

APPENDIX 8

UTILIZATION OF COMPUTER MODELS IN PUGET SOUND

The possibility for simulating Puget Sound on a computer will more than likely fascinate the layman; but to those more knowledgeable in computer science, it may evoke more criticism than plaudits. The many varied physical characteristics of Puget Sound, together with its multitude of islands and inlets, requires the programming of an enormous quantity of data.

This appendix presents three separate, but related, operations utilizing a computer model for the Sound. Preliminary analysis of one operation is presented in detail. The selection of the three tasks was influenced by the current state-of-the-art technology (whether computer-oriented or not) which can be summed up to be, at best, minimal. The three operations are:

1. tracking the behavior of an oil spill;
2. traffic control/advisory system;
3. response capability to an oil spill incident.

These are discussed individually in the following pages. The response capability model integrates the outputs of the first two operations in addition to utilizing other input data.

A. Oil Spill Movement Prediction

1. Introduction

One of the major difficulties in the present state-of-the-art of oil spill containment and cleanup is the tracking of the behavior of an oil slick. Various techniques of remote sensing have been discussed in this report; but as yet, their effectiveness has not been proven.¹ If the meteorological and hydrographic conditions of a given portion of Puget Sound are known, the movement of oil on water at a given site could be predicted by utilizing a computer model. The computer system can ask the model a pre-arranged set of queries, and oil spill response operation could be based on the model output. For example, the model will be asked where a spill will spread, and equipment could be deployed to this site by the time the oil reaches this location. It must be remembered that answers from the computer are only as good as the input data.

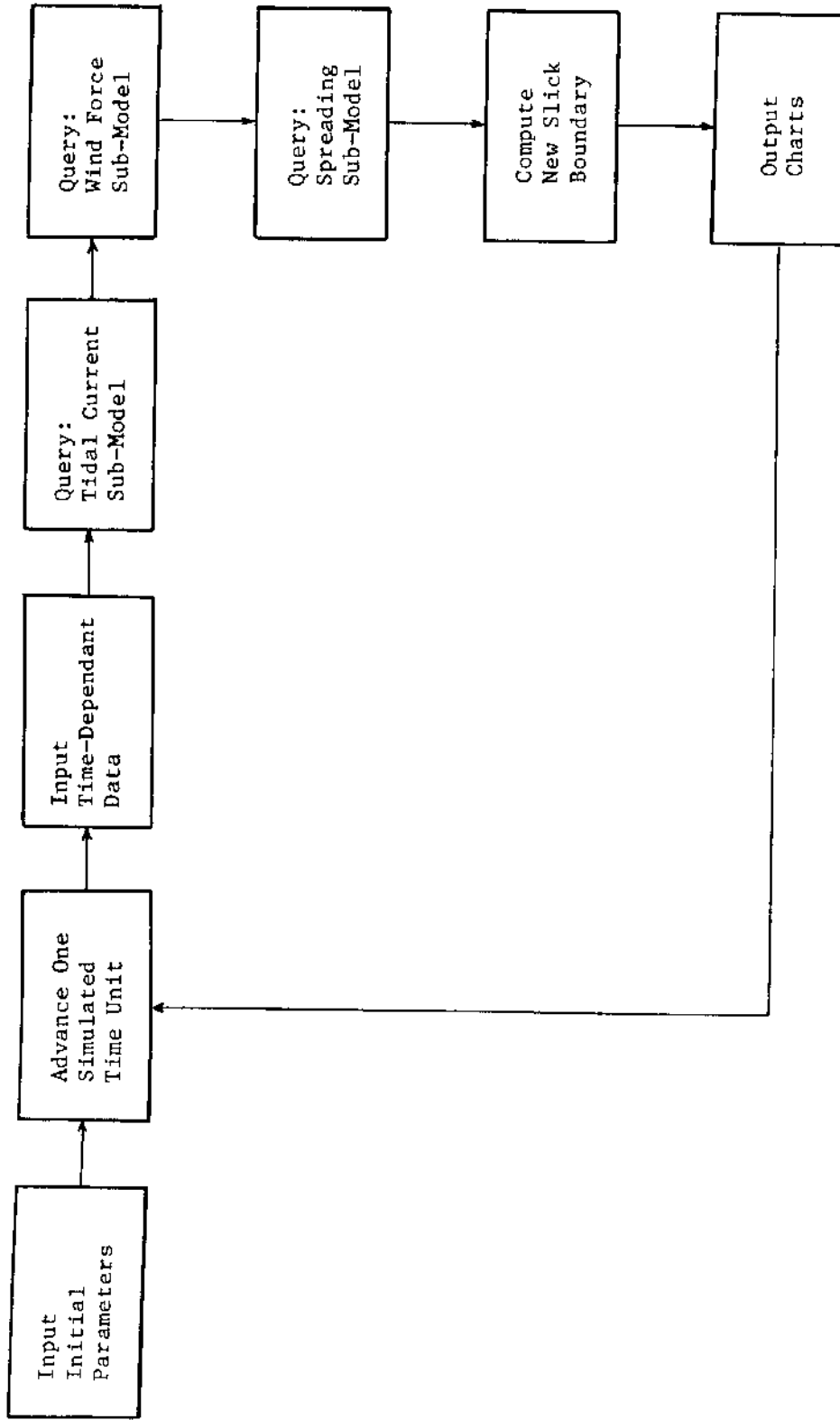


Figure 8-1

BASIC FLOW CHART FOR COMPUTER MODEL

Thus, for the discussion in this appendix, it is assumed that accurate information is available on Puget Sound meteorology and hydrography.

The following is a discussion of a model to simulate the spreading of oil on estuarine waters, with direct application to Puget Sound. It is emphasized that this was a pilot project, and that further refinement will increase the model's accuracy. To the study team's knowledge, it is the first attempt known to use computers for oil spread predictions in complicated estuarine areas.

The model is intended to be used by personnel involved in an oil spill cleanup situation. Among other things, this leads to the selection of computer-drawn charts as the output medium. This in turn leads to the concept of a data base using computerized maps, especially where land-areas are concerned. The emphasis is on a tool for oil spill response capability, rather than a study of the mathematics of oil slick movements.

2. Model Structure

The model was programmed in FORTRAN for the CDC 6400 at the University of Washington Computation Center.

Figure 8-1 is a block diagram showing the basic sequential steps in model operation. Each of these steps will be discussed below to provide an overview of the structure of the model.

Input Initial Parameters -

The model is currently designed to operate without permanent data files in a batched-job environment. This means that, at the beginning of each model run, the data base must be loaded into the system from punched cards. These are called parameter cards and their syntax is laid out in Table 8-1. The sort key is used to order parameters into sequence based on when, in simulated time, that parameter takes effect. All "initial" parameters are identified by a date of year 00, day 00 and a time of 00 hours and 00 minutes. The data base information loaded at this time is as follows:

TABLE 8-1: SYNTAX FOR COMPUTER MODEL

<parameter card>	: = <sort key> <variable data>
<sort key>	: = <year> <day> <hour> <minute> <code>
<year> <day> <hour> <minute>	: = <number> <number>
<code>	: = <major code> <minor code> <card count>
<major code>	: = [A C D I P T W]
<minor code>	: = [G S]
<card count>	: = <number> <number>
<number>	: = [0 1 2 3 4 5 6 7 8 9]
<variable data>	: = depends on parameter type

- a. Geographical bounds of data base expressed as North latitude, South latitude, East longitude, and West longitude.²
- b. Tidal currents for sea areas, and denomination of land areas. Current information is referred to a standard point and consists of the difference in time and current magnitude between the area specified and the reference point. Thus an area may have a flood tide which occurs 30 minutes later than flood at the reference point and with a current of 1.2 times the current at the reference point. Land areas are noted as those areas having a special, reserved, reference point.
- c. The simulated date and time at which the spill begins and ends.
- d. The amount of simulated time that is to elapse between calculation of slick boundaries, and the simulated time lapse between output displays. The latter must be greater than or equal to the former. The minimum time expressible is 1 minute.
- e. The latitude and longitude of the source of the spill. The model cannot except a slick already on the water.
- f. The rate at which oil is being spilled in barrels per minute, and the total amount of oil to be spilled in barrels. The spillage rate may be set to zero, in which case the oil is considered to have appeared instantaneously at a point source.

Currently, the type of oil spilled is assumed by the system to be an oil with a specific gravity of 0.886.

Advance One Simulated Time Unit -

All internal clocks are reset according to the simulated time that is to pass between computations. The model operates on a time-line rather than an event-line basis.

Input Time-Dependent Data -

All parameter cards which specify a date and time less than or equal to the current simulated time are loaded into the system.

Parameters which may be entered here are:

- a. Tidal currents for standard reference points. Each card specifies the standard reference point, time of

day (in addition to being part of the sort key),
type of current situation: ebb, flood or slack
tide, and the current in knots (0 for slack tide).

