

OIL SPILL TRAJECTORY MODEL FOR WINYAH BAY, SOUTH CAROLINA

James P. May, Ph.D.
Department of Chemistry and Geology

The Citadel
Charleston, South Carolina 29409

June 1982

Property of CSC Library

OIL SPILL TRAJECTORY MODEL FOR WINYAH BAY, SOUTH CAROLINA

James P. May, Ph.D.
Department of Chemistry and Geology
The Citadel
Charleston, South Carolina 29409

June 1982

Final Report on Research
Funded by

Coastal Energy Impact Program
National Oceanic and Atmospheric Administration
Department of Commerce

Administered in South Carolina by

Coastal Energy Impact Program
Division of Natural Resources
Room 304, 1205 Pendleton St.
Columbia, South Carolina 29201

TD 427. P4 M39 1982

9126009

MAR 25 1982

U. S. DEPARTMENT OF COMMERCE NOAA
COASTAL SERVICES CENTER
2234 SOUTH HOBSON AVENUE
CHARLESTON, SC 29405-2413

TABLE OF CONTENTS

LIST OF FIGURES	iii
LIST OF TABLES	iv
INTRODUCTION	1
Purpose of Study	1
Acknowledgements	1
Previous Works	1
Note on Units of Measure	2
Geographic Setting	3
MODEL DESCRIPTION	5
Introduction	5
Tidal Currents	8
River Currents	11
Wind-driven Currents	16
Geometry of Winyah Bay	17
Field Study	19
WBO/TRS-80	21
WBO/II-59	28
WBO/manual	35
SAMPLE RUNS OF THE MODEL	44
REFERENCES	51

LIST OF FIGURES

1. Geographic location of Winyah Bay, South Carolina.	4
2. Winyah Bay shorelines superposed onto a 22 x 40 grid.	18
3. Map showing the location of field study stations.	20
4. Printout of computer program for WBO/TRS-80.	22
5. Listing of program for WBO/II-59.	29

LIST OF TABLES

I.	East-West components of tidal currents (cm/sec).	9
II.	North-South components of tidal currents (cm/sec).	10
III.	East-West components of river currents (cm/sec).	13
IV.	North-South components of river currents (cm/sec).	14
V.	Rating tables for rivers entering Winyah Bay.	15
VI.	Correction factors for tidal phase angle.	39
VII.	DXT (X displacement due to tidal currents) per 15 minutes.	40
VIII.	DYT (Y displacement due to tidal currents) per 15 minutes.	41
IX.	DXR (X displacement due to river currents) per 15 minutes.	42
X.	DYR (Y displacement due to river currents) per 15 minutes.	43

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

This research was funded by a grant from the Coastal Energy Impact Program, National Oceanic and Atmospheric Administration, without whose support the study would not have been possible. A significant contribution to the development of the model was made by Jerry Galt and Glen Watabayashi of the Modeling and Simulation Studies Group, Office of Marine Pollution Assessment, NOAA.

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 $16,289 \text{ ft}^3/\text{s}$ ($462 \text{ m}^3/\text{s}$). The Pee Dee system accounts for over 92% of the total.

