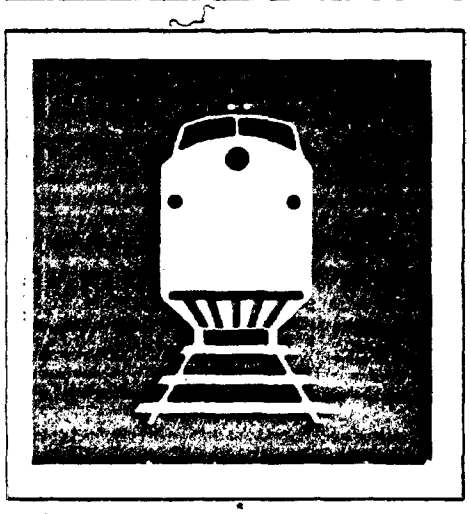

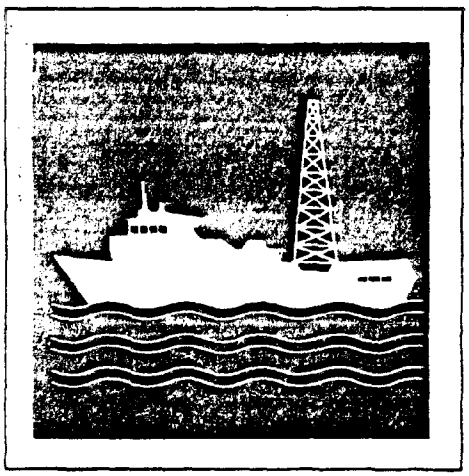

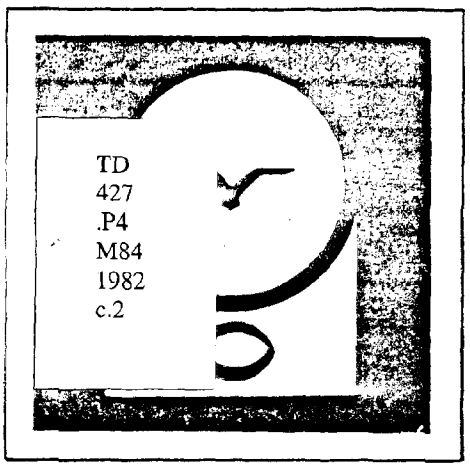

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Review and Evaluation of Oil Spill Models for Application to North Carolina Waters

Bruce J. Muga
Consulting Engineer
Durham, NC

AUGUST 1982

North Carolina
Coastal Energy Impact Program
Office of Coastal Management
North Carolina Department of Natural Resources
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REVIEW AND EVALUATION OF OIL SPILL MODELS

(for Application to North Carolina Waters)

by

Bruce J. Muga
Consulting Engineer
Durham, North Carolina

Prepared for

Office of Natural Resources Planning and Assessment
N. C. Department of Natural Resources and Community Development

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Executive Summary

A review of the general status of oil spill modeling is presented. The major processes of importance to oil spill motion are advection, spreading, dispersion and evaporation. The relative importance of each of the processes is depicted on a time-length diagram. This diagram is also employed to indicate those processes that are most important to the various North Carolina waters. The relative importance of these processes, in effect, dictate the model requirements.

It was found that approximately twenty-five distinct modeling efforts have been undertaken in recent years. Summary information for each of these processes are presented in the Appendix. A number of these models were found to be suitable for adaptation to the offshore, nearshore and inland and estuary waters of North Carolina. For each category, those models that are best suited are identified. Finally, some recommendations regarding prediction of oil slick behavior in North Carolina waters are presented.

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Chapter 1

Introduction

Recent interest in exploratory drilling for hydrocarbon deposits off the coastlines of North Carolina and neighboring states has disclosed the need to understand a number of environmental risks attendant to this activity. Among the most important of these risks is the spillage of liquid hydrocarbons. Since risk is the product of the probability of occurrence of an event and its effect (should the event occur), the transport mechanisms of spills is a topic of critical interest.

This topic has been the object of numerous studies in recent years. These studies have resulted in the development of various models for predicting the movement of spills. Each of these models was developed for a particular set of conditions. The result is that no reliable prediction scheme has yet evolved which is applicable to a general set of conditions. It is noteworthy to mention that development of such a scheme is a formidable task.

Therefore, the main focus of this study is an evaluation of the methods for predicting the movement of oil spills under the particular environmental conditions that exist in North Carolina waters. Although

the idea for this study stems from the potential drilling activity offshore, our interest in models for predicting spill movements is not limited to these occurrences. To a parallel degree, we are interested in methods for predicting spills that occur in connection with the transportation and transfer of hydrocarbons, within and adjacent to North Carolina waters. For example, methods for predicting the movement of spills that occur in ports, harbors and/or estuaries as well as along the adjacent transportation routes of North Carolina, are also of concern.

In response to the various needs, oil spill models have evolved along two separate paths. The earliest models were developed to predict one-of-a-kind events occurring in real time. These are after-the-fact models and depend upon reliable wind and current forecasts for achieving even moderate success. Most frequently, these models were roughly calibrated from real observations taken during and following a spill. Such models, of necessity, are programmed to accept real time data as input. With the passage of time, other model types were developed in connection with the evaluation of various impacts. These models are much more sophisticated than the earlier models and are designed to assist decision makers in the environmental assessment and planning

processes. These models use the historical climatological data as input and are programmed to generate sufficient data to disclose all possible consequences of an event.

For other fundamental reasons, the former and latter models tended to be deterministic and probabalistic in nature, respectively. This characteristic will be examined in more detail in the following section. Bishop (1979) has categorized the model types according to Type I, Type II or Type III, which he describes as follows:

> "Type I models: Multiple trajectory models for long-term strategic forecasts based on archived data.
>
> Type II models: Single event (highly structural) models for specific day-to-day tactical forecasts usually based on up-to-date data, and
>
> Type III models: Type I or Type II models implemented in a receptor (reverse) mode such that one can project areas from which trajectories would impact resources."

We see that Type III models are not really a separate category but rather a unique application and use of either Type I or Type II models. It is also interesting to observe that the sequence of presentation is actually the reverse of the historical development. In other words, Type II models evolved and preceeded the development of Type I models.

Chapter 2

Background

There is a substantial volume of literature dealing with oil spills, most of it of recent origin. Surprisingly, there have been only a few attempts to review the literature in a systematic manner within a comprehensive framework of the overall problem. The work by Stolzenbach, et.al. (1977) is an important reference in this regard. Most of the studies as published in the open literature treat only one aspect of the overall problem in an isolated context and often under a narrow combination of circumstances that make it difficult to apply the results to other situations with reasonable confidence.

It is instructive to make a few preliminary observations in connection with the treatment of the oil spill problem. This is a general problem in the field of fluid mechanics, the solution for which requires a broad understanding of chemical and biological processes. The solution can be approached in one of two fundamental ways; i.e., probabalistic or deterministic.

Because of the fact that (1) the environment (i.e., winds, waves and currents) has an enormous influence on the spill behavior, and (2) the environment

is a geophysical random process, one would expect that the approach should be a probabalistic one. In other words, the solution approach should be compatible with the nature of the problem. On the other hand, there are some features of the problem which are decidedly deterministic. An example would be the spreading of oil on a quiescent sheltered body of water in the absence of any winds, waves or currents. Also, the approaches are not mutually exclusive since elements of deterministic methods can be and are incorporated within probabalistic-based approaches and vice-versa. In reviewing the literature, it is important to recognize the existence of these two fundamental solution methods.