- b. The elapsed simulated time between computations and the elapsed time between outputs may be altered.
- c. The force and direction of the wind over various areas may be entered.

Query: Tidal Current Sub-Model³ -

For each point on the edge of the slick, the tidal current sub-model determines the tidal current at that point. The tidal sub-model may determine that a point is on land, in which case, no further calculations are done for that point.

A point is identified by its latitude and longitude. These parameters are sent, along with the fact that we desire a search of the tidal data, to special routines which look in the data base for the entry that contains the point desired. All data associated with this entry is returned to the tidal sub-model.

The data returned in the current version of the model are:

- a. The standard reference point, identified as a number.
- b. The time at which slack water occurs and the time at which maximum current occurs, relative to the standard reference point. For example, the maximum current entry may be +30 minutes. This means that the maximum flood or ebb tide occurs 30 minutes after flood or ebb at the reference point.
- c. Two multipliers, one for ebb and one for flood, which when applied to ebb and flood predictions at the reference point, yield ebb and flood predictions for the points covered by this data base entry. These multipliers apply only to maximum flood and ebb.
- d. The true compass heading for the flood direction and the ebb direction.

The tidal sub-model then looks up the data for the standard reference point. This data consists of the time of day for each slack, flood, or ebb tide, along with the current force. The entry

closest in time to the current simulated time is used; and this, with the data base information results in a vector in knots and compass degrees representing the tidal current for the point initially specified.

Query: Wind Force Sub-Model -

This is a simpler version of the mechanics of the tidal sub-model. The data base contains wind force and wind direction and this vector is the output of this sub-model.

Query: Spreading Sub-Model -

This sub-model is based on an equation provided by Battelle Memorial Institute⁴ which gives slick thickness as a function of the elapsed time, the volume of oil, and the specific gravity of the oil.

Assuming the oil to lie in a circular mass, the spreading sub-model obtains the radius of the circle thus:

$$\begin{aligned} \text{AREA} &= \text{Volume/Thickness} \\ \text{RADIUS} &= [\text{Area}/\pi]^{1/2} \end{aligned}$$

The difference between this radius and the radius computed for the previous time segment is returned as the amount of spreading that has occurred over the current time slice. Obviously, this calculation makes the assumption that the amount of spreading on calm seas with no winds approximates whatever the spreading is under real circumstances. For the sake of convenience, this sub-model returns its results in units of knots as a scalar quantity. Other sub-models produce vectors with units of knots.

Compute New Slick Boundary -

The edge of the slick (as intuitively defined) is referred to as the boundary. The boundary set consists of 360 points on the boundary. Each point corresponds to one true compass degree around the edge of a presumably circular slick (see Figure 8-2). Initially, all 360 points are the same, i.e. the source of the spill. For each point P_i ($1 \leq i \leq 360$) in the boundary set (see Figure 8-3):

FIGURE 8-2

**HYPOTHETICAL UNIFORM SLICK &
SOME OF THE BOUNDARY POINTS**

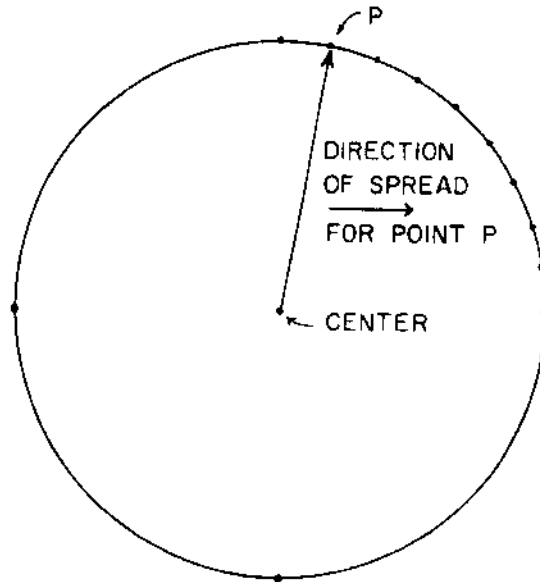
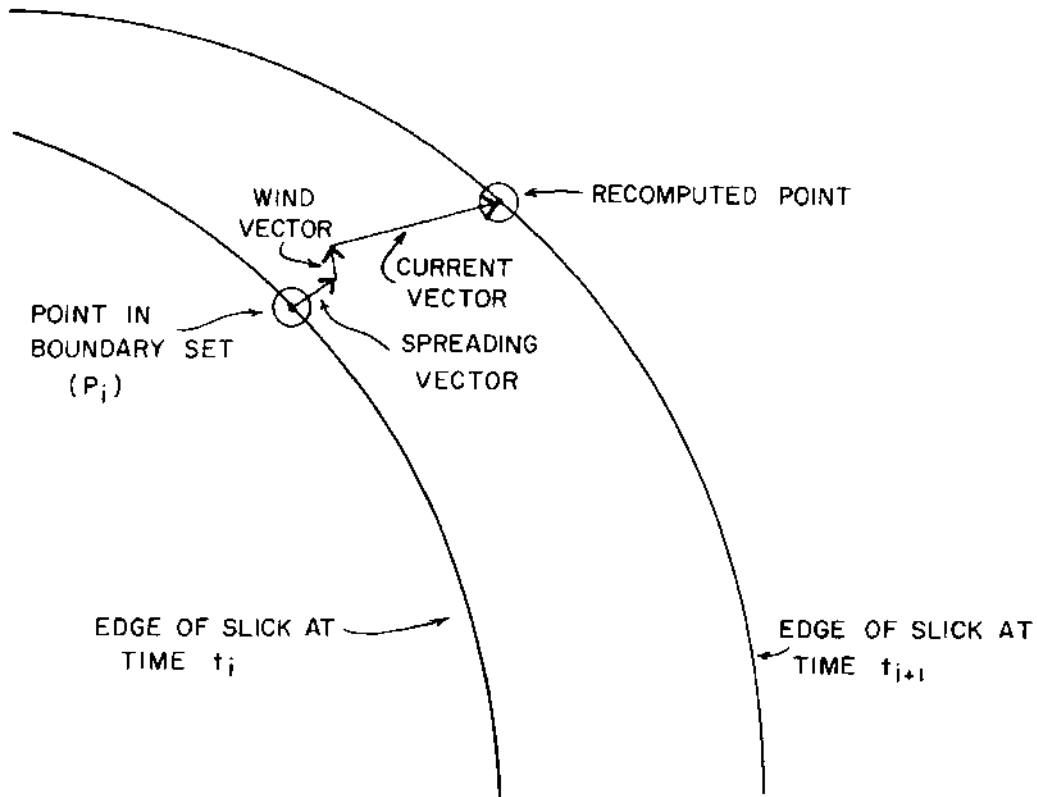


FIGURE 8-3

BOUNDARY CHANGE



$$P_{i \text{ new}} = P_i + 0.033 \overline{(\text{wind})} + \overline{\text{current}} + \overline{\text{spread}}$$

$\overline{\text{WIND}}$ is returned by the wind sub-model

$\overline{\text{CURRENT}}$ is returned by the tidal current sub-model

$\overline{\text{SPREAD}}$ is $(s.\sin(i), s.\cos(i))$
 where s is returned by the spreading sub-model,
 and $(-)$ denotes a vector.

The wind and current factors are noted on in the Battelle report,⁵ the spreading factor is as reported under the spreading sub-model applied along the line from the center of the slick to P_i . The model does not recognize the change in direction which occurs as the slick goes from circular to elliptical under constant wind and current vectors with spreading being applied in all directions. This error is not considered significant since the spreading velocity itself is small (about .2 knots for 5,000 bbls of crude one hour after spill).

This computation is done to all these points in the boundary set except those which have moved onto land areas as a result of previous calculations. If the current calculation moves a point onto land this is not noted until the next iteration. This makes it possible for the model to "move" oil far onshore, since the "beach" is not recognized.

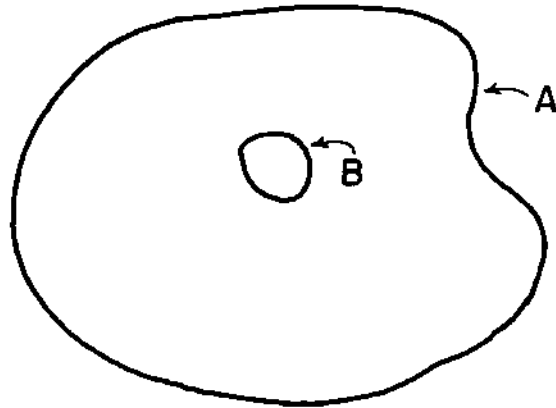
Output Charts -

This stage is executed at intervals specified by the user. This stage of the model may run less frequently than the computation stage but not more frequently. The most effective way to display the output of the model (the contents of the boundary set) is to mark all the points of the boundary set on a nautical map. Many satisfactory schemes are available. For simplicity, the geographical boundaries were produced on a computer printer. This is equivalent to trying to produce maps on a typewriter.