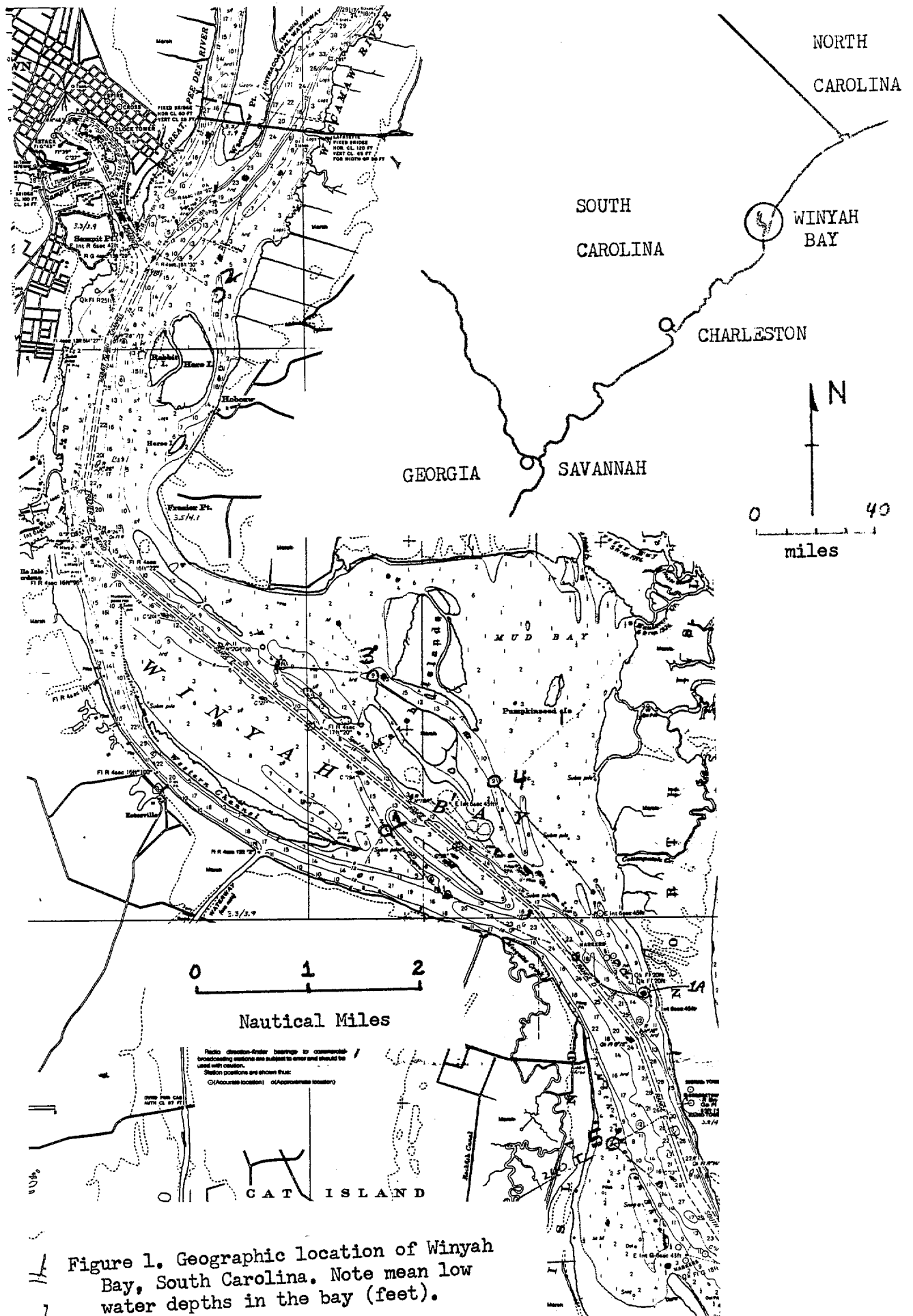


Figure 1. Geographic location of Winyah Bay, South Carolina. Note mean low water depths in the bay (feet).

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/TT-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:

<u>Actual Time</u>	<u>WBO/TRS-80</u>	<u>WBO/TT-59</u>	<u>WBO/manual</u>
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	0	-10	-17	-13	-13	-7	-7	0	0	0	0	0	0	0	0	0	0	0	0	0	
35	0	6	0	-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	0	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	0	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	0	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	40	36	25	14	0	0	
9	0	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	0	34	26	20	0	0
7	0	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	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	0	29	33	0
4	0	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	0	-17	-7	37	37	30
2	0	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	0	13	24	84	69
0	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	-19	-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	-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
30	-14	-40	-46	0	0	-10	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	-40	-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	0	0	-17	-17	-7	-7	-7	0	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	-10	-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	0	-6	-5	-9	-17	-43	-41	-42	-31	-30	-12	-23	0	0		
12	0	0	0	0	0	0	0	0	0	0	0	0	-9	-20	-22	-40	-56	-35	-30	-34	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	0	-101	-101	-127	-104		
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-107	-120	-103		
4	0	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	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	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	0	0	-38	-36	-29	-40	-69
0	0	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	0	1	3	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	-5	-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	-8	-8	0	0	1	0	0	0	0	0	0	0	0	-8	0	0	0
22	-2	-4	-6	-5	-5	-1	-1	0	0	1	0	0	0	-1	-1	-8	-1	-1	-1	-1	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	-8	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	0	-1	-2	-2	-4	-5	-3	-3	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	-3	-3	-3	-3	-4	-4	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-8	-8	-6	-5	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-8	-9	-8	-6	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-8	-7	-6	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-7	-7	-7	-7
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-7	-9	-7	-7
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-9	-7	-7
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-7	-6	-6
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-3	-6	-6	-6
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	-4	-5	-5
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-3	-3	-4	-3
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	-4

TABLE V. Rating tables for rivers entering Winyah Bay.

