0	0	0
19	0	1	1	3	9	10	10	7	5	5	0	0	0	0	0	0	0	-0	-1	0	0	0
18	0	0	2	4	4	5	8	6	5	5	0	0	0	0	0	-0	-0	0	-1	0	0	0
17	0	0	2	4	2	1	5	5	5	5	3	0	0	-2	-1	-1	-0	0	0	0	0	0
16	0	0	0	4	4	1	2	2	6	6	6	4	3	4	-0	-0	0	0	0	0	0	0
15	0	0	0	0	5	2	2	1	4	4	6	4	5	6	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	4	4	3	1	6	6	7	6	6	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	5	5	5	4	7	6	5	5	3	3	1	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	4	8	9	9	7	6	3	1	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	9	14	14	4	2	2	2	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	6	4	2	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	6	6	3	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	4	3	0	0
7	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	4	4	4	4	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	5	4	4	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-3	-2	4	4	4
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	0	3	3	3
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	6	8	7
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	5	7	11	8

TABLE X. DYR (Y displacement due to river currents) per 15 minutes.

FILE R6

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
39	0	0	0	0	0	-12	0	-9	-9	-8	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	-5	-11	-6	-9	-8	-8	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	-9	-10	-6	-8	-8	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	-1	-4	-9	-11	-9	-7	-7	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	-1	-3	-7	-10	-11	-8	-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	-10	-12	-10	-10	-6	-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	-5	-8	-12	-12	-7	-5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	-11	-10	-12	-12	-9	-6	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	-10	-10	-13	-11	0	-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	-4	-12	-14	0	0	-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	-10	-16	-14	-6	-4	-5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	-12	-15	-10	-4	-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	-9	-15	-11	-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	-11	-17	-12	-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	-11	-17	-12	-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	-10	-16	-14	-4	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	-8	-10	-12	-7	-6	-1	-0	0	0	1	0	0	0	0	0	0	0	0	-1	0	0	0
22	-4	-7	-11	-9	-9	-3	-1	0	0	2	1	0	0	-2	-1	-1	-1	-1	-1	0	0	0
21	0	-5	-9	-8	-9	-6	-5	-2	-3	2	1	3	0	-2	-2	-2	-1	-1	-1	0	0	0
20	0	-5	-7	-6	-6	-6	-7	-5	-4	-1	0	1	0	0	-3	-3	-1	-1	-1	0	0	0
19	0	-4	-5	-2	-4	-6	-6	-4	-5	-5	-1	0	0	0	-3	-3	-2	-2	-2	0	0	0
18	0	0	-4	-4	-3	-3	-6	-5	-5	-5	-4	0	0	0	-3	-3	-2	-2	-2	0	0	0
17	0	0	-3	-4	-2	-1	-5	-4	-5	-5	-7	0	0	-2	-3	-3	-2	-2	0	0	0	0
16	0	0	0	-4	-4	-1	-2	-2	-5	-5	-4	-3	-2	-4	-3	-3	-3	-3	0	0	0	0
15	0	0	0	0	-2	-1	-2	-1	-3	-4	-4	-4	-5	-4	-5	-3	-3	-3	-1	0	0	0
14	0	0	0	0	0	0	-2	-2	-2	-1	-4	-4	-7	-6	-6	-3	-3	-2	-2	0	0	0
13	0	0	0	0	0	0	0	0	-2	-2	-2	-3	-7	-7	-7	-5	-5	-2	-4	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	-2	-3	-4	-7	-9	-6	-5	-5	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	-4	-5	-6	-6	-6	-7	-8	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-15	-15	-10	-9	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-15	-16	-15	-11	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-15	-13	-11	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-14	-14	-13	-13	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-12	-17	-13	-13	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-16	-13	-13	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-13	-12	-12	-12
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-5	-12	-11	-11	-11
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-4	-7	-9	-9	-9
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-5	-6	-7	-5	-7
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	0	0	0	-8