In view of the realization that the probabalistic nature of the problem derives from consideration of the environmental influences (which have regional 'geographic' dependency) and that the deterministic influence is based on the physical mechanics of the problem, we can identify two broad categories of processes which are of importance to the oil spill and transport problem. These processes are depicted in Table I, with some explanatory notation.

The spreading and dispersion processes are, to a large degree, geographic-independent, but are, nevertheless, dependent upon certain characteristics of the event

TABLE I

Processes of Importance to the Oil Spill and Transport Problem

Process	Nature	Dependency
Spreading	Deterministic	Oil properties at ambient temperature, largely site dependent
Dispersion	Deterministic (with probabalistic elements)	Turbulence intensities in water medium, weakly site dependent
Advection (Drift) (wind, currents, waves)	Probabalistic (with deterministic elements)	Strength of advecting fluids, strongly site dependent
Weathering and Other Processes biodegradation dissolution emulsification evaporation oxidation (photo) patch (large-size) breakup sinking and sedimentation	Probabalistic and Deterministic	Various site dependent and site independent conditions

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$  17  650  0  Oil well drilling, Submarine 'z North Carolina. %
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such as spill size, rate of spill and other physical and chemical characteristics which describe the spill material and receiving waters. In contrast, the advection (drift), weathering and other processes are directly related to and dependent upon conditions that characterize the site environment at the time of the spill and immediately thereafter. In other words, the processes which characterize oil spill movement consist of both site-dependent and site-independent ones. A brief review of the various processes governing the mechanics of the problem is presented in the following section.

Problem Formulation. Stolzenbach, et.al.(1977) have formulated the essential boundary value problem for oil slick transformations. The system of differential equations were derived on the basis of some simplifying assumptions and averaging approximations. The simplifying assumptions seem to be well justified and are used to some degree in all of the models that have been developed and reported in the literature. Therefore, any error due to the simplifying assumptions would not affect any relative evaluation of the various models. With regard to the averaging approximations, Stolzenbach, et.al. (1977) states that it is justified "only for the analysis of the oil motion and may not be a good approximation for studying the diffusion of oil through the slick boundaries."

The continuity equation which expresses the conservation of mass relationship appears as

$$\frac{\partial \bar{c}_i h}{\partial t} + \frac{\partial \bar{u} h \bar{c}_i}{\partial x} + \frac{\partial \bar{v} h \bar{c}_i}{\partial y} = k_i \left[\frac{\partial}{\partial x}\left(h \frac{\partial \bar{c}}{\partial x}\right) + \frac{\partial}{\partial y}\left(h \frac{\partial \bar{c}}{\partial y}\right)\right] - \phi_{si} - \phi_{bi} - \bar{R}_i h \quad (1)$$

The conservation of momentum relationship appears as

$$\frac{\partial \bar{u}}{\partial t} + \bar{u} \frac{\partial \bar{u}}{\partial x} + \bar{v} \frac{\partial \bar{u}}{\partial y} = -g \left(\frac{\rho_w - \bar{\rho}}{\bar{\rho}}\right) \frac{\partial h}{\partial x} - \frac{\tau_{bx}}{\rho h} + \frac{\tau_{sx}}{\rho h} \quad (2a)$$

$$\frac{\partial \bar{v}}{\partial t} + \bar{u} \frac{\partial \bar{v}}{\partial x} + \bar{v} \frac{\partial \bar{u}}{\partial y} = -g \left(\frac{\rho_w - \bar{\rho}}{\bar{\rho}}\right) \frac{\partial h}{\partial y} - \frac{\tau_{by}}{\rho h} + \frac{\tau_{sy}}{\rho h} \quad (2b)$$

The boundary condition on the slick boundary appears as

$$f_n = \sigma_{aw} - \sigma_{oa} - \sigma_{ow} \quad (3)$$

In the above equations,

x, y = variables of moving coordinate system with respect to origin at center of mass of oil slick

u, v = components of oil particle velocities relative to the center of mass of the slick

C_i = mass per unit volume of oil of the ith oil fraction

h = local slick thickness

k_i = molecular diffusion rate for ith oil fraction within the slick

R_i = rate of removal of the ith oil fraction per unit volume

ϕ_{si} = flux of the ith oil fraction outward through the surface of the slick

ϕ_{bi} = flux of the ith oil fraction outward through the bottom of the slick

$\bar{\rho}$ = average density of oil mass within the slick

ρ_w = density of water underlying the oil slick

t = time

τ_{sx}, τ_{sy} = shear stresses on oil slick surface

τ_{bx}, τ_{by} = shear stresses on oil slick bottom

g = acceleration due to gravity

f_n = net surface tension per unit length of oil slick boundary

$\sigma_{aw}, \sigma_{oa}, \sigma_{ow}$ = surface tension of air-water, air-oil and oil water interfaces, respectively

Equations (1) through (3) constitute, in a simplified form, the boundary value problem of oil slick transformations. In relating the physical processes shown in Table 1 to the various terms in the system of equations, we can point out that the effects of weathering (and other processes) are treated indirectly via the concentration term $\bar{C}_i$ for the different oil components and directly by the last three terms of Equation (1).

We can also note that the motions (i.e., particle velocities $\bar{u}$ and $\bar{v}$) are given relative to the center of mass of oil in the slick. Therefore, motions resulting from the advection processes (appropriate for the center of mass of the slick) must be superposed on the relative velocities to determine the motions in an absolute sense.

In a preliminary review of the literature, we found that models for the spreading, dispersion and advection processes have been developed and compared with model and prototype data to a sufficient degree to enable some reasonable conclusions and evaluations to be made. Except for evaporation, this is not the case for other weathering processes which remain incompletely understood. Moreover, the interactions between weathering and the other processes is even more poorly understood. As a consequence, the scope of this study is limited to an assessment of the spreading, dispersion and advection models and their applicability to North Carolina waters. In addition, some comments concerning evaporation models and models of other weathering processes will be provided but it is beyond the scope of the present study to consider such models on the same level with spreading, dispersion and advection models.

Spreading and Dispersion Model Solutions. Returning to the fundamental system of equations, different solutions can be obtained depending on the type of additional simplifications that can be made. As indicated by Stolzenbach, et.al. (1977) two broad categories of solutions can be identified. These are the spreading and dispersion solutions. The distinction between these two processes (and solutions) depends upon the relative strength of the external shear stresses acting on the oil slick. If the external shear forces (i.e., the last two terms of Equations (2)) are absent, or negligible, then the solution corresponds to the spreading process since the resulting motion depends upon the density differences and interfacial tensions. On the other hand, if the external shear forces are very large, then the solution corresponds to the dispersion process.