River Discharge (cfs)					
STAGE (feet)	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 shear. 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.

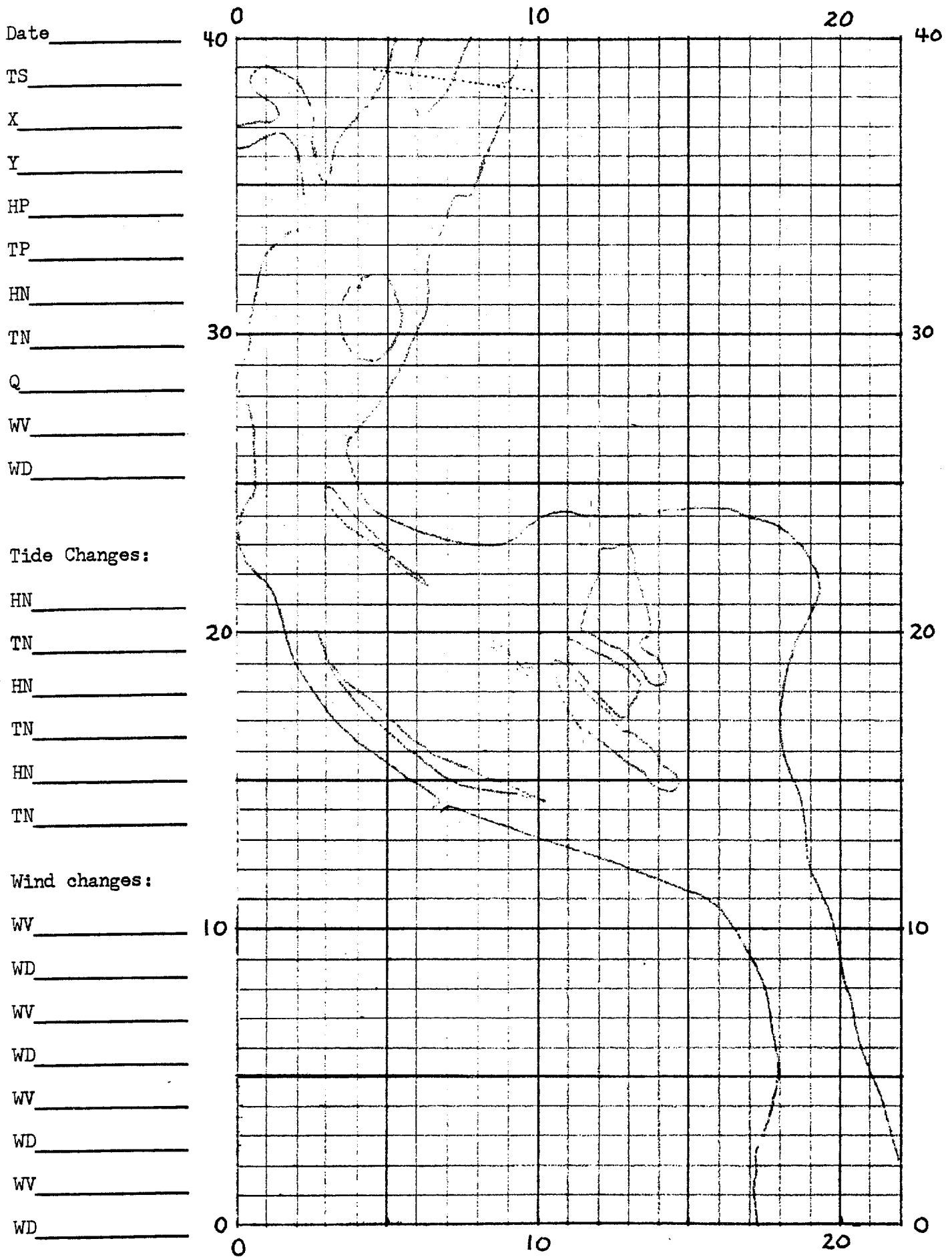


Figure 2. Winyah Bay shorelines superposed onto a 22 by 40 grid. Each grid square measures 484 m on a side.

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 meteorological 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).