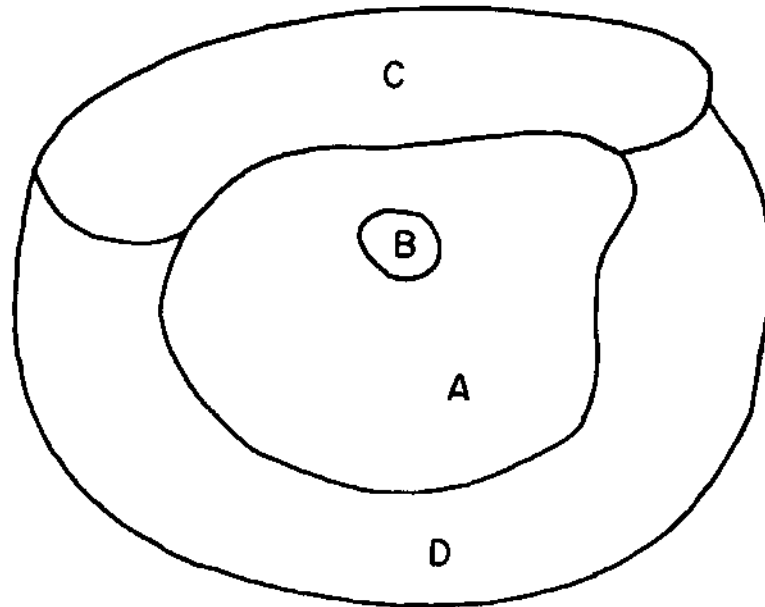
The model currently produces maps in sections one nautical degree by one nautical degree. For example, a map section will cover

FIGURE 8 - 4

SAMPLE AREAS FOR DATA BASES



E = ENTIRE AREA



48°-49°N. lat. by 122°-123° W. long. If more than one section is required, they can be produced. Also, land points are marked in to aid recognition. The resolution of a map is one square nautical minute. The resolution is a function of page size. This produces a very crude map, since any land point in a square minute causes the whole square to come out as land. The overall quality of the maps could be improved only by better resolution, producing enough land points to cover a wall.

Some trace values are also produced. The average tidal current and the average net wind effect are displayed in x-y coordinate form. Other values, namely scalar, are expressed with a zero-y coordinate. These include the spreading force from the spreading sub-model, the thickness in centimeters, and the volume of oil spilled.

3. Data Base Structure

Organizing the data base for this model is not unlike organizing any random access data base, except for one index: geographical location. In general, a specific datum, or attribute, applies not just to one point, but to an entire area. An island, for example, represents a collection of points with a common attribute: they are all land points.

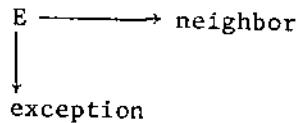
As a consequence of this point of view, data base entries are associated with an "area," and there exists a simple mechanism for associating a point with the area that contains it. In addition, two concepts of area organization are introduced: covering, and exceptions.

An exception is an area which is a proper subset of another area. In the top frame of Figure 8-4, area B is an exception in area A. Conceptually, one might think of A as a water area, and B as an island. Thus all points in area A, with the exception of area B, have the same attribute: water.

In point of fact, the tidal current data base assigns to each area a specific current characteristic, with land points represented by special current data. In the bottom frame of Figure 8-4, areas

C and D have been added. C, D and A represent water with three different tidal current characteristics, and B is an island. Areas A, C and D, together (AACAD) provide a "covering" of area E. Note that each of A, C and D, are "exceptions" to area E.

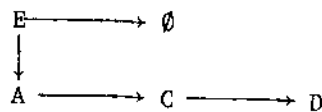
The data base coordinates all this by a series of linked pointers. Let us take area E as an example. Among the data entered for area E is a pointer to a "neighboring" area, and a pointer to an exception area. Thus:



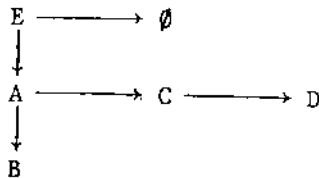
There is no neighbor to area E, so the pointer is empty: $E \longrightarrow \emptyset$. For exception areas we have A, C or D. Thus we can write:



Let us choose A as the exception. What about C and D? They are neighbors of A; thus:



and we can add area B:



This method of organization provides some notable advantages. First, without the linking of exception points, area A, for example, would have to be described as an area with a "hole" in it; very difficult. Additionally, the number of sequential searches required is much reduced, saving a considerable amount of computer time. The more areas there are in the system, the more the linked list tends to "zero in" on the right area.

The only difficulty is that the computer is not very good at representing arbitrary geometries. As a result, all areas are represented as rectangles. Figure 8-5 shows a land area being approximated by rectangles. Each rectangle is a separate data base entry with two latitudes and two longitudes supplied. Of course, data must also be supplied for each rectangle. Defining and entering rectangles into the system is a very tedious operation.

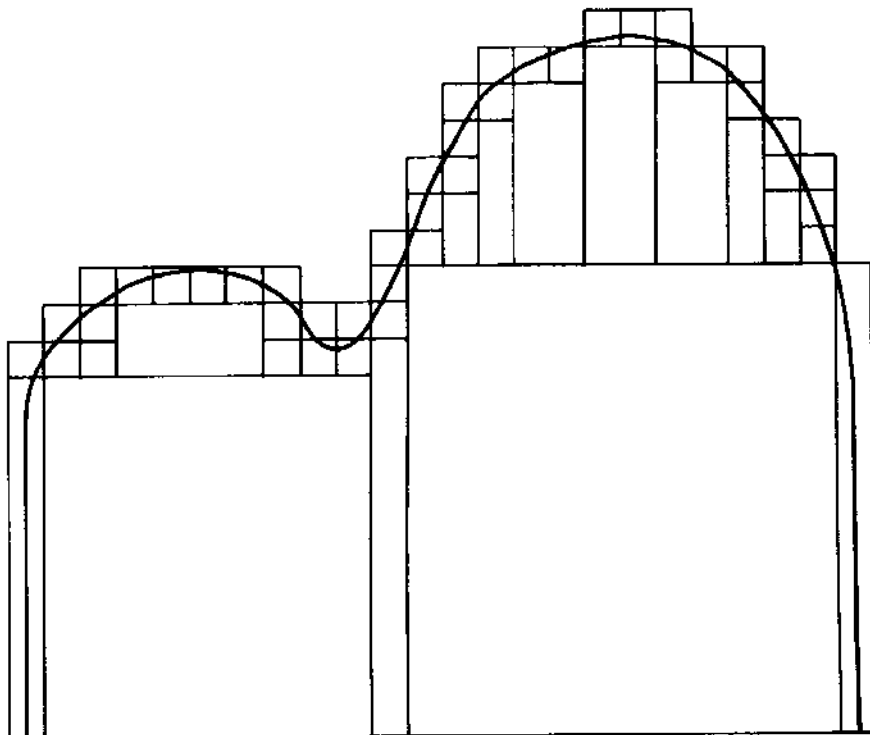


FIGURE 8-5: APPROXIMATION OF LAND AREA BY RECTANGLES

The model's current data base consists of three parts: the wind data-geographically keyed, the tide data-geographically keyed, and the standard reference points-time keyed. The two geographical section are represented by four arrays:

- a. AWK - Array Wind Keys,
- b. AWD - Array Wind Data,
- c. ATK - Array Tide Keys, and
- d. ATD - Array Tide Data.

These are FORTRAN arrays defined as:

- a. DIMENSION AWK (100,7),
- b. AWD (100,2),
- c. ATK (100,7),
- d. ATD (100,9).

This limits the system to 100 data entries and 100 keys, the latter being the more serious restriction.

Both key arrays are alike and are structured as follows:

- (i,1): Westerly longitude.
- (i,2): Easterly longitude.
- (i,3): Southerly latitude. .defines rectangular area
- (i,4): Northerly latitude.
- (i,5): j such that ATK(j,-) is exception to entry ATK(i,-)
- (i,6): k such that ATD(k,-) is data entry associated with ATK(i,-)
- (i,7): m such that ATK(m,-) is a neighbor to ATK(i,-)

Each parameter card specifies enough data to fill both a key and a data entry. The model provides programs which automatically link key entries correctly.

Time is represented in the tidal data base by array DAYCRT. This array contains one day's worth of tide predictions for each of the standard reference points. DAYCRT is a FORTRAN array:

DIMENSION DAYCRT (10,11,4).

DAYCRT(i,j,k) is defined as: the standard reference point, (i), from data entry in ATD; at the j-th time entry, up to 10 different times for flood, ebb, and slack tide; and k is one of four data items. Table 8-2 shows a sample DAYCRT entry. The times shown are monotonically increasing since the input parameter cards are sorted. In this case, however, the sort is on the card count field (see Table 8-1), since the hours and minutes fields are 00. This is an arbitrary setup based on internal programming ease. The net result is that the user must sort this data by hand for all data with the same year and day. DAYCRT is reloaded every day of simulated time at 00 hrs. 00 minutes.