Most, if not all, of the spreading solutions appear to be based on or related in some way to the work of Fay (1969, 1971). Two sets of results have been obtained which are based on certain idealistic assumptions. The one-dimensional set of results is appropriate when it is assumed that the slick spreads in one direction only. The two-dimensional case is based on radial spreading. A summary of the spreading functions for the two different sets of results is given in Table II. These functions

TABLE II

Spreading Laws for Various Regimes
According to Fay (1971)

Regime (Driving/Resisting Force)	Spreading Formula One-Dimensional	Radial
Gravitational/Inertial	$L = k_{\ell_1}\left[\left(\frac{\rho_w-\rho}{\rho_w}\right) gAt^2\right]^{\frac{1}{3}}$	$D = 2k_{r_1}\left[\left(\frac{\rho_w-\rho}{\rho_w}\right) gVt^2\right]^{\frac{1}{4}}$
Gravitational/Viscous	$L = k_{\ell_2}\left[\left(\frac{\rho_w-\rho}{\rho_w}\right) At^{\frac{3}{2}}/\nu^{\frac{1}{2}}\right]^{\frac{1}{4}}$	$D = 2k_{r_2}\left[\left(\frac{\rho_w-\rho}{\rho_w}\right) V^2t^{\frac{3}{2}}/\nu^{\frac{1}{2}}\right]^{\frac{1}{6}}$
Surface Tension/Viscous	$L = k_{\ell_3}\left[\sigma^2t^3/\rho_w^2\,\nu\right]^{\frac{1}{4}}$	$D = 2k_{r_3}\left[\sigma^2t^3/\rho_w^2\,\nu\right]^{\frac{1}{4}}$

where ρ_w = density of water

ρ = density of oil

g = acceleration of gravity

L = length of one-dimensional oil spill from fixed origin to leading edge of oil slick solubility

D = diameter of radial (axisymmetric) spill

A = volume of oil per unit length normal to spill direction

V = volume of oil

ν = kinematic viscosity of water

σ = interfacial tension

t = elapsed time from initial spill

From various sources, the coefficients k may have the following values:

$k_{\ell_1} = 1.5$ $\quad k_{r_1} = 1.14$

$k_{\ell_2} = 1.5$ $\quad k_{r_2} = \begin{Bmatrix} 0.98 \\ 1.12 \\ 1.45 \end{Bmatrix}$

$k_{\ell_3} = 1.33$ $\quad k_{r_3} = 1.60$

are presented with the unknown length (distance from leading edge to center of gravity of spill) in an explicit formulation. The other known or assumed variables appear on the right-hand side (RHS) of the equation.

The dispersion models result in the following solution form:

$$\tilde{h} = \frac{m}{2\pi\rho\sigma_x\sigma_y} \exp\left\{-\frac{x^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2}\right\}$$

where

$\tilde{h}$ = average spill thickness

m = total slick mass

ρ = density of oil

and σ_x and σ_y are related to the dispersion coefficients, respectively, as follows

$$\frac{\partial\sigma_x^2}{\partial t} = 2k_x \quad \text{and} \quad \frac{\partial\sigma_y^2}{\partial t} = 2k_y$$

As noted by Stolzenbach, et.al. (1977) observations of real oil slicks rarely fit the assumptions made in formulating the spreading/dispersion models. Thus, comparisons between observations and predictions tend to be mixed. As a result of this behavior, Stolzenbach, et.al. (1977)

conclude that

" 1. Both spreading and dispersion processes may be important in determining the total growth of the slick.

2, Existing techniques for estimating the growth of surface oil slicks provide at best only an order of magnitude estimate of what the actual slick size will be.

3. Because of the complex and usually random nature of the processes controlling slick growth, it is unlikely that a significant improvement in deterministic capability will be possible. However, estimates of the variance in slick sizes should become more accurate as additional observations are obtained.

4. The applicability of available spreading and dispersion models should be judged on a case by case basis in terms of the site specific conditions."

The usefulness of the modeling work as well as Stolzenbach's, et.al. (1977) review lies in their development of a time and length scale diagram, as shown in Figure 1. Such a diagram enables one to determine the relative importance of the various processes which affect

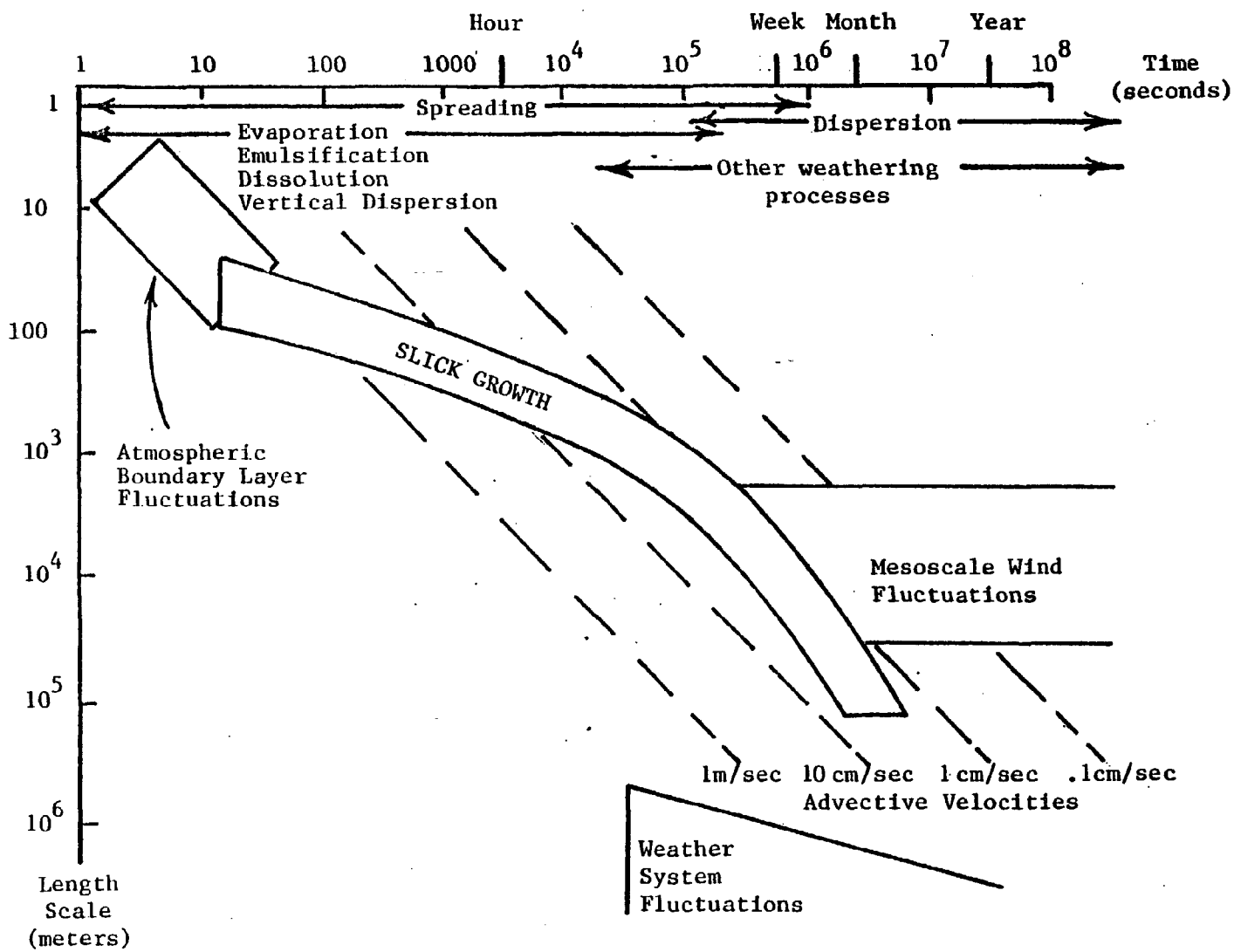

FIGURE 1 Time-Length Scale Diagram for Determination of Relative Importance of Various Processes (After Stolzenbach, et.al., 1977)

oil spill motions. This diagram clearly shows that spreading is important during the early stages (or, alternatively, over shorter distances) of a spill whereas the opposite is true of dispersion. Other processes are also indicated. An example of the use of such a diagram in the case of selecting appropriate models for North Carolina waters will be indicated in Chapter 4.