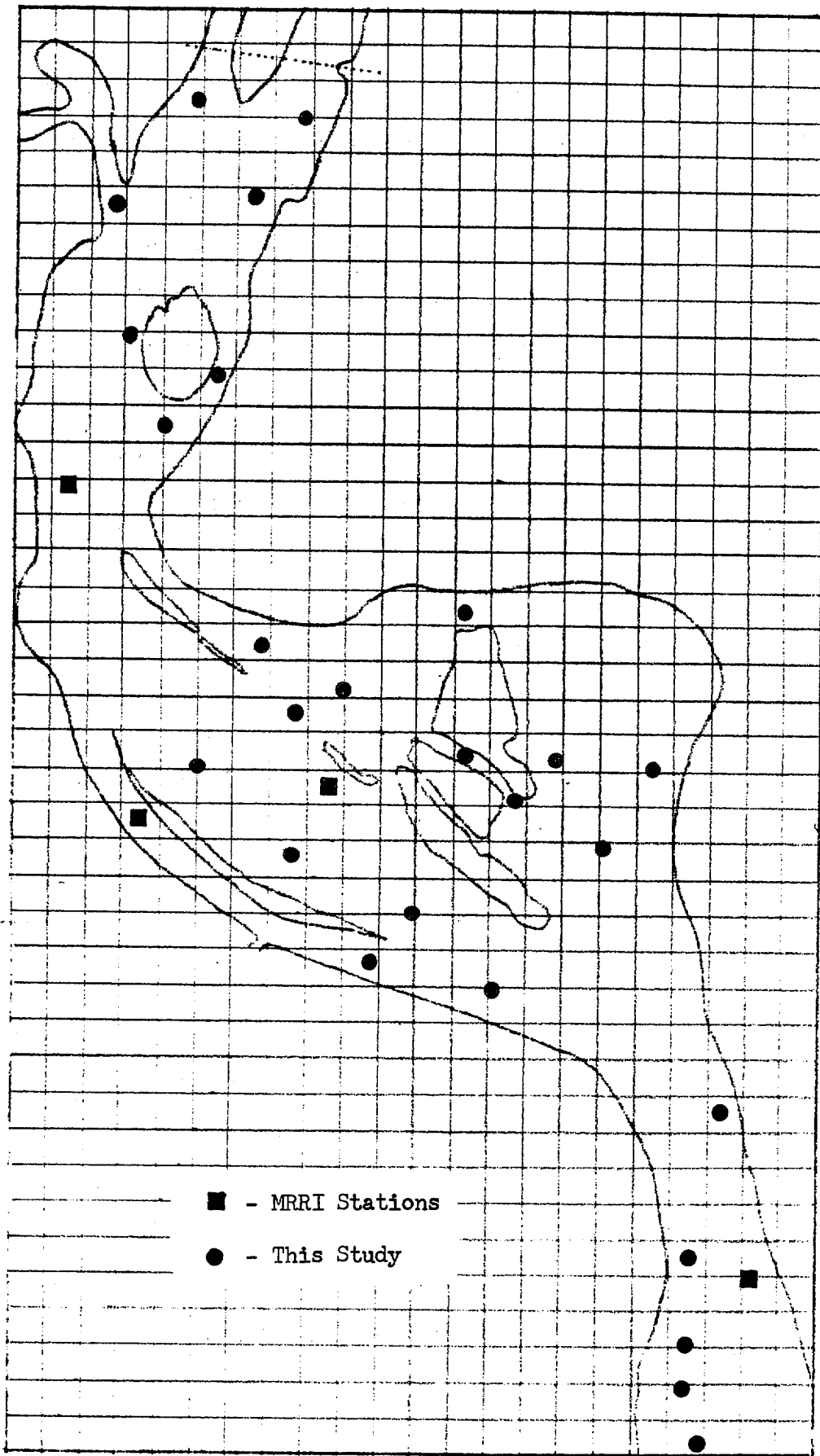


Figure 3. Map showing location of field study stations.