Wind data changes with time by reloading the data array. To date, only the simplest wind data has been used and new wind data has always gone in with the same keys as previous data. In this case a simple update of AWD occurs. The only problem in updating the data base in this fashion is that old entries are not deleted. Thus, if areas are redefined, old definitions and new definitions are both present in the data base.

TABLE 8-2: DAYCRT Entries for Standard Reference Point 1 - DAYCRT(I,J,K)

	DATA			
	K = 1	K = 2	K = 3	K = 4
	Type of Tide	Hour Tide Occurs	Minute Tide Occurs	Force in Knots
J = 1	Ebb	00	00	0.9
J = 2	Slack	03	48	0
J = 3	Flood	05	00	0.3
J = 4	Slack	06	00	0
J = 5	Ebb	10	48	2.5
J = 6	Slack	15	12	0
J = 7	Flood	18	06	1.8
J = 8	Slack	22	06	
J = 9	to J = 10: all zero.			

In this example reference point 1 is Rosario Strait. The data is for April 15, 1971.

Parameter Cards -

A parameter card is physically implemented by at least two cards. The first card contains the sort key in columns 1-13, columns 14-80 are blank. Any number of additional cards are used to carry the parameter data. These cards are interpreted by the FORTRAN NAMELIST facility, and therefore follow the rules set forth in the CDC 6600 FORTRAN manual.

Initially, it was intended that each parameter card would be entered as a variable length logical record, and would then be sorted - hence the sort key. This plan was never carried out, so the user must manually arrange his cards. Another unfulfilled plan involved the use of minor codes G and S (see Table 8-1). Advances in the data base programming obsoleted this arrangement, although some remnants of it still remain. In particular, the minor code is ignored in all cases except major codes I and W, where the minor code is G. Codes are defined as follows in Table 8-3.

FIGURE 8-6
SAMPLE PARAMETER DECK

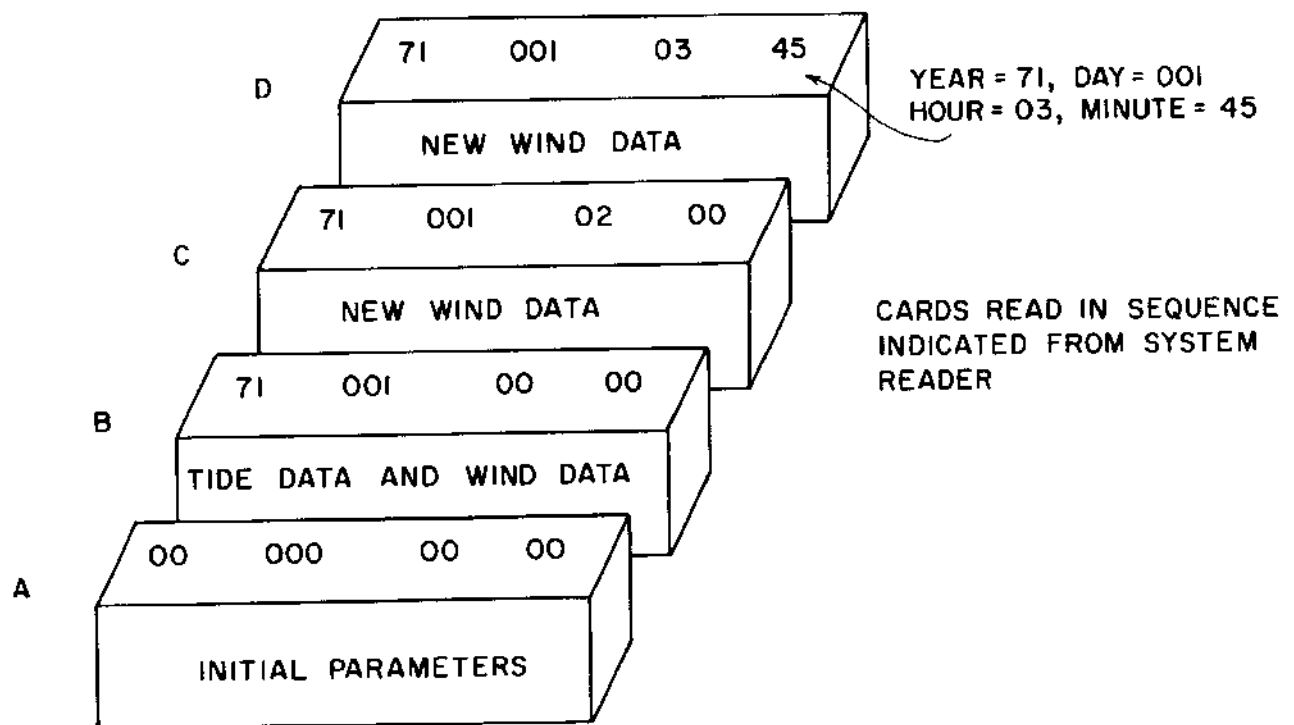


TABLE 8-3: CODES

Code	Name	Use
A	A CODE	Defines absolute geographical limits of data base in terms of latitude and longitude.
C	C CODE	Data for DAYCRT. One parameter card per standard reference point.
D	D CODE	Obsolete.
IG	IG CODE	Defines key and data entries for tidal data base (ATK,ATD).
IS	Not used	
P	P CODE	Problem parameters such as time spill starts and stop, spill location, spill rate and volume, computation interval, etc.
T	T CODE	Re-defines computation interval and output interval.
WG	WG CODE	Defines key and data entries for wind data base (AWK,AWD).

Figure 8-6 shows a sample parameter deck divided into four sections. Section A provides initial data base information and has a sort key of year = 00, day = 000, hour = 00, and minute = 00. Section B provides data base information of the standard reference points for the tidal data base and the initial wind data. There is usually one such section for each day of simulated time to be run. Hours = 00 and minute = 00 puts this data ahead of all other data for the day 001 of year 1971. Sections C and D are two changes in the wind date. The sort key specifies when this data takes effect. Section A contains cards with codes A, IG and P; Section B has codes C and WG; sections C and D contain code WG. In addition, a code T card may occur in any section. To date, wind data has been

represented in the model by only one parameter card (WG), thus the wind has uniform velocity over all geographical points in the system.

Figures 8-7 through 8-12 are a series of reproductions of the output obtained from a typical run. The problem concerns an oil spill off March Point, under the influence of wind only with no tidal currents. The problem parameters are: start of simulation at 01 hours 00 minutes on day 001 of year 71; end of simulation at 01 hours 00 minutes on day 002 of year 71. Location of spill is 122° 34'0" W longitude, 48° 30'30" N latitude; rate of spill is 42 barrels per minute; total volume is 5000 barrels. The model computes the slick boundary once every 30 minutes of simulated time, and produces output once every hour. The trace data along the top includes the spreading force in knots, the volume in barrels, and the thickness in centimeters. Each of these is a scalar quantity and the figure "0" is extraneous. The average tide is, of course, zero, and the average wind is shown in x-y coordinates in units of knots. On the map 'L' stands for land, 'O' for oil, '-', 'I', and '+' are grid symbols, and water is represented by blanks. The block of 'L's on the bottom of each chart represents an area not defined in the data base. The maps tend to spill over a few lines onto the following page due to not having the printer exactly lined up.

4. Model Improvements

In the course of operating what is in effect a 'pilot' model several needed improvements have been recognized. These are summarized below. For the most part they fall into two different parts, improvements related directly to the oil slick model, and improvements to the data base structure. This division is a result of considering those problems which apply to environmental modeling in general, and to the oil slick model in particular.