Chapter 3

Review of Literature

As noted in the introduction, there has been an enormous volume of literature published within recent years on the subject of oil spills. Approximately 200 references constituting roughly 15% of the available number of articles have been consulted in connection with this report. Only a small number of these references are cited in the bibliography, however, since many references deal with the topic in only a peripheral way. From these references, about 25 distinct modeling efforts have been identified. For each of these efforts, a summary report has been prepared identified by the model name and citing the primary reference and accompanying abstract along with the reviewers comments. These summary reports, one for each modeling effort are presented in the Appendix. In this section, a summary of the reviews is presented so that the reader can gain a panoramic view of the current status of oil spill models. To reiterate, our main emphasis is concerned with advection, spreading, and dispersion processes and with evaporation. For reasons discussed in the introduction, less emphasis is placed on other weathering processes. Also, we are concerned with application of these models to North Carolina waters.

For that reason, a number of Canadian sources were not consulted since, in many cases, they deal with Artic conditions.

A satisfactory means of classifying models is to take note of the processes that the model considers. This has been done by Stolzenbach, et.al. (1977) and is presented herein as an update in Table III. Discussions are presented in the following paragraphs for each of the major processes that are of interest to this study.

Advection. Advection is probably the most important process by which oil spills are transported over any sensible distance, and is treated by every oil spill model that was reviewed. Advection occurs as a result of wind and currents and to an unknown extent, waves. Both wind and currents induce shearing stresses on the top and bottom surfaces, respectively, of the oil slick. These shearing stresses, in turn, cause the oil slick to move. Because of the fact that the shearing stresses are not, in general, uniform (or constant), the oil slick experiences not only a net motion of its center of mass but also differential motions of the oil slick geometry about its center of mass. As a matter of fact, the shearing stresses are, in the general case, time and space dependent.

TABLE III

OIL SPILL MODELS
(Listed According to Date of Origination)

Model Name	Date	Processes Modeled*
1. U.S. Navy	1970	Advection
2. WGD	1972	Advection
3. Narragansett Bay	1973	Advection, Spreading
4. Tetra Tech, Inc.	1974	Advection, Spreading, Dispersion
5. CEQ	1974	Advection
6. BOSTM	1975	Advection, Spreading, Dispersion
7. USCG (New York Bight)	1975	Advection, Dispersion
8. Delaware Bay	1976	Advection, Spreading, Dispersion
9. USCG (New York Harbor)		Advection, Spreading, Dispersion
10. USC/API	1977	Advection, Spreading, Dispersion, Evaporation
11. SLIKTRAK (SLIKFORCAST, OILSIM)	1977	Advection, Spreading, Dispersion, Evaporation
12. MOST	1978	Advection, Spreading, Dispersion
13. DPPO (Garver and Williams)	1978	Advection, Spreading, Dispersion, Evaporation
14. URI (Georges Bank)	1979	Advection, Spreading, Dispersion, Evaporation
15. Puget Sound	1979	Advection, Spreading
16. CAES	1979	Advection, Spreading, Dispersion, Evaporation
17. Riverspill	1979	Advection, Spreading
18. NWS/NOAA	1979	Advection, Spreading
19. USCG (Long Island Sound)	1980	Advection, Spreading, Dispersion
20. SPILSIM	1980	Advection
21. EDIS	1980	Advection, Spreading
22. PIC	1980	Advection, Spreading, Dispersion
23. OSTA	1980	Advection
24. OSSM	1980	Advection, Spreading, Dispersion
25. DRIFT	1980	Advection, Spreading, Dispersion, Evaporation

* Weathering processes other than evaporation are not listed.

Wind. A substantial effort has been devoted to the development of wind field and current submodels. One of the distinguishing features of oil spill models is the degree of realism that has been incorporated into their wind and current submodels. In the case of wind models, this degree ranges from the simplest and crudest approach to the most elegant and sophisticated. At least three different categories can be identified. These include constant wind fields, time and spatially dependent wind fields.

Table IV is a listing of the types of wind field input that is programmed for oil spill models that were reviewed. A majority of the models can be operated to accept either measured (or real time data) or simulated data. The measured data is, in general, time and spatially dependent but this may not be a meaningful characteristic if the grid size is large or if the elapsed time between observations is long both relative to the volume of the spill. The simulated data input capability is useful for conducting contingency planning environmental assessment studies.

As noted above, the simulated wind field submodels can be highly variable in complexity. However, the degree of complexity is not an assurance of suitability for a particular site dependent oil spill. Even a simple

TABLE IV

WIND FIELD MODEL TYPES

Oil Spill Model Name	Simulated				Other	Measured
	Constant	Time Dependent		Spatially Dependent		
		Random Walk	Markov Chain			
1. U.S. Navy	X					X
2. WGD						X
3. Narragansett Bay	X					X
4. Tetra Tech, Inc.						X
5. CEQ			X			X
6. BOSTM		X				X
7. USCG (New York Bight)			X			
8. Delaware Bay	X					X
9. USCG (New York Harbor)						X
10. USC/API					X	X
11. SLIKTRAK (SLIKFORCAST, OILSIM)			X	X		X
12. MOST						X
13. DPPO (Garver and Williams)				X		X
14. URI (Georges Bank)					X	X
15. Puget Sound				X		
16. CAES		X				X
17. Riverspill	X					X
18. NWS/NOAA				X		X
19. USCG (Long Island Sound)						X
20. SPILSIM		X				X
21. EDIS						X
22. PIC						
23. OSTA	X					X
24. OSSM		X				
25. DRIFT	X					X

constant wind field under a given set of circumstances might be quite proper for predicting advection. Time-dependent submodels consists of "random-walk" models, for which there is no correlation between successive time steps, and autoregressive models (Markov chain) for which there is limited correlation in time between successive time steps. Most natural processes such as wind are continuous functions of time, thus, Markov chain models appear to be the superior type of time-dependent simulation. However, wind is also a spatially dependent function. A number of models have been developed or are in the process of development which simulate the wind on the basis of its spatial dependence. These models are the most general and represent the most sophisticated of all types of wind simulation models. Finally, a few models employ wind field models that do not fit any of the above categories. They are listed under "other" on Table IV. In some cases, there was insufficient information to categorize the wind field submodel.

In nearly all cases (the CAES model being the only exception) the determination of wind drift currents follows the wind factor approach. In this approach, the wind-induced surface current is assumed to be a fixed percentage of the wind velocity taken at a height of 10 meters above the sea surface. Often a value of 3% is

assumed but this value can range from 2.0% to 4%. These values have been estimated from numerous observations and experiments. In at least two references, Madsen (1977) and Huang (1979), show theoretically that this factor should be slightly in excess of 3% for deep water. The angle between the wind vector and the wind induced current vector is known as the wind drift angle. This angle has been taken to vary from 0° to approximately 20° depending on latitudinal influences. Huang (1979) also shows that the wind drift angle can vary from 0° to a maximum (which depends upon the latitude) depending on the duration that the winds have been blowing. This angle also depends on the water depth and approach a value of 0° for very shallow water.