WBO/TRS-80 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
- } 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=404:GY=404: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 TI=T
240 GOSUB1340 :TS=T
250 PRINT
260 INPUT"ENTER SPILL COORDINATES (X,Y). SEE BASE MAP":X,Y
270 XS=X:YS=Y:X0=X:Y0=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 WFS ";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':Y5
420 IF Y4="N" THEN GOTO390
430 PRINT
440 INPUT"ENTER HEIGHT OF NEXT TIDE AT CHARLESTON":HN
450 PRINT
460 PRINT"ENTER TIME OF NEXT TIDE AT WINNAP BR"
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=170200:NEXT
540 PRINT
550 CP=ABS(HR/RN)
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 MW=W*5280*30.48/3600
660 PRINT"WIND VELOCITY IS ";W;" MPH = ";MW/100;" M/SEC"
670 PRINT
680 PRINT"ENTER DIRECTION FROM WHICH WIND IS COMING"
690 INPUT"DEGREES CLOCKWISE FROM NORTH":MD
700 PRINT"WIND COMING FROM ";MD
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 T5=T5+TI/60
770 IF T5>24 THEN T5=T5-24
780 GOSUB1300 : 'COMPUTE TIDAL HALF-PERIODS AND PHASE ANGLE
790 IF A>TT THEN TP=TN:HP=HN:KK=2:T5=T5-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=X5:YU=Y5:GOTO1070 : 'EBB
830 X=XU:Y=YU:GOSUB860 :XU=X:YU=Y:XD=X5:YD=Y5: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/(GW*100)
880 TY=CP*SIN(T)*TV(X,Y)+TI*PH*60/(GW*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(MD*RD)+TI*60/(GW*100)
940 WY=-0.03*WV*COS(MD*RD)+TI*60/(GW*100)
950 'RIVER EFFECT
960 RX=RUX(X,Y)+RC*TI*60/(GW*100)
970 RY=RV(X,Y)+RC*TI*60/(GW*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=T5:GOSUB1360
1070 TC=T5: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)":V5
1110 IF V5="Y" THEN 640 ELSE 760
1120 LPRINT"END OF RUN":KK=1:CLS:GOTO100

```

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=TF: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 ";MD;" 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"1";L,TU$
1480 FORJ=@TONY-1:FOR I=@TONX-1:INPUT#L,TU(L,J):NEXT:NEXT:CLOSE
1490 OPEN"1";L,TV$
1500 FORJ=@TONY-1:FOR I=@TONX-1:INPUT#L,TV(L,J):NEXT:NEXT:CLOSE
1510 OPEN"1";L,RU$
1520 FORJ=@TONY-1:FOR I=@TONX-1:INPUT#L,RU(L,J):NEXT:NEXT:CLOSE
1530 OPEN"1";L,RV$
1540 FORJ=@TONY-1:FOR I=@TONX-1:INPUT#L,RV(L,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 micro-computer. 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 "0".
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 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	050	01	1	100	76	LBL
001	42	STD	051	44	SUM	101	13	C
002	00	00	052	00	00	102	43	RCL
003	07	7	053	43	RCL	103	00	00
004	32	X:T	054	00	00	104	91	R/S
005	43	RCL	055	77	GE	105	42	STD
006	00	00	056	11	A	106	11	11
007	91	R/S	057	91	R/S	107	01	1
008	88	DMS	058	61	GTD	108	44	SUM
009	85	+	059	00	00	109	00	00
010	93	.	060	39	39	110	43	RCL
011	01	1	061	76	LBL	111	00	00