The data base problem is very critical although it has not restricted the work done so far. This is simply due to the fact that the

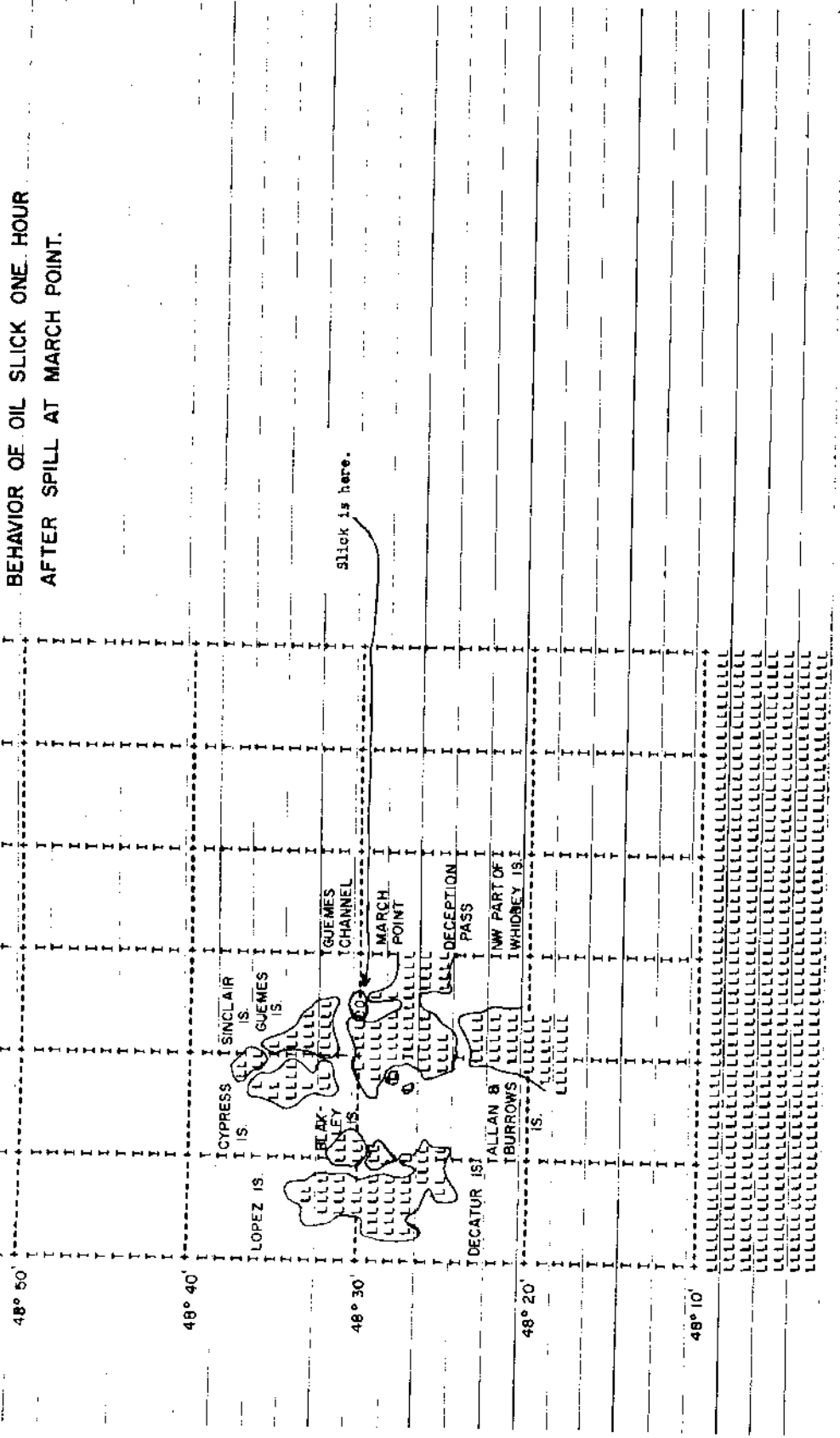
YEAR = 71 DAY = 1 AT 2 HOURS AND 1 MINUTES. CHART FOR 123 TO 172 DEGREES WEST LONGITUDE, 48 TO 49 DEGREES NORTH LATITUDE. PAGE 1

SPREAD 2.37145E-71 KNOTS
 VOLUME 2.52002E+03 BARRELS
 49° 00'

AVE WIND 3.96600E-01 5.37639E-05

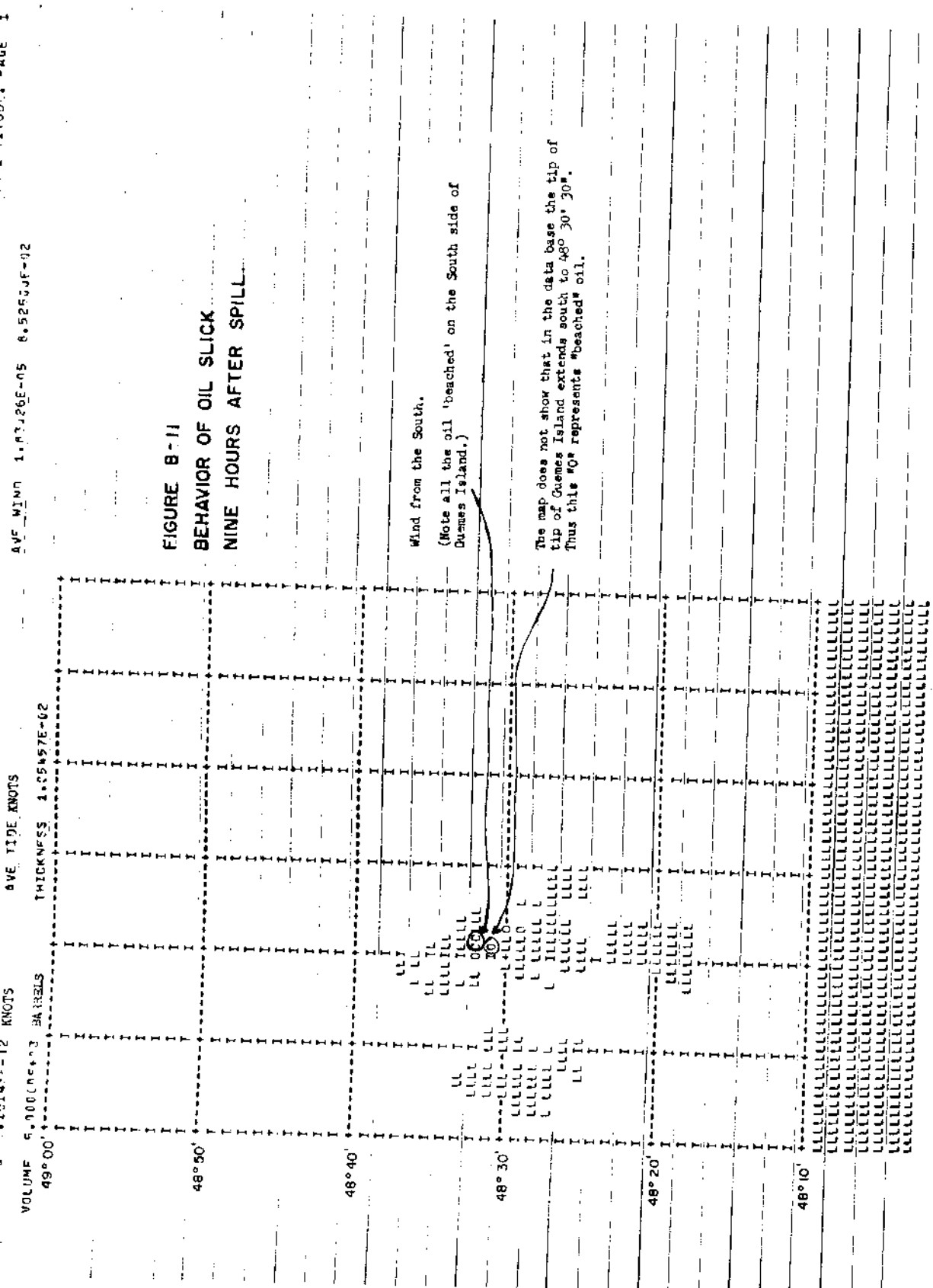
AVE TIDE KNOTS
 THICKNESS 3.43110E-02

FIGURE 8-7
 BEHAVIOR OF OIL SLICK ONE HOUR
 AFTER SPILL AT MARCH POINT.



YEAR = 71 DAY = 1 AT 10 HOURS AND 7 MINUTES, CHART FOR 123 TO 122 DEGREES WEST LONGITUDE, 48 TO 49 DEGREES NORTH LATITUDE, PAGE 1
 SORFAD 7.16147F-12 KNOTS
 VOLUME 6.000000003 BARRELS
 THICKNESS 1.55457E-02
 AVE. TIDE KNOTS
 AVE. WIND 1.03726E-05 8.5255JUF-92

FIGURE 8-11
BEHAVIOR OF OIL SLICK
NINE HOURS AFTER SPILL



Wind from the South.
 (Note all the oil 'beached' on the South side of GAMES Island.)
 The map does not show that in the data base the tip of tip of GAMES Island extends south to 48° 30' 30\". Thus this #0* represents 'beached' oil.

present output has a low degree of geographical resolution, plus the very preliminary nature of the testing done to date. The formulation of a detailed data base necessitates the assistance of clerical help.

There are three basic problems to constructing a data base for a general environmental model.

The first is diversity. Consider any given point in a bay, for example. How many different things might you want to know about? How deep is the water? At what time? What is the salinity? How much friction to tidal currents is presented by the underwater geography? What is the long wave action? What is the marine life? At which time of year? The only sure thing is that as an environmental model is constructed, the number of attributes will multiply.

The second problem is resolution. In many cases the data base must model a continuous datum. How does one represent the shoreline? This is a typical problem. As mentioned above, the approach taken here was representing 'areas'. Another approach which is more common is to represent an area as a number of fixed, uniformly distributed points, foregoing the notion of boundary. This technique is used in conjunction with finite difference equations. Mungall and Matthews⁶ present a fine exposition of what is involved. Clearly, whatever form the data base takes it will have to support finite difference calculations. And yet another untried approach would be the use of an analog-digital hybrid computer.