Surface Currents. Although wind-induced drift currents are important mechanisms in the transport of oil slicks, they are not the only ones of importance. Therefore, we must examine the role of residual and tidal currents as well as waves. The residual currents include those circulations due to thermohaline and geostrophic causes. In general, the residual currents are most important for open ocean spills in deep water whereas the tidal currents are most important for near inshore and estuary (tidal) spills in shallow confined waters. In many models, both residual and tidal currents are considered together and

a procedure similar to the wind factor approach is employed to estimate the surface drift current. The factor most often used has a value of 56%. Many models are structured to utilize information on currents as obtained from prototype measurements or from estimates obtained from circulation submodels. The circulation submodels are often major components in the oil spill transport prediction procedures.

The numerical circulation submodels are not true three-dimensional models; rather they are two-dimensional representations obtained by making certain simplifications. Among others, these simplifications include the averaging (in the vertical) of the component velocities. This averaging presents some difficulty in estimating the surface currents especially in regions where the wind and tide are the dominant contributors to the circulation pattern. Another difficulty is related to the model boundaries especially where there is an interface with major large scale circulations systems such as the Norwegian current or the Gulf Stream. With the exception of SLIKTRAK, none of the models attempt to model the large scale circulation pattern. SLIKTRAK attempts to model the effect of the Norwegian current by providing for acceptance of predicted values of velocities (presumably obtained from another submodel) at the model boundaries.

The state-of-the-art consists of calibrating the numerical circulation submodel with available field measurements. The resulting currents predicted from such a model are then combined with wind-induced drift to estimate the advection.

Subsurface Currents. Because of the fact that oil spills generally appear on the surface, little attention has been directed to the advection by subsurface currents. It is generally believed that subsurface advection is not an important mechanism in oil slick transport. However, it is known that advection of dispersed oil droplets occurs as a result of subsurface currents. Two models include this behavioral feature. One is the DPPO model (Garver and Williams, 1978) and the other is the URI (Georges Bank) model.

River Currents. Even though a large number of spills occur in river estuaries or harbors where there is substantial fresh water inflow as well as other currents, this aspect of oil spill transport has received little attention. One model, Riverspill, was developed specifically for river-type spills (Mississippi River). Considerable effort has been directed toward determination of advection by river currents. Another model, USCG (New York Harbor) has also been developed to consider the fresh water inflows from the Hudson River. Both

models have been calibrated by comparison with numerous field observations.

Waves. Advection by waves directly or by currents generated by waves is one of the least understood aspects of oil spill transport. Some authors believe that it is an important mechanism but only three models (SLIKTRAK, Delaware Bay and USC/API) have recognized the possibility of considering its effect.

In summary, advection is one of the most important processes by which oil spills are transported. The prediction of advection resolves into a determination of the wind and current fields. From a knowledge of the wind and current fields, a number of numerical techniques have evolved from which advection of oil spills can be made. The role of subsurface currents is probably not important in transport of large oil slicks but very important in advection of oil droplets. The contribution of waves to the advection process is very poorly understood.

Spreading and Dispersion.* We consider spreading and dispersion together since these mechanisms are responsible for the growth of an oil slick after the initial spill. During the initial stages, spreading is

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* Not to be confused with emulsification or oil-in-water formulation of droplets.

clearly the most important of these mechanisms. Spreading is dependent upon the oil properties at the time of the spill whereas dispersion depends upon the external shear forces acting on the oil spill surfaces. A number of investigators (e.g., Stolzenbach, et.al., 1977) have shown that, for a given spill volume, after a certain time, the dispersion process becomes more important than spreading.

There are essentially three distinct approaches that are employed in the treatment of spreading and dispersion. Table V presents a listing of the spreading submodels that have been employed by the oil spill models that were available for review. Most of the models that treat spreading do so by using a method that is related in some way to Fay's (1971) theoretical analysis of spreading. Some models combine Fay's spreading analysis with a diffusion approach. Other models consider the growth of oil slicks to be dominated by diffusion aspects and ignore altogether the role of the oil properties such as surface tension. For example, the Delaware Bay model substitutes a diffusion equation in lieu of the third stage (viscous-surface tension) of Fay's (1971) three-regime spreading model. As another example, the USC/API model eliminates the second stage (gravity-viscous) of Fay's (1971) model altogether. As mentioned above, a few models treat the growth of oil slicks solely by

TABLE V

TYPES OF SPREADING MODELS

Oil Spill Model Name	Fay's Spreading Theory	Fay's Spreading with Diffusion	Diffusion Theory	Independent Statistical or Numerical Treatment
Narragansett Bay	X			
Tetra Tech, Inc.		X		
BOSTM		X		
USCG (New York Bight)			X	
Delaware Bay		X		
USCG (New York Harbor)			X	
USC/API		X		
SLIKTRAK (SLIKFORCAST, OILSIM)	X			
MOST		X		
DPPO (Garver and Williams)		X		
URI (Georges Bank)	X			
Puget Sound				X
CAES	X			
Riverspill	X			
NWS/NOAA				X
USCG (Long Island Sound)			X	
EDIS	X			
PIC	?			
OSSM		X		
DRIFT			X	

means of a diffusion theory such as that developed by Murray (1972) or a random Fickian diffusion model. The rationale for this is based on observations of oil spills that are continuously discharging (i.e., versus instantaneous spills) wherein it was concluded (Murray, et.al. 1972) that the growth a short distance from the source, was controlled by the horizontal eddy turbulence rather than surface tension effects. For example, the USCG models use Murray's turbulent diffusion theory while DRIFT uses a random Fickian diffusion approach.

One approach which is decidedly deterministic is the NWS/NOAA model wherein a numerical solution of the equations of motion (oil) is envisioned. At the opposite end of the philosophical spectrum is the Pudget Sound model which is best described as an independent statistical (probabalistic) model. It is based on the use of a system of empirical regression equations. In this connection, all of the models that treat spreading-dispersion with a diffusion theory in any way require some evaluation of a set of diffusion/dispersion coefficients. In general, these coefficients must be obtained empirically or from published values which have been obtained from experiments. In some cases, where there are actual observations of oil spills, the

diffusion coefficients have been employed as calibration coefficients. This is illustrated by the USCG (New York Harbor) model.

From a theoretical viewpoint, those models which treat spreading-dispersion by use of Fay's spreading theory in combination with a diffusion approach are probably superior to the other approaches. However, all of these models do not treat spreading-dispersion in the same way because there are some subtle, minor differences in their procedures which may have profound consequences in the results. As a general observation, none of the models contain any provision for eliminating or evaluating the numerical errors that may be present. This is an important consideration in the treatment or diffusion/dispersion because of the possible contamination of the real physical dispersion with numerical dispersion. The latter is merely an artifact of the computational scheme whereas the former is real. This is clearly illustrated in the case of the Tetra Tech, Inc., model about which Stolzenbach, et.al. (1977) has commented in some detail.

One interesting treatment of spreading-dispersion is the Delaware Bay model in which the third phase of Fay's three-regime spreading model is replaced by a compatible diffusion model. The justification for making this substitution stems from the observation that whereas the

third phase exists in laboratory situations (where the background turbulence levels are low), no such conditions exist in the real world. Therefore, in the prototype case, the higher turbulence levels require the existence of a diffusion approach. This justification seems very rational and plausible and is consistent with Murray's et.al. (1972) observations and conclusions.