012	02	2	062	11	A	112	91	R/S
013	05	5	063	00	0	113	42	STD
014	95	=	064	32	X:T	114	12	12
015	72	ST*	065	43	RCL	115	09	9
016	00	00	066	09	09	116	55	÷
017	01	1	067	75	-	117	43	RCL
018	44	SUM	068	43	RCL	118	04	04
019	00	00	069	07	07	119	95	=
020	43	RCL	070	95	=	120	42	STD
021	00	00	071	42	STD	121	22	22
022	77	GE	072	20	20	122	43	RCL
023	12	B	073	00	0	123	01	01
024	91	R/S	074	32	X:T	124	75	-
025	61	GTD	075	43	RCL	125	43	RCL
026	00	00	076	20	20	126	07	07
027	15	15	077	77	GE	127	95	=
028	76	LBL	078	22	INV	128	42	STD
029	12	B	079	02	2	129	17	17
030	07	7	080	04	4	130	00	0
031	42	STD	081	85	+	131	32	X:T
032	00	00	082	43	RCL	132	43	RCL
033	01	1	083	20	20	133	17	17
034	01	1	084	95	=	134	77	GE
035	32	X:T	085	42	STD	135	23	LNK
036	43	RCL	086	20	20	136	02	2
037	00	00	087	76	LBL	137	04	4
038	91	R/S	088	22	INV	138	85	+
039	88	DMS	089	66	PAU	139	43	RCL
040	72	ST*	090	43	RCL	140	17	17
041	00	00	091	10	10	141	95	=
042	01	1	092	75	-	142	42	STD
043	44	SUM	093	43	RCL	143	17	17
044	00	00	094	08	08	144	76	LBL
045	43	RCL	095	95	=	145	23	LNK
046	00	00	096	94	+/-	146	43	RCL
047	91	R/S	097	42	STD	147	17	17
048	72	ST*	098	21	21	148	55	÷
049	00	00	099	66	PAU	149	43	RCL

Figure 5. Listing of WBO/TI-59.

150	20	20	200	66	PAU	250	22	22
151	95	=	201	01	1	251	95	=
152	42	STD	202	44	SUM	252	42	STD
153	18	18	203	00	00	253	28	28
154	65	x	204	43	RCL	254	66	PAU
155	89	≠	205	00	00	255	01	1
156	95	=	206	90	LST	256	44	SUM
157	42	STD	207	76	LBL	257	00	00
158	19	19	208	14	D	258	43	RCL
159	70	RAD	209	42	STD	259	00	00
160	38	SIN	210	13	13	260	91	R/S
161	42	STD	211	01	1	261	76	LBL
162	23	23	212	40	IND	262	15	E
163	43	RCL	213	00	0	263	65	x
164	21	21	214	43	RCL	264	04	4
165	55	÷	215	00	00	265	04	4
166	43	RCL	216	91	R/S	266	93	.
167	05	05	217	42	STD	267	07	7
168	95	=	218	14	14	268	95	=
169	42	STD	219	43	RCL	269	42	STD
170	24	24	220	06	06	270	15	15
171	43	RCL	221	55	÷	271	01	1
172	11	11	222	01	1	272	44	SUM
173	65	x	223	05	5	273	00	00
174	43	RCL	224	00	0	274	43	RCL
175	23	23	225	06	6	275	00	00
176	65	x	226	06	6	276	91	R/S
177	43	RCL	227	65	x	277	60	DEG
178	22	22	228	23	LNK	278	42	STD
179	65	x	229	14	D	279	16	16
180	43	RCL	230	65	x	280	38	SIN
181	24	24	231	43	RCL	281	65	x
182	95	=	232	22	22	282	43	RCL
183	42	STD	233	95	=	283	15	15
184	25	25	234	42	STD	284	65	x
185	66	PAU	235	27	27	285	93	.
186	43	RCL	236	66	PAU	286	00	0
187	12	12	237	23	LNK	287	03	3
188	65	x	238	07	7	288	65	x
189	43	RCL	239	55	÷	289	43	RCL
190	23	23	240	01	1	290	22	22
191	65	x	241	05	5	291	95	=
192	43	RCL	242	00	0	292	34	+/-
193	22	22	243	06	6	293	42	STD
194	65	x	244	06	6	294	29	29
195	43	RCL	245	65	x	295	66	PAU
196	24	24	246	43	RCL	296	43	RCL
197	95	=	247	14	14	297	16	16
198	42	STD	248	65	x	298	39	CDS
199	26	26	249	43	RCL	299	65	x

Figure 5. (cont.)

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

Figure 5. (cont.)