SAMPLE RUNS OF THE MODEL

1. Test run 1 simulates a spill occurring at 0800 hours located at grid coordinates (4.0,23.0) (see map grid). Tide, river, and wind characteristics are indicated on the computer printout. The spill occurred on the ebb phase of the tide; therefore, the initial drift was downstream. The tide changed at 0915 and an upstream end of the spill developed. The TRS-80 version shows the locations of both ends of the spill until 1245, at which time the downstream end made landfall near (0.5,27.3). The results of the TI-59 version are shown on the worksheet. Only the downstream end is shown. Landfall is near (0.46,27.22) in agreement with the TRS-80 result. In an actual situation, the upstream end would also have been monitored, as it could have made landfall before the downstream end. The first part of the results of the manual version is also shown. The results are similar to the first two, but were not carried to completion due to the time-consuming nature of the process.
2. Test run 2 simulates a spill occurring at 2300 hours located at grid coordinates (18.0,11.0). Tide, river, and wind conditions are shown. The spill occurred during the flood phase of the tide and landfall occurred before the change of the tide. The results of the TRS-80 and TI-59 versions agree. The manual version was not performed.

Test runs ① and ②:

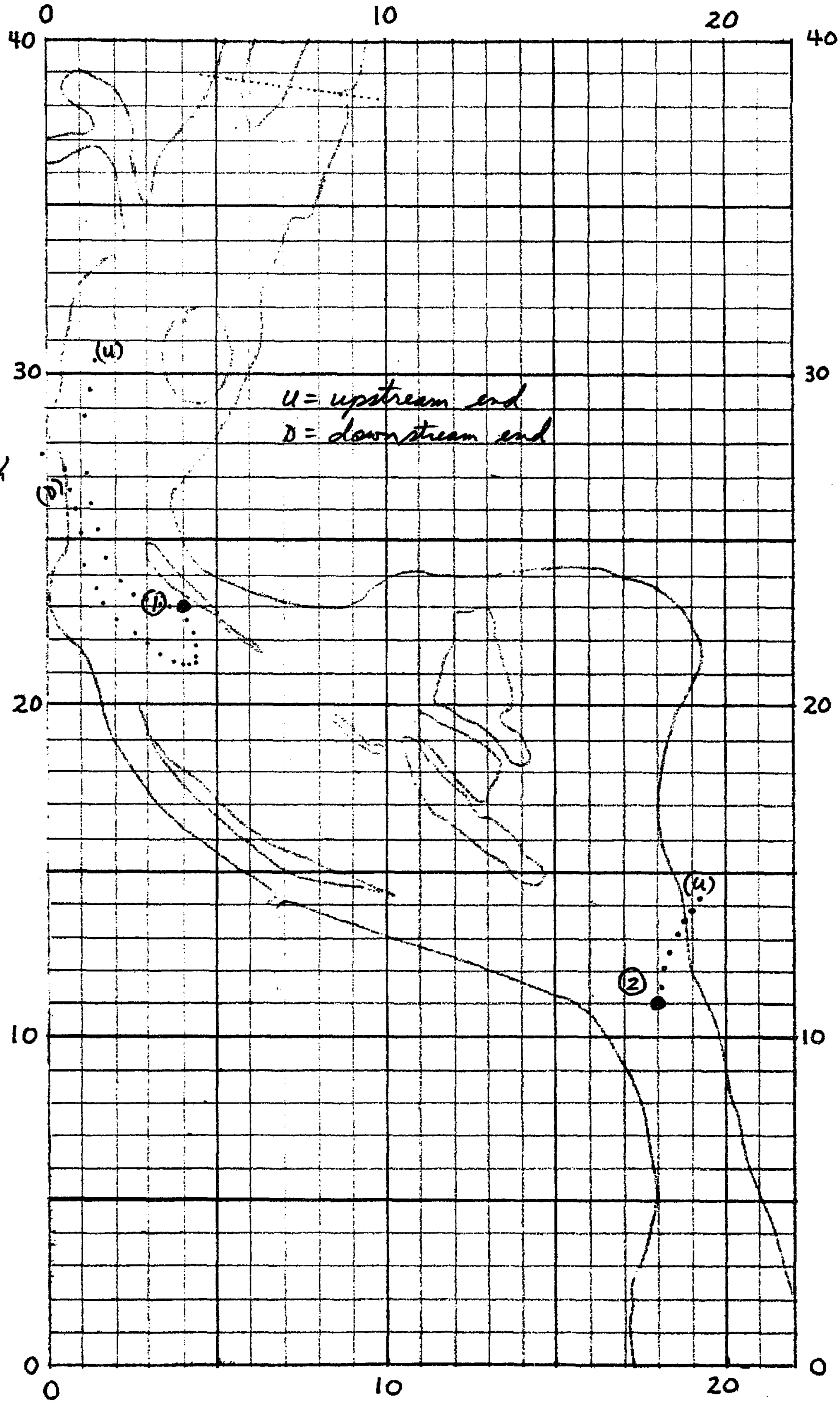
	①	②
Date	①	②
TS	0800	2300
X	4.0	18.0
Y	23.0	11.0
HP	5.3	0.0
TP	0300	2100
HN	0.0	5.0
TN	0915	0315
Q	15066	20000
WV	7 mph	12 mph
WD	80°	270°