The third problem is size. There is a minimum geographical area for which random access is necessary. An oil slick for example may cover a 3 square-mile area. In working with points within this area the model can be assumed to require random access to any of several attributes. If points are allowed to be spaced over a grid at 1000 foot intervals, there will be approximately 30 points to a square yard. Further, in the present model each tide point has 9 data items associated with it yielding 270 words of storage per square-mile. Also, since the slick will not be uniform (perhaps it is a large streamer) the output will have to represent more than

3 square-miles to hold the spill. Experience suggests 15 square miles, yielding about 4000 words of storage. And this is just one attribute. With little thought one can readily imagine the volume of data involved.

Below are listed those improvements to the oil spreading model which are felt necessary and feasible.

The major error in model formulation is the concept of tracking only the edge of the slick. Like a hollow egg, when the edge of the slick touches land the shell bursts and nothing comes out. Thus, although in fact the slick may still be spreading, the model operates as though all the oil is on shore.

The model should keep track of a set of points representing the entire spill. This would allow a much more accurate picture of oil transport to be developed. Some of the improvements would be:

- a. ability to note differing thicknesses in slick, thus providing better fluid flow information;
- b. a basis for developing the mechanics of slick breakup;
- c. an estimation of oil volume in various areas of interest, such as bays, and channels;
- d. a more accurate representation of slick shape, especially with regard to streamers.

The model should also be upgraded to include information on the chemistry of oil. Evaporation and solution of oil should be calculated. A composite map, produced at the end of a model run, showing the predictions of the amount of oil in solution at various points would be of great assistance in damage assessment. The model could also greatly assist in cleanup by predicting the nature of the oil on the beach; is it thick enough to be picked up with pitch forks, or is sorbent needed?

It is also apparent that a whole new oceanographic scheme must be developed. For example, slick breakup would seem to be a function of long wave action, amongst other things. Also, the concentration of oil in water channels will require that the model predict their

existence. Cross channel transport should also be included to increase model accuracy. Tide heights will have to be added for damage prediction where the amount of beach polluted is a function of the difference in tide heights.

The model must also be rearranged to follow an event-line instead of a simple time-line. Currently if a wind change occurs twice in a time slice, the first wind shift is lost.

A mechanical improvement is that the model should be able to accept aerial reconnaissance pictures in order to correct model errors. In this circumstance, the model will have to be able to restart when cleanup personnel determine that predictions are not holding up.

Some improvements in the data base could be made. First, land points should be separated from tidal data; this to allow improvements in tide modeling. And second, the area definition mechanism should be improved to allow: 1) easier specification, 2) more accurate definition of boundaries, and 3) faster response for points on or near boundaries.

An exploration should be made to see if the tidal sub-model could be improved. The tidal model would be much more accurate if, for any given point, the tide at that point could be determined by interpolating from the nearest reference points. This would probably eliminate the geographically keyed data base and expand the number of standard reference points.

Finally, an improved output technique must be devised. Perhaps by using a mechanical plotter, or a video display, charts with better resolution could be produced.

B. Traffic Control Systems

1. Introduction

The basis of a computerized oil spill prevention system is an automated traffic control system. A later section describes the technical details of such a system. Basically, a series of radar stations are built to provide a small, centralized computer with input. The computer compares vessel courses, looking for a potential collision.

2. Two Types of Prevention Systems

At this point it is important to note the distinction between 'traffic control' and 'traffic advisory'. It is, in essence, the difference between 'you must' and 'you should'. There are two important obstacles. One is the considerable reluctance of ship masters to have their traditionally absolute command superceded. The other difficulty is the question of who is to assume liability for any damage that may occur as a result of commands issued by traffic control. If the agency operating the traffic system is liable, then we have a true 'control' system. In an 'advisory' system the master, and through him the steamship company, retains liability. An advisory system has no affect on the master, it merely is a tool to be used by pilots.

There would appear to be two solutions to the problem of liability insurance. One is to have the agencies which contract for the traffic control service provide the insurance. Currently, the U.S. Government assumes liability for ships going through the Panama Canal, since a Government pilot is mandatory. The other solution is a trifle more speculative. It is based on the supposition that a traffic control system is sufficiently safer than no system so that insurance premiums would be reduced. Perhaps it is possible that the insurance companies would use some of the reduction to insure the traffic control company. It seems that everyone might benefit from such an arrangement.

So far objections from the pilots have not been mentioned. Some people might think that the pilots would be the strongest opponents

of a traffic system. This is not necessarily true. In fact, the pilots would seem to benefit from the system. One point to note is that there is nothing to support the idea that a traffic system would eliminate onboard pilots. Systems running now have retained onboard pilots and there is no evidence that anyone is trying to design a system which would replace pilots. It is, in fact, a distinct advantage to the system to have pilots onboard, since they would be experienced in interacting with the system; 'onboard' pilots because the person operating the traffic system on shore should also be a pilot. This is the feature that should do the most to make a traffic control system palatable to the pilots. Like any professional, pilots dislike taking commands from someone not in the profession. Not to mention that having a pilot at the computer console provides a reliable check that the computer is operating correctly. Finally, there are several small things the computer can do to aid pilots. One example is that the computer knows where buoys are supposed to be. On a map, a buoy has an approximate location; in the computer, it is an exact location. Likewise, the computer is not bothered by a missing buoy, while at the same time the loss of a radar response would provide the earliest indication of a missing buoy. Another example, is that the computer could provide better control over places like Rosario and Haro Straits. In general, it is not good practice for ships to go in opposite directions on these waters at the same time. The computer, by means of radar, can detect this situation with greater reliability than is now possible. The computer could also easily schedule ships to use such 'one-way' waters when there is possibility of crowding. In all, it seems that the pros outweigh the cons for the pilots.

3. Marketability

One suggestion for a scheduling application is to use satellites to provide position data. Thus ships which run up and down the coast could be accurately scheduled. It is argued that it would be better to start with such a system and then expand to provide traffic systems in ports such as Seattle. Economically, the satellite

system would seem to be more desirable to steamship operators and thus could be sold easily, providing revenues to finance expansion. At this point, there is no way of knowing if this service could be provided at a marketable price.

A better market for the services of the traffic system than the steamship companies would be organizations that operate only on the Sound, such as tugs, barges, and some government operations.

To expand the marketability of scheduling services we shall make a slight technical improvement in the traffic system. The object of this improvement shall call a 'responder'. A responder is a small electronic radio transmitter and receiver. It constantly monitors a set frequency for a code, and when it hears it, responds with an answering code. Up to one thousand responders can operate on one frequency since the entire response cycle takes only one thousandth of a second. At the main station, all the codes are sent out and the responses listened for. Typically, each responder is queried once a second. The responder is small, and may be battery powered if necessary.

The responder is used in two ways. It provides identification to the traffic system, i.e., the radar blips are identifiable. Also, the responders can be located by triangulation and thus can provide position data for things that do not show up on radar.

What is desired is to put a responder on each tug and barge operating under the system. The computer could keep track of the individual characteristic of each tug and barge and by using this information along with knowing the vessels' location, cargo, and status, could provide extremely efficient scheduling. Job orders could be put into the computer and the system would see to it that the orders were executed at the right time, eliminating the possibility of losing orders or incorrectly executing them.

There are some interesting capabilities of a computer-based traffic system; in particular, its ability to deal with emergencies. Consider a vessel in distress. The system can both route rescue vessels to the

ship, and can re-route other traffic around the site. A dock fire presents a similar situation which could be readily controlled by a prepared emergency response plan. In each instance, the service would be contracted for by the responsible agency; the Coast Guard, and the Port of Seattle for example.

The responders are of great use in such situations. They could be built into buoys and dropped from airplanes at the sight of a distressed vessel or downed aircraft, thus entering these locations into the traffic system. Such buoys might also be used to track oil spills. Presumably they would float with the slick and thus provide more accurate detection, especially during the night. Since the buoys will not necessarily float the same as oil, buoys which are no longer following the slick will have to be excluded by putting their codes into the computer with instructions to stop polling these buoys. There are many uses to which the responders could be put, all depending upon the idea that the responder allows one to mark any location quickly by means of a dropped buoy.

C. Role of Computer in Oil Spill Response

The final touch to the system, which does most to expand the services to be offered, is a large-scale computer.

Perhaps the most important opportunity given us by a large computer is the ability to run models. The oil spreading model, in particular, could be run on the large computer at the request of the small computer. Thus the model could be used when a pollution incident occurs to get predictions to aid in cleanup. This, and other models, could be used to provide firms with a planning service; i.e., studies on the environmental impact of various projects could be performed.

If one imagines a hypothetical spill incident, he can see some of the capabilities of the system.