of origin of the spill and continue until the upstream end makes land-fall. 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/II-59

1. Load program onto II-59; Turn on II-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":

<u>Display</u>	<u>Item</u>
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
8.00	- Enter height of previous tide
9.00	- Enter time of next tide
10.00	- Enter height of next tide
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

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 calculation 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 point 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.

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) \div 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) \div (5c) = phase angle						
(e) Table VI factor						
(f) Table VII DXT						
(g) $X(4c)X(7e) \div 100 =$						
(h) Table IX DXR						
(i) $X(6b) \div 100 =$						
(j) Wind DXW						
(k) Total (g+i+j) =						
(l) New X						
(m) Table VIII DYT						
(n) $X(4c)X(7e) \div 100 =$						
(o) Table X DYR						
(p) $X(6b) \div 100 =$						
(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

0.00 0.00
 0.01 0.03
 0.02 0.06
 0.03 0.09
 0.04 0.13
 0.05 0.16
 0.06 0.19
 0.07 0.22
 0.08 0.25
 0.09 0.28
 0.10 0.31
 0.11 0.34
 0.12 0.37
 0.13 0.40
 0.14 0.43
 0.15 0.45
 0.16 0.48
 0.17 0.51
 0.18 0.54
 0.19 0.56
 0.20 0.59
 0.21 0.61
 0.22 0.64
 0.23 0.66
 0.24 0.68
 0.25 0.71
 0.26 0.73
 0.27 0.75
 0.28 0.77
 0.29 0.79
 0.30 0.81
 0.31 0.83
 0.32 0.84
 0.33 0.86
 0.34 0.88
 0.35 0.89
 0.36 0.90
 0.37 0.92
 0.38 0.93
 0.39 0.94
 0.40 0.95
 0.41 0.96
 0.42 0.97
 0.43 0.98
 0.44 0.98
 0.45 0.99
 0.46 0.99
 0.47 1.00
 0.48 1.00
 0.49 1.00

PHASE ANGLE CORRECTION FACTOR

0.50 1.00
 0.51 1.00
 0.52 1.00
 0.53 1.00
 0.54 0.99
 0.55 0.99
 0.56 0.98
 0.57 0.98
 0.58 0.97
 0.59 0.96
 0.60 0.95
 0.61 0.94
 0.62 0.93
 0.63 0.92
 0.64 0.90
 0.65 0.89
 0.66 0.88
 0.67 0.86
 0.68 0.84
 0.69 0.83
 0.70 0.81
 0.71 0.79
 0.72 0.77
 0.73 0.75
 0.74 0.73
 0.75 0.71
 0.76 0.68
 0.77 0.66
 0.78 0.64
 0.79 0.61
 0.80 0.59
 0.81 0.56
 0.82 0.54
 0.83 0.51
 0.84 0.48
 0.85 0.45
 0.86 0.43
 0.87 0.40
 0.88 0.37
 0.89 0.34
 0.90 0.31
 0.91 0.28
 0.92 0.25
 0.93 0.22
 0.94 0.19
 0.95 0.16
 0.96 0.13
 0.97 0.09
 0.98 0.06
 0.99 0.03

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	-0	-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	0	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	0	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	0	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	0	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	0	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	-8	0	0	1	0	0	0	0	0	0	0	0	0	-1	0	0	
22	-4	-7	-11	-9	-9	-3	-1	0	0	2	1	0	0	-2	-1	-1	-1	-1	-1	-1	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	0	-2	-3	-4	-7	-9	-6	-5	-5	0	0	