Tide Changes:

HN	5.1	
TN	1530	
HN		
TN		
HN		
TN		

Wind changes:

WV	
WD	
WV	
WD	
WV	
WD	
WV	
WD	



WBO/TRS-80

(1)

DATE- 82/06/15
PREVIOUS TIDE TIME= 300 HEIGHT= 5.3
NEXT TIDE TIME= 915 HEIGHT= 0
EBB PHASE
RIVER DISCHARGE IS 15066 CFS
WIND AT 7 MPH FROM 80 DEGREES
TIME AND COORDINATES OF SPILL FRONTS (D=DOWNSTREAM: U=UPSTREAM)

TIME	XD	YD	XU	YU
800	4.0	23.0	4.0	23.0
815	4.1	22.6	4.0	23.0
830	4.3	22.2	4.0	23.0
845	4.4	21.8	4.0	23.0
900	4.4	21.5	4.0	23.0
915	4.4	21.3	4.0	23.0

PREVIOUS TIDE TIME= 915 HEIGHT= 0
NEXT TIDE TIME= 1530 HEIGHT= 5.1
FLOOD PHASE
RIVER DISCHARGE IS 15066 CFS
WIND AT 7 MPH FROM 80 DEGREES
TIME AND COORDINATES OF SPILL FRONTS (D=DOWNSTREAM: U=UPSTREAM)

TIME	XD	YD	XU	YU
915	4.4	21.3	4.0	23.0
930	4.2	21.3	3.9	22.9
945	4.0	21.3	3.6	23.0
1000	3.7	21.4	3.4	23.1
1015	3.4	21.6	3.0	23.2
1030	3.0	21.9	2.7	23.4
1045	2.6	22.2	2.2	23.9
1100	2.0	22.7	1.7	24.5
1115	1.7	23.1	1.5	25.3
1130	1.5	23.7	1.3	26.2
1145	1.1	24.3	1.2	27.1
1200	1.0	25.3	1.2	27.9
1215	0.8	26.0	1.2	28.8
1230	0.6	26.6	1.3	29.6
1245	0.5	27.3	1.4	30.4

SPILL EXITED GRID BOUNDARY AT -0.2 27.8
END OF RUN

(2)

DATE- 82/06/15
PREVIOUS TIDE TIME= 2100 HEIGHT= 0
NEXT TIDE TIME= 315 HEIGHT= 5
FLOOD PHASE
RIVER DISCHARGE IS 20000 CFS
WIND AT 12 MPH FROM 270 DEGREES
TIME AND COORDINATES OF SPILL FRONTS (D=DOWNSTREAM: U=UPSTREAM)