In summary, spreading-dispersion is an important mechanism for the transformation and/or growth of oil slicks. In the early stages, spreading is the dominant process whereas after a critical time (for a given volume) dispersion seems to predominate. Models which seem best suited for a wide variety of time-dependent situations are those which combine Fay's spreading theory with a diffusion approach. Two extreme cases can be noted. In confined nearshore areas, where the time and distance scales are relatively short, a model which employs only Fay's spreading approach would be quite valid. In a similar way for regions where the time and distance scales are relatively long, such as far offshore, a model which employs only a diffusion theory would be valid. In the case of the latter, an independent statistical or numerical approach might also be considered. In any of the diffusion-statistical- or numerical-based submodels, the degree of numerical diffusion (or dispersion) should be determined.

Evaporation. Although evaporation is known to be an important factor in the fate of oil spills — especially in the case of spills far offshore, it has received less attention from modelers than the other processes. Only six (6) of the models reviewed include an evaporation submodel. Moreover, because evaporation usually occurs in the presence of other weathering processes such as photo-oxidation, dissolution, biodegradation and sinking and sedimentation, it is difficult to make reasonable evaluations concerning the appropriateness of the evaporation submodels. Of the oil spill models reviewed, there seem to be no essential differences in the manner in which evaporation was estimated. In general, an evaporation function or decay rate is derived from the main factors which affect the evaporation. These include: (1) the vapor pressures of the various oil fractions, (2) the size of the spill (area and thickness), (3) the evaporative mass transfer coefficient, and (4) the environmental (climatic) conditions, including wind speed.

All of the submodels employed a mass transfer coefficient but some did not consider the spill area or slick thickness in their evaluations. These are indicated in Table VI. Also, the basis for the submodel can be categorized as being empirical; experimental- or theoretically-related. These are also indicated in Table VI.

TABLE VI

CLASSIFICATION OF EVAPORATION SUBMODELS

Oil Spill Model Reviewed	Type	Area Considered	Slick Thickness Considered
USC/API	Theoretical	-	-
SLIKTRAK (includes SLIKFORCAST AND OILSIM)	Experimental	X	X
DPPO (Garver and Williams)	Empirical	-	-
URI (Georges Bank)	Empirical	X	-
CAES	Experimental	X	X
DRIFT	Empirical	X	-

In summary, only a few models attempt to evaluate evaporation in spite of its importance to the ultimate fate of oil spills. Unfortunately, there is insufficient data to permit a rigorous evaluation of the various approaches.

Chapter 4

Evaluation of Oil Spill Models for Use in North Carolina Waters

In order to select a suitable model or family of models for predicting oil spill behavior in waters located within and adjacent to North Carolina, it is necessary to identify the physical characteristics (and associated mechanisms) that (1) govern this behavior and (2) serve as adequate descriptors of the referred-to waters. The analysis carried out by Stolzenbach, et.al. (1977) and summarized in Chapter 2, provides a convenient means of identifying these features, but it is not the only means. An order of magnitude analysis of the governing equations could also be carried out. But, it is very convenient to use the work of Stolzenbach. Moreover, it provides a clear visual representation of the conceptual framework.

Therefore, we can utilize Figure 1 which indicates the major mechanisms of importance to oil spill movement in terms of time and length scales. We can immediately realize that two additional types of information are needed to complete our analysis. One is a parameter that describes North Carolina waters. For any given spill locality, the parameter that seems natural is the minimum distance from the spill source to shore

(i.e., x-number of meters). This can be used to describe localities in inland waters (in the Cape Fear River, for example) or localities nearshore or localities far offshore (an oil drilling platform, for example). For estuaries, bays, inland waters and other confined or semi-confined waters, these distances can be scaled from any hydrographic chart. We can assume that a value of from 0 to 500 meters would be a reasonable value to use to describe these waters. To distinguish between near-shore and offshore areas, we can adopt the arbitrary criteria that offshore areas are those beyond which shoreline impacts from tidal currents are virtually non-existent. On this basis, we can make the following descriptions for North Carolina waters in terms of single-length parameter:

Inland waters and estuaries	. . . . . 0 to 500 meters
Nearshore areas	. . .0 to 1000 or 10,000 meters
Offshore areas	. . . . >1000 or 10,000 meters

These values are not to be construed as actual distances of any specific locality but are generally representative of distances that characterize the indicated regions for the purpose outlined above.

The other source of information that is needed is derived from climatic data for the indicated regions. Again, precise values are not needed; only an order of

magnitude is required. For this purpose, we can assign the following values of advection velocities (in the direction of the distances indicated above) for the three regions.

Inland waters and estuaries	0.1^m/sec - 1.0^m/sec
Nearshore areas	0.01^m/sec - 0.1^m/sec
Offshore areas	0.001^m/sec - 0.01^m/sec

More precise values can be obtained from detailed examination of the climatic data (wind and currents). The above advective velocities are related only indirectly to the actual wind-induced surface currents and/or tidal or residual currents since we are interested only in that component taken parallel to and along the minimum trajectory path from spill source to impact location.

These features can be illustrated by referring to the length-time scale diagram shown in Figure 2. First, consider a spill in an estuary or inland waterway where the characteristic length is 500 meters and the characteristic advection rate lies somewhere between 1.0 and 0.1 meters per second. We can see from Figure 2 that the total elapsed time from spill to impact is rather short ranging from 425 to 4100 seconds. Figure 2 shows that dispersion can be neglected and we also note (from other information) that evaporation occurs along with other processes