First, we must recognize that the operating center for the traffic system will also be the center for cleanup operations. The operating center already has, as a necessary adjunct of its operations, radio facilities for

all types of sea-going vessels. It has a medium-duty telephone system, normally used for client contact. It has a dispatcher and a pilot on duty. It has some type of apparatus, perhaps a video unit, for keeping track of ships which can now be used for showing the slick as well. It has the equipment for putting instruction and data into the computer. It also has automatic equipment which allows the computer to place telephone calls. To this one needs to add the ability to expand into a heavy duty telephone net, and perhaps some pre-recorded messages.

The system starts by being notified of the spill. This message is received by the traffic center by radio or telephone. The traffic center enters all known data into the computer and activates the appropriate response plan. The computer automatically notifies all agencies specified on a list stored in memory. It does this by automatically dialing the telephone numbers on the list and sending either teletype messages, or broadcasting one of the pre-recorded messages. The pre-recorded message may be made by the dispatches and thus it will include all pertinent information. The computer will continue to call all the people on its list until it receives a positive response. This can be simply done by having people call a pre-arranged number and then dialing in extra numbers as a response code.

In the meantime, the computer has assessed all available information and provided the traffic center with a list of ship dispatches to be made for rescue vessels and cleanup equipment. The computer can do this because it knows the disposition of all ships that can be used and it can select the vessels that can get there in the least amount of time. In the case of tugs, the computer can determine the availability of vessels by computing the optimum route for disposing of the tug's current cargo and then sending it on cleanup duty. The computer can even initiate communication to get dockside personnel ready to receive the tug's current cargo and to make ready the cleanup equipment the tug needs.

The computer has also activated the oil spreading model and thus has useful information concerning the amount of oil on the water and where it is going. This information goes into the plan held in the computer's memory and controls the scheduling of equipment. Thus, a tug may be instructed to drop off its cargo at one port, go to another port to pick

up a specified amount of sorbent and proceed to a certain beach. There it may meet with another tug, similarly dispatched to pick up boom perhaps, and the two of them will go to work to protect the beach, before the oil gets there. The computer can provide such scheduling because it knows the speed of the tugs, the route they must take, the projected route of the oil, and in a minute can compute all possible intercepting paths.

As spill cleanup progresses the computer keeps up its scheduling activity. Since the cleanup vessels have responders on them, the computer knows exactly who is where and what they are supposed to be doing. As additional equipment arrives, perhaps from other cities, responders are assigned, and the equipment's characteristics are entered into the system. This permits the computer to send the right equipment to the right place, such as skimmers and oilvators. Thus the system provides that which experience indicates is most important: control.

It should be emphasized that much of what the system is supposed to do is not at all 'far out'. It is in fact, quite a common accomplishment in process control applications.

Finally, it should be noted that such a system, made operational in the Sound, would be highly marketable in other areas providing the State of Washington with a profitable engineering export.

This would appear to be the kind of public utility that makes money for everyone by filling a need created by advancing technology. To get it started requires only that a thorough study be made of all the possible applications to the maritime industry to provide a solid economic base to the system.

D. Endnotes for Appendix 8

1. See Section III-C, Part 3 for a discussion of oil-on-water detection equipment.
2. All latitudes are represented on cards in degrees, minutes, and seconds, based on North Latitude units. Longitudes are also in degrees, minutes, and seconds, based on West Longitude units.
3. This sub-model is an automated version of the manual hookup technique associated with Table 2 of "Tidal Current Tables, 1971," U. S. Department of Commerce, ESSA, Coast and Geodetic Survey.
4. Battelle Memorial Institute, Study of Equipment and Methods for Removing Oil from Harbor Waters, Battelle Memorial Institute Report #C12-70-001, August 25, 1969, pp. 4-5, 4-6.
5. Ibid.
6. J. C. H. Mungall and J. B. Matthews, A Variable-Bounding Numerical Tidal Model, Institute of Marine Science, March 6, 1970.

Example of IMCO resolutions include:

- #157) use and testing of shipboard navigational equipment;
- #158) port advisory services related to arrival times of ships carrying noxious or hazardous cargoes;
- #159) define ships subject to mandatory pilotage services;
- #160) data on ship maneuvering capabilities under various conditions made available on the bridge;
- #161) establish traffic separation schemes;
- #162) lighting of channels; and
- #188) updated training manual for masters, officers, and crew.

All these recommendations have also been suggested in this report for the waters of Puget Sound. (See Section III-C.)

The conference reviewed the significant breakthroughs in federal legislation. Included were the Water Quality Improvement Act of 1970 and the National Contingency Plan. One point brought up by members of EPA³ is of interest to Puget Sound and concerns itself with an illegal discharge of oil. The 1965 Water Quality Act states that "no oil..... should be discharged... that (1) can be detected as a visible film or sheen...." This statement was part of a set of adapted recommendations of the subcommittee for Fish, Other Aquatic Life and Wildlife, which consisted of "29 scientists and leaders of the field."⁴ Their 1965 recommendations were supposedly interim, effective until more information or toxicology and other chemical effects of oil in sea water were obtained. As of June, 1971 no further modifications to this regulation have emerged from the subcommittee. The least that can be done is to evaluate the effects on those species unique to Puget Sound and recommend to the Washington Department of Ecology (DOE) or the regional EPA office some quantitative interpretation of this ruling.

With regard to the National Contingency Plan, the significant comment was made in an article by Commander Charter, USCG. He wrote that "...non-federal plans should, if possible, be developed in such fashion as to be responsive to the Federal planning effort."⁵ While this appears compatible on the surface, there are two factors that can lead to conflict. First, the federal plan is aimed at coordination of the management roles of the various departments and agencies of the federal government, and between

federal, state, and local response system. The plan is weak in the areas of operational controls. Since the governmental agencies do not have the equipment or manpower to physically control an oil spill, an updated data bank of private sector capabilities must be an integral part of the national plan. Also, guidelines for recovery of costs incurred by these organizations must be set forth at the national level. The second factor is related to conflicts between local goals and national goals. While nationwide uniformity is ideal, it is the localized areas that bear the consequences of any oil spill. Thus, their efforts must receive proper sanction.

State jurisdiction over oil spills is still in its infancy. Four states enacted laws in 1970. These include Florida, Maine, Massachusetts, and Washington. Currently, the legislation enacted by Florida and Maine are not operational due to legal tieups in the federal courts. Here again, as it was demonstrated above, state and federal governments should strive to iron out jurisdictional conflicts in their control over water pollution.

B. Oil Spill Prevention, Control, and Monitoring

Based on the articles presented in this portion of the conference, oil spill prevention efforts are aimed at oil production facilities and shipboard operations, both in harbor and open seas. Methods to prevent such spills included training programs for shipboard personnel, use of oil separators on tankers, ballast water treatment, and use of skimming points at oil production facilities.

The Gulf Oil Corporation display on mammoth tankers was of special interest. The firm presented a historical sketch of the development and construction of the Universe Ireland, a 326,000 dwt tanker, incorporating many modern prevention techniques, including the load-on-top (LOT) procedure of tank cleaning and ballasting, and a collision avoidance radar computer system. Gulf has also incorporated a ballast processing plant into their operations at Bantry Bay, Ireland.

The state-of-the-art of monitoring oil-in-water is, at best, in the developmental stages. Though several articles were presented on techniques of sensing oil spills, little evidence of commercially available hardware was on display. Those displayed monitored possible tank overfills rather than monitoring the water to determine if and when significant amounts of

oil were present. Devices or systems to track oil spills were not available at the exhibits, though USCG presented an article on surveillance of oil slicks.⁶

C. Treating Agents

As testimony to the containment controversy of using dispersants in treating oil spills, four of the ten papers in this portion of the proceedings addressed themselves to the effectiveness and consequences of this type of agent. The sentiment of the articles can best be summed up by the following comment by EPA:

"..., it would appear that more than knowledge of toxicity and emulsion efficiency should guide our decisions regarding the use of chemical dispersants for oil spill cleanup."⁷

Table 9-1 is a list of treating agents displayed in the exhibit hall which have not been evaluated in Appendix 6 of this report. Since no test data was available on their performance, only the manufacturer's name is included. When performance data is obtained, these should be included in the evaluation in Appendix 6 on cleanup devices applicable to Puget Sound.

TABLE 9-1: TREATING AGENTS DISPLAYED AT THE 1971 OIL SPILL
CONFERENCE (and not included in Appendix 6).

Agent	Manufacturer or Distributor
Chemo-Mechanical:	
Petro-Pak	Coastal Services 22 Industrial Park Road Hingham, Mass. 02043
Absorbent-1012	Colloid Chemical Co. 31 Perkins Street Brockton, Mass. 02402
Type 100	3M Company
Type 150	3M Center
Type 200	220-6E
Sorbing Boom	St. Paul, Minn. 55101
Slikwik	Slickbar, Inc. 10 Saugatuck Avenue Westport, Mass. 06880
Chemical:	
Coastal Cleaner	Coastal Services 22 Industrial Park Road Hingham, Mass. 02043
Oil Lok	International Oil-Lok Control Ltd. 1970 Spicer Road No. Vancouver, British Columbia Canada

D. Physical Removal and Containment

Nine papers were presented in this segment of the conference. Six described various concepts of containment, while the other three developed experiments and test procedures for evaluating devices. The concepts discussed included an oleophilic belt scrubber, a free vortex system to recover oil, a disc oil recovery system, and a dynamic keel boom. However, none of these concepts has evolved into a production model as yet. The three evaluation articles outline test conditions and procedures, but do not present any test results.