TIME	XD	YD	XU	YU
2300	18.0	11.0	18.0	11.0
2315	18.0	11.0	18.1	11.5
2330	18.0	11.0	18.2	12.1
2345	18.0	11.0	18.4	12.6
2400	18.0	11.0	18.6	13.2
15	18.0	11.0	18.8	13.5
30	18.0	11.0	19.0	13.9
45	18.0	11.0	19.2	14.2

LANDFALL AT 19.2 14.2
END OF RUN

WBO/TI-59

I. Date Test (1) Technician

II. Initial Conditions:

1. TS(HH.mm) 8.00
2. X 4.0
3. Y 23.0
4. Grid (484)
5. MTR (5.2)
6. Discharge 15066 *

* if unknown = 15066

III. Tidal Cycle Data

		(1)	(2)**	(3)	(4)	(5)
7.	TP	3.00	9.15	.	.	.
8.	HP	5.3	0.0			
9.	TN	9.15	15.30	.	.	.
10.	HN	0.0	5.1			

** TP&HP = TN&HN of previous cycle

IV. 15 Minute Increments

Ebb | Flood

INPUT						OUTPUT		
11. UT	12. VT	13. UR	14. VR	15. WV	16. WD	Time	X	Y
26	-26	3	-3	7	80	8.15	4.15	22.65
32	-43	4	-5	7	80	8.30	4.31	22.18
32	-43	4	-5	7	80	8.45	4.40	21.80
37	-44	4	-5	7	80	9.00	4.43	21.52
37	-44	4	-5	7	80	9.15	4.38	21.35
37	-44	4	-5	7	80	9.30	4.24	21.28
37	-44	4	-5	7	80	9.45	4.02	21.30
37	-44	4	-5	7	80	10.00	3.71	21.43
27	-39	3	-5	7	80	10.15	3.38	21.61
27	-39	3	-5	7	80	10.30	3.00	21.87
27	-39	3	-5	7	80	10.45	2.57	22.20
39	-48	5	-6	7	80	11.00	1.98	22.69
5	-30	1	-4	7	80	11.15	1.75	23.03
9	-45	1	-6	7	80	11.30	1.45	23.61
9	-45	1	-6	7	80	11.45	1.15	24.23
0	-67	0	-9	7	80	12.00	0.97	25.21
0	-45	0	-6	7	80	12.15	0.80	25.89
0	-45	0	-6	7	80	12.30	0.63	26.57
0	-44	0	-6	7	80	12.45	0.46	27.22
34	-34	5	-5	7	80	13.00	-0.22	27.70

WBO/TI-59

I. Date Test (2)   Technician ____________

II. Initial Conditions:

1. TS(HH.mm) 23.00
2. X 18.0
3. Y 11.0
4. Grid (484)
5. MTR (5.2)
6. Discharge 20,000 *
* if unknown = 15066

III. Tidal Cycle Data

	(1)	(2)**	(3)	(4)	(5)
7. TP	21.00	.	.	.	.
8. HP	0.0				
9. TN	3.15	.	.	.	.
10. HN	5.0				

** TP&HP = TN&HN of previous cycle

IV. 15 Minute Increments

Flood

INPUT						OUTPUT		
11. UT	12. VT	13. UR	14. VR	15. WV	16. WD	Time	X	Y
13	-41	1	-4	12	270	23.15	18.12	11.54
13	-41	1	-4	12	270	23.30	18.23	12.13
9	-34	1	-3	12	270	23.45	18.40	12.84
9	-34	1	-3	12	270	24.00	18.56	13.17
6	-23	1	-2	12	270	00.15	18.78	13.53
6	-23	1	-2	12	270	00.30	18.99	13.89
6	-23	1	-2	12	270	00.45	19.21	14.24
0	0	= Landfall						