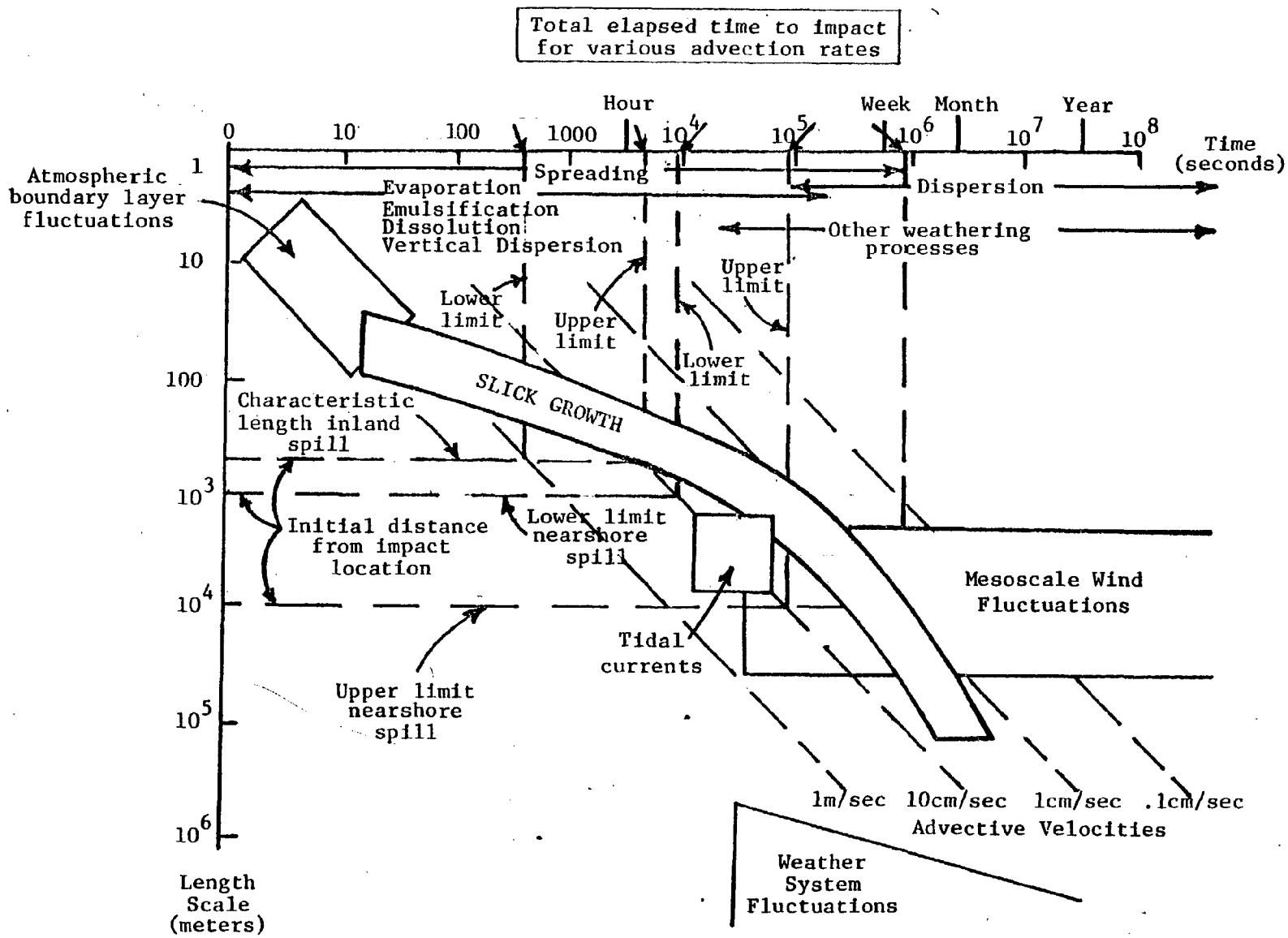

FIGURE 2 Time-Length Scale Diagram for Evaluating Relative Importance of Various Processes (After Stolzenbach, et.al., 1977)

throughout the growth and transport of the slick. However, evaporation and the other weathering processes are still in their early stages of development by the time of impact.

Therefore, modeling of oil spill behavior in estuaries and inland waters should include the simulation of advection, spreading and evaporation. From a knowledge of additional details concerning the spill, such as spill volume, and properties of the spill material as well as detailed climatic conditions, we can evaluate the relative importance of the growth (i.e., spreading) or transport (i.e., advection) activities in causing impacts. For example, as a general trend for fixed advection rates, the spreading activity increases in importance with increases in spill volumes.

Finally, consider an offshore spill at a distance greater than 10,000 meters from an impact location and with characteristic advection rates less than 0.01 meters per second. On this basis we can determine that the impact time is greater than 830,000 seconds or 230 hours (almost 10 days). We take note of the fact that dispersion is the dominant process in the growth of the slick and that spreading has been completed. Evaporation has been completed. In some cases, advection may be an important mechanism

but advection by tidal currents is unimportant by definition. Evaporation has been completed.

Therefore, modeling of spills in the offshore region should include advection, dispersion and evaporation. Dispersion is very important but advection by tidal currents, in general, can be neglected.

Next, consider a spill in the nearshore region (as defined above) such that the characteristic length has a value of between 1000 and 10,000 meters and characteristic advection rates of between 0.01 and 0.1 meters. Again, using Figure 2, we can determine that the elapsed time from initial spill to impact varies from 7700 to 83,000 seconds for the 1000 meter distance, and from 83,000 to 830,000 seconds for the 10,000 meter distance.

In the first instance where the distance from the spill source to impact is 1000 meters, we see that spreading is almost complete and dispersion has not yet become effective whereas in the second instance (where the source-impact distance is 10,000 meters), spreading has been essentially completed and dispersion has become an important activity — remember that scales are logarithmic. In spite of the apparent low advection rates, the transport process (including advection by tidal currents) plays an important role in determining the time of impact. Evaporation has been active throughout and, in the case of

the longer impact times, essentially has been completed. Other weathering processes have become significant.

From these observations, then, we may conclude that modeling of oil spills in the nearshore region should include provision for simulating advection, spreading, dispersion and evaporation. Advection by tidal currents should definitely be included in the modeling scheme.

From the foregoing, we can list the modeling requirements for the various regions.

Inland waters and estuaries	Advection, spreading, evaporation
Nearshore areas	Advection, spreading, dispersion, evaporation
Offshore areas	Advection, dispersion, evaporation

As stated in the Introduction, one of the goals of this study is to evaluate and select models for the prediction of oil spill behavior in North Carolina waters. As implicitly suggested, the possibility of identifying a single model, while attractive on a superficial level, is not realistic. Among other objections, the use of a single model for solution of all cases of interest would require use of the most complex and sophisticated model for all cases. Therefore, it would be too expensive

for the simplest cases and might require input data that is not even available. Thus, the approach has been to classify the number of cases into the categories of inland waters and estuaries, nearshore areas and offshore areas. Within these categories, we have attempted to identify families of models which would be appropriate. In other words, there has been an attempt to gear the model solution capability to the problem requirements.

At this stage, we can drop from further consideration the U.S. Navy, WGD, CEQ, SPILSIM and OSTA models, since they treat only advection. The WGD model has been applied to offshore spills and the CEQ model has been applied to both nearshore and offshore spills but there are other models that include the other processes as well. The same is true to a lesser extent of SPILSIM which was developed for application to the special case of the Great Lakes.

We can then reclassify (in a subjective way) those models that are suited for the three regions of interest. This is shown in Table VII, where it will be noticed that some models can be applied to more than one region.

TABLE VII

CANDIDATE MODELS FOR APPLICATION

TO NORTH CAROLINA WATERS

Inland Waters and Estuaries	Nearshore	Offshore
Narragansett Bay	USCG (New York Bight)	USC/API
Tetra Tech, Inc.	BOSTM	SLIKFORCAST (SLIKTRAK)
Delaware Bay	CAES	URI (Georges Bank)
USCG (New York Harbor)	Delaware Bay	DPPO (Garver and Williams)
Puget Sound	USC/API	NWS/NOAA
Riverspill	URI (Georges Bank)	EDIS
USCG (Long Island Sound)	DPPO (Garver and Williams)	OSSM
PIC	EDIS	MOST
	PIC	DRIFT
	OSSM	
	DRIFT	

Inland Waters and Estuaries. As shown in Table VII, we have some eight (8) candidate models for possible application to North Carolina.

The USCG (New York Harbor) model has been well calibrated by a number of oil spills in New York Harbor but it requires a comprehensive knowledge of the fresh water inflows (Hudson River) and dispersion coefficients. Fortunately for New York Harbor, thanks to the intense interest over a long period of time, this information is available. Essentially, the USCG (New York Harbor) and USCG (Long Island Sound) models are empirical type models which have the advantage of having been calibrated by numerous observations and therefore have been validated. Such information is generally not available for North Carolina waters.

The Narragansett Bay model is a simplistic easy-to-understand model that could be applied to North Carolina inland waters. However, two changes would have to be implemented. The wind drift angle would have to be changed to something other than 20° and the spill-spill interaction effect would have to be taken into account for non-instantaneous spills. The latter may require a substantial reprogramming effort.

Although the Tetra Tech, Inc., model has been applied and calibrated to San Pedro Bay, California,

there are a number of reasons why this model should not be considered for application to North Carolina waters. These reasons are given in a review by Stolzenbach, et.al. (1977), but the major reason is that the dispersion is a numerical dispersion that is not related to the physical dispersion, if it exists.

The PIC model is theoretically sound and a very fundamental approach but the difficulty with this model is that it has not been proven or validated.