Of all the concepts, the disc recovery system appears the most promising. Two firms, Atlantic Research, and Lockheed Missiles and Space Company, have separately developed a similar system.^{8,9} It consists of a set of closely packed vertical discs, which are nominally half immersed in the water. Rotation of these discs through oil creates a viscous shear which attaches oil to the disc surface. The oil is then removed by a scraper, and the disc surface is again exposed to oil on its next rotation. Lockheed has tested a full scale 8 ft. diameter by 10 ft. system.

Table 9-2 presents a partial list of commercially available devices for physical removal and containment of oil spills. This list does not include displayed devices which have been evaluated in Appendices 5 and 6 of this report.

TABLE 9-2: PHYSICAL REMOVAL AND CONTAINMENT DEVICES EXHIBITED AT THE 1971 OIL SPILL CONFERENCE (and not included in Appendices 5 and 6).

Devices	Manufacturer or Distributor
Booms:	
Absorbent Boom Model 12D	Colloid Chemical Company Pollution Control & Research, Inc. 31 Perkins Street Brockton, Mass. 02402
Sea Serpent	Johns-Manville Corp. 22 E. 40th Street New York, N.Y. 10016
Sea Boom	Spiltrol 2400 W. Loop South (Suite 322) Houston, Texas 77027
Marsan Oil Barrier	Marsan Oil Recovery Service 31W060 W. Bartlett Road Box 83, Rt. 1 Elgin, Illinois 60120
Mechanical Cleanup:	
Reclam-ator	Welles Corporation P. O. Box J Roscoe, Illinois 61073
Oil Spill Reaction System	Atlantic Research 3333 Harbor Boulevard Costa Mesa, California 92626
Olea III	Pearson Bros. Co. P. O. Box 192 Galva, Illinois 61434
(Disc Recovery System)	Lockheed Missiles & Space Co. P. O. Box 504 Sunnyvale, California
Sea Boom	Submarine Engineering Associates, Inc. 278 Forest Ave. Cohasset, Mass. 02025

TABLE 9-2: PHYSICAL REMOVAL AND CONTAINMENT DEVICES EXHIBITED AT
 THE 1971 OIL SPILL CONFERENCE (and not included in
 Appendices 5 and 6). Cont'd.

Agent	Manufacturer or Distributor
Mechanical Cleanup:	
Buda II	Marine Pollution Control Corp. 9010 Roselawn Avenue Detroit, Michigan 48204
Magnecol Magnetic Broom Magnecol Oil Spill Harvester	Avco Systems Division 201 Lowell St. Wilmington, Mass. 01887
Oil Hawg	Parker Systems, Inc. Box 1652 Norwalk, Virginia 23501
Sea Skimmer	Spiltrol 2400 W. Loop South (Suite 322) Houston, Texas 77027
Mobile Beach Cleaner	Meloy Laboratories 6631 Iron Place Springfield, Virginia 22151
Floating Saucer	Acme Products, Inc. 8158 E. 44th Street Tulsa, Oklahoma 74145

E. Physical-Biological Effects

It is of significance to the study of oil spills that the two most controversial topics each warranted an entire session. Treating agents were discussed earlier, while this session dealt with the physical and biological effects of oil on water. It should also be noted that the status of the two topics did not change much as a result of the conference findings.

The first half of the session was devoted to biological effects. Studies at Milford Haven, England, and Santa Barbara, California were included. One consistent conclusion which is brought forth by the articles: there is some alteration in the biological environment as a result of the presence of oil. The articles do not identify whether this alteration has any long term detrimental effects or not. Most likely, knowledge on this topic is not fully developed at this time. A suggestion to enhance this knowledge is to continuously monitor the flora and fauna of a region such as Puget Sound to develop a biological inventory. From this, behavior and life patterns could be predicted. In addition, observed deviations from the normal pattern due to adverse conditions could be determined with a higher degree of certainty.

The second half of the session dealt with the physical behavior of oil on water. The state-of-the-art of analyzing behavior of oil on water is still in the formative stages. There are two primary reasons which have influenced this situation. First, techniques of detecting and tracking oil on water have not been thoroughly explored. Second, deliberate discharge of oil into water for study purposes is frowned upon. Thus, scientists and engineers have resorted to theoretical analysis and scale model tests. While the bulk of these are of some value, real life situations exhibit certain characteristics which cannot be duplicated in laboratory or paper models. A solution to the problem is to develop a readily deployable tracking system and obtain the necessary authorization and funds to utilize it at a major oil spill, should one occur. After several real-life tests, an evaluation of the system could determine its effectiveness. Though this approach is expensive, it is far more economical than the discharge of large quantities of oil into waters for testing purposes.

F. Oil Spill Cleanup

The final session of the 1971 oil spill conference was concerned with oil spill cleanup, including program, technique, and equipment evaluation. The session began with a British paper on cleanup programs.¹⁰ The main conclusion of the article was that optimum cleanup operation for unique conditions of each spill requires preparedness, flexibility, and an integration of appropriate techniques.¹¹

Subsequent papers discussed methods of cleaning oil contaminated beaches. Techniques included were utilization of earthmoving equipment, froth floatation cleaning, and hot water fluidization. Only the first technique has been used in a real life spill situation.

A panel discussion on oil spill cleanup experiences highlighted the session. The following trends were perceived from the dialogue:

1. Firms in the oil industry have relied on third party contractors and cooperatives to provide the oil spill cleanup capabilities required at the various facilities.
2. The biggest problem involved in responding to an oil spill is getting organized, initially.
3. On-scene commander relies on expertise of his subordinates and members of other organizations at the spill site.
4. The decision to terminate cleanup operations and the judgement of post cleanup water quality is vested solely with the on-scene commander.

Several comments come to mind with respect to the above statements. First and foremost should be a re-evaluation of contingency plans, both at the national and regional level. What portions of each are ineffective and why? Determine courses of action to improve the plans. A second suggestion is related to the operational readiness of the response. Initiation of periodic drills analogous to fire drills should improve the response time, and point up deficiencies in the operation. Lastly, increased levels of inter-agency communication is recommended to familiarize key personnel with each other's capabilities. (See Section III-B part 1, for the study group's proposal.)

The quality of preparedness for response prior to an oil spill is a key to the effectiveness of that response. Once oil is detected on water, there is no time to resolve jurisdictional or organization questions.

G. Summary and Remarks

It is interesting to note the similarities between those problems discussed in the conference and those analyzed by the Study Group in the main body of this report. What is disturbing, though, is the continued fragmentary approach to oil spill prevention. The inertias inherent to government bureaucracies and big business were evident at the conference, though tangible progress has been made since the Torrey Canyon incident over four years ago. But the truly remarkable revelation is that the quality of analysis and findings of the Study Group, presented in this report, can do far more to enhance the prevention effort of oil spills in Puget Sound than the generalized levels of effort presented in the Conference.

H. Endnotes for Appendix 9

1. American Petroleum Institute, Proceedings of Joint Conference on Prevention and Control of Oil Spills, Library of Congress Catalog No. 74-124324, 1971, pp
2. Captain R. I. Price, USCG, "International Activity Regarding Shipboard Oil Pollution Control, Proceedings of Joint Conference on Prevention and Control of Oil Spills, American Petroleum Institute, pp. 27-42.
3. K. E. Biglane and R. H. Wyer, Environmental Protection Agency, "Oil Pollution Control Legislation and the Water Quality Improvement Act of 1970, The Federal Viewpoint," Proceedings of Joint Conference on Prevention and Control of Oil Spills, American Petroleum Institute, pp. 11-15.
4. Ibid., p.13.
5. Commander D. B. Charter, Jr., USCG, "National Contingency Planning," Proceedings of Joint Conference on Prevention and Control of Oil Spills, American Petroleum Institute, p. 24.
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8. Uyeda, Chuan, Connolly, and Johnson, Atlantic Research, "Concept Development of a Powered Rotating Disk Oil Recovery System," Proceeding of Joint Conference on Prevention and Control of Oil Spills, American Petroleum Ins. pp. 329-338.
9. B. Bruch and K. R. Maxwell, Lockheed Missiles and Space Corporation, "Lockheed Oil Spill Recovery Device," Proceedings of Joint Conference on Prevention and Control of Oil Spills, American Petroleum Inst., pp. 339-356.
10. W. E. Betts and H. I. Fuller, Esso Research Center, U.K., "An Integrated Program for Oil Spill Cleanup," Proceedings of Joint Conference on Prevention and Control of Oil Spills, American Petroleum Inst., pp. 497-504.
11. Ibid., p. 497.