WBO/manual user form

1. Date Test (1) Technician ____________

2. Time of spill (24 hour clock) 0800 = 8.0

3. Grid coordinates of spill: X = 4.0, Y = 23.0

4. Tidal heights (See NOAA Tide Tables for Charleston):

   (a) Height of previous tide 5.3 ft.
   (b) Height of next tide 0.0 ft.
   (c) Tidal range factor = ((4a) - (4b))/5.2 = 1.02

5. Tidal times (See NOAA Tide Tables for Charleston):

   (a) Time of previous tide 0300 = 3.00 hrs. (if high, add 1 hr; if low, add
   (b) Time of next tide 0915 = 9.25 hrs. 2 hrs; if on DST add another 1 hr.)***
   (c) Period of half-cycle = (5a) - (5b) (if less than 0, add 24) = 6.25 hrs.

6. River discharge factor:

   (a) Compute river discharge from upstream stations 15066 cfs.
   (b) ÷ mean discharge (15066 cfs) = 1.0
   (If (6a) is unobtainable, enter 1.0 in (6b).)

7. Grid coordinates at 15 minute time intervals:

(a) Time*	8.25	8.5	8.75	9.0	9.25	
(b) - (5a) 3.0 =	5.25	5.5	5.75	6.0	6.25	
(c) - 0.125 =	5.125	5.375	5.625	5.875	6.125	
(d) ÷ (5c) = phase angle	.82	.86	.90	.94	.98	Tide change
(e) Table VI factor	.54	.43	.31	.19	.06	Start new sheet
(f) Table VII DXT	48	73	73	69	69	
(g) X(4c)X(7e) ÷ 100 =	.26	.32	.23	.13	.04	
(h) Table IX DXR	6	7	7	8	8	
(i) X (6b) ÷ 100 =	.06	.07	.07	.08	.08	
(j) Wind DXW	-.17	-.17	-.17	-.17	-.17	
(k) Total (g+i+j) =	.15	.22	.13	.04	-.05	
(l) New X	4.15	4.37	4.50	4.54	4.49	
(m) Table VIII DYT	-48	-73	-73	-82	-82	
(n) X(4c)X(7e) ÷ 100 =	-.26	-.32	-.23	-.16	-.05	
(o) Table X DYR	6	-9	-9	-9	-9	
(p) X (6b) ÷ 100 =	-.06	-.09	-.09	-.09	-.09	
(q) Wind DYW	-.03	-.03	-.03	-.03	-.03	
(r) Total (n+p+q) =	-.35	-.44	-.35	-.28	-.17	
(s) New Y	22.65	22.21	21.86	21.58	21.41	

etc. . . . . .

* Note time conventions: 9:30 AM = 0930 = 9.50 hrs
3:15 PM = 1515 = 15.25 hrs

*** Note spill time after correcting times of Charleston tides to Winyah Bay. It may be found that the "previous tide" is no longer previous, in which case the tide before that should be used.

When "Time" passes time of next tide, one should return to item 4 and begin a new tidal cycle on a new sheet.

Wind Factor Calculation

(to be re-calculated for each change in wind velocity or direction)

1. Enter wind velocity: 7 mph.

2. Multiply by .025: WV = 0.175 grids/15 minutes.

3. Enter wind direction: WB = 080 degrees clockwise from north.
   (Direction from which wind is coming)

4. DXW = -WV sin WD = -.172 ≈ -.17

   DYW = -WV cos WD = -.030 ≈ -.03

Wind Factor Calculation

(to be re-calculated for each change in wind velocity or direction)

1. Enter wind velocity:__________ mph.

2. Multiply by .025: WV = __________ grids/15 minutes.

3. Enter wind direction: WB = ________ degrees clockwise from north.
   (Direction from which wind is coming)

4. DXW = -WV sin WD = __________

   DYW = -WV cos WD = __________

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