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-4	-5	-6	-6	-7	-8	0	0	
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-15	-15	-10	-9	0	
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-15	-16	-15	-11	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-15	-13	-11	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-14	-14	-13	-13
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-12	-17	-13	-13
5	0	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	0	-13	-12	-12	-12
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-5	-12	-11	-11
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-4	-7	-9	-9
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-5	-6	-7	-7
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	0	0	0

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:

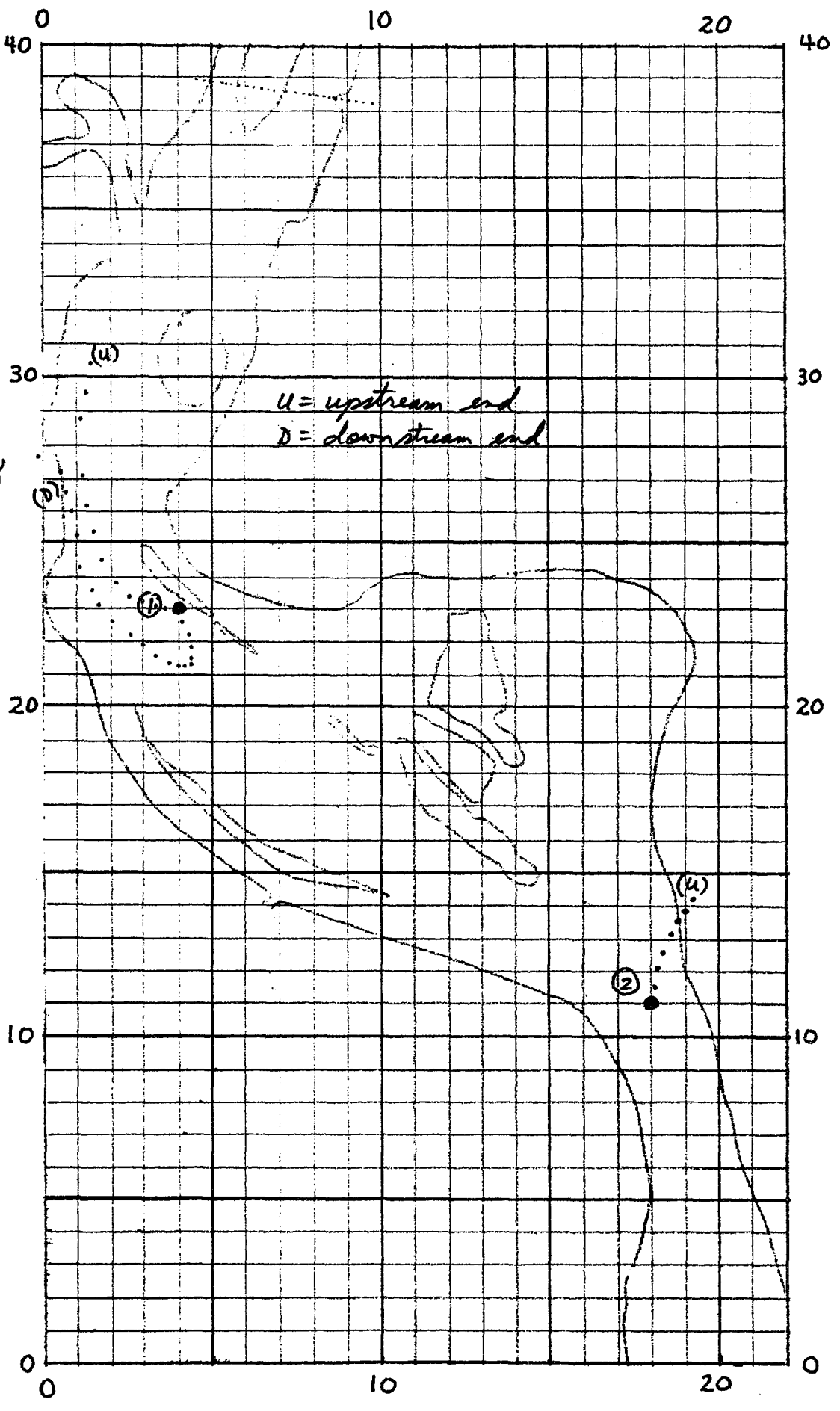
Date	①	②
TS	0800	2300
X	4.0	18.0
Y	23.0	11.0
HP	5.3	0.0
TP	0300	2100
HN	0.0	5.0
TN	0915	0315
Q	15066	20000
WV	7 mph	12 mph
WD	80°	270°

Tide Changes:

HN	5.1
TN	1530
HN	
TN	
HN	
TN	

Wind changes:

WV	
WD	
WV	
WD	
WV	
WD	
WV	
WD	



(1)

DATE- 02/06/15

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 00 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 00 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- 02/06/15

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
45	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

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	
(e) Table VI factor		.54	.43	.31	.19	.06	
(f) Table VII DXF		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	

* 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 = _____

LIST OF REFERENCES

- Bishop, Joseph M., 1980, Proceedings of the workshop on government oil spill modeling, November 7-9, 1979, Wallops Island, Virginia. Environmental Data and Information Service, NOAA, 25 p.
- Galt, J. A. and Payton, D. L., 1981, Finite Element routines for the analysis and simulation of nearshore circulation. Symposium on Mechanics of oil slicks, Int. Assoc. for Hydraulic Research and Societe Hydrotechnique de France, Paris, 7-9 Sept., 1981, p. 121-132.
- Stolzenback, K. D., Madsen, O. S., Adams, E. E., Pollack, A. M., and Cooper, C. K., 1977, A review and evaluation of basic techniques for predicting the behavior of surface oil slicks. MIT Ralph M. Parsons Lab. for Water Resources and Hydrodynamics, Report No. 222, 315 p.
- Tide Tables, 1981, National Ocean Survey, NOAA, U. S. Dept. of Commerce. 285 p.
- Trawle, Michael J. , 1978, Georgetown Harbor, South Carolina: Hydraulic, Salinity, and shoaling verification, Hydraulic Model Investigation, Report 1, U. S. Army Engineer Waterways Experiment Station Misc. Pap. H-78-6, 146 p.
- Water Resources Data for South Carolina: Water Year 1981, 1982, U. S. Geological Survey Water-Data Report SC-81-1 (in press).