The remaining three models (Riverspill, Delaware Bay and Puget Sound) constitute the three candidates for potential application to North Carolina inland waters. All three models have more or less been validated by comparison with actual spills or simulated exercises. Riverspill was developed for the situation on the Mississippi River and is the simplest of the three models to implement. Although it is intended for the situation where there is substantial river current, there is no reason, in principle, why it could not handle the situation of tidal currents. Riverspill is highly deterministic whereas the Puget Sound model is statistical in nature.

The Delaware Bay model is also a deterministic model and one that might prove to be better suited to handle those cases of spills at estuary junctions with

the open ocean. Unlike the other two models, it includes the advective drift due to waves as well as dispersion. One of the difficulties in using the Delaware Bay model is that the diffusion coefficients must be known or assumed.

In summary, the following models seem well suited for the prediction of oil spill behavior in North Carolina inland waters and estuaries. These are the Delaware Bay model, Puget Sound model and Riverspill.

Nearshore. Some eleven (11) models reviewed were selected as potential candidates for modeling spills in the nearshore regions of North Carolina. For a number of reasons, this is the most difficult region to model. On the one hand, a very large area offshore must somehow be considered and often this can only be done at a very crude scale. On the other hand, in order to make meaningful evaluations, modeling of details near coastal impact locations requires a smaller, finer scale. The result is that none of the models listed in Table VII can be applied with confidence directly to North Carolina waters without some modification.

The USCG (New York Bight) has been applied to the study of spills off the Delaware and New Jersey coasts

but it has been only partially validated. Moreover, as noted by Stolzenbach, et.al. (1977), many details are lacking and some of the assumptions cannot be justified.

Neither the BOSTM or CAES model actually treat dispersion (in a strict sense), and the BOSTM has the additional disadvantage in that it does not consider any of the weathering processes. For continuous spills, the BOSTM model neglects spreading, whereas, the CAES model neglects the spill-spill interaction effect. However, results of both models have been applied to prototype oil spills or to simulated spills.

If weathering processes were added to the Delaware Bay model, it is possible that this model might be adapted to the nearshore regions off the North Carolina coast. Other comments regarding this model have been provided in the previous section.

The USC/API model is a very comprehensive, composite model, but the model as a whole has not been validated by comparison with prototype spills. Moreover, many of the component parts are somewhat dated. More up-to-date information is available that could be used in this model.

The EDIS model has been applied to the oil spill in Campeche Bay (IXTOC-I) and to the Argo Merchant spill but insufficient details are available to evaluate the

predictions. The model includes only advection and spreading and therefore does not appear suitable for the nearshore region off North Carolina.

The PIC model is still under development but is very sound in a theoretical way and might be used off North Carolina when the model has been completed and validated. The OSSM model is still under development although it has been applied to the IXTOC-I blowout in the Gulf of Mexico.

From the foregoing discussion, we are left with the following three models as the leading candidates. These are the DRIFT, URI (Georges Bank) and DPPO (Garver and Williams). DRIFT is a simple type model which takes into account the tidal oscillations and which has been applied to model a spill off Anglesey, North Wales. The URI (Georges Bank) model is a substantially more comprehensive model that has also been applied to a prototype spill (i.e., Argo Merchant). The DPPO (Garver and Williams) is the most comprehensive of the three models, yet many of the submodel formulations are quite simple and crude. Different versions of the DPPO model have been applied to oil spill simulations in the Gulf of Mexico.

In summary, modeling of oil spill behavior in the nearshore region is a difficult task. None of the

models reviewed can be applied without some modification. The following models seem best suited for this purpose: DRIFT, URI (Georges Bank), and DPPO (Garver and Williams). With slightly more modification, the Delaware Bay model might also be a possibility.

Offshore. Recall that for the offshore region, spreading and advection due to tidal currents can, in general, be neglected. As a result of these simplifications, modeling of oil spill behavior in the offshore region tends to be somewhat less difficult than in the nearshore region, all other factors being equal.

Models which are appropriate for the offshore region are listed in Table VII. Comments regarding all of the models except three have already been provided. One of the deficiencies of the MOST model is that it does not take into account evaporation. It has been applied to the BRAVO blowout (North Sea) but the agreement with observations needs substantial improvement. The NWS/NOAA model is still under development but when completed will probably represent the most comprehensive and fundamentally sound basis for predicting offshore oil spills. The remaining model, SLIKFORCAST (SLIKTRAK) has been employed to simulate the BRAVO blowout and the predictions seem to compare favorably with observations

at different locations. SLIKFORCAST is a very comprehensive simulation program which can be used for both contingency planning and emergency tracking. The structure of the program is in many ways similar to the DPPO model (Graver and Williams).

In summary, SLIKFORCAST appears to offer the greatest potential for modeling of oil spills in the offshore region. However, the NWS/NOAA model, when completed and validated, may be equally or better suited. As secondary choices, the DPPO model (Garver and Williams) and URI (Georges Bank) might also be considered.

All of the foregoing models require a certain quality of climatological and oceanographic data for input in order to obtain reasonable predictions. Nearly all of the models employ a numerical approach utilizing a given areal mesh of fineness ratio such that the following two requirements are satisfied. One requirement is that the spacing dimension be small enough so that all important and relevant details are known. In practical terms, this translates into selecting a mesh size that utilizes all quality environmental data. The other requirement is that the area covered be large enough so that boundary effects are minimized. The latter introduces another restriction in that the mesh spacing cannot be too small; otherwise, a system

involving an unmanageable number of equations must be solved simultaneously at each time step. At the same time, both the time step and the spacing must be selected in order to minimize error propagation.

The data of most concern is that which affects advection and dispersion. Advection is determined from the wind field, surface currents and subsurface currents and to a lesser extent by the wave field. Although each oil spill model is affected somewhat differently by the quality of the input data, the relative evaluation of the models is not very sensitive to data which is available for North Carolina waters. Therefore, only a few general observations concerning this data (as obtained from a review of the available open literature) are made.

As a general rule, wind information appropriate for North Carolina inland waters and estuaries and for the nearshore region is very poor. Wind data for the offshore region is only marginally better. Wind data for the inland waters and estuaries is based on extrapolation of data collected from nearby airports whereas that for the offshore region is based on ship reports. Obviously, the geographic distribution is not uniform since it is biased in favor of the more heavily traveled shipping lanes.

The quality of current data for the inland waters the estuaries is highly variable. Current due to tides in some locations (i.e., Cape Fear River estuary) is adequate. In other locations, such data is spotty. Currents due to fresh water inflows is also highly variable.

The quality of current data for the nearshore region is also highly variable. In the case of the offshore region, the three-dimensional circulation pattern for currents appears to be adequate for that portion south of Cape Hatteras. At the same time, knowledge of the circulation pattern for that portion north of Cape Hatteras is only grossly known or, at best, uncertain.

The foregoing comments are based on a review of a large number of references including but not limited to those cited in connection with the Draft Environmental Impact Statement, Proposed 1981 Outer Continental Shelf Oil and Gas Lease Sale No. 56, Bureau of Land Management Outer Continental Shelf Office, New Orleans, Louisiana. Among those references reviewed were the following in-house reports not available for general distribution at this time (July, 1982).

1. Kantha, L.H., A.F. Blumberg, and G.L. Mellor A Diagnostic Technique for Deducing the Climatological Circulation as Applied to the South Atlantic Bight, Report No. 69 Dynalysis of Princeton, Prepared for Bureau of Land Management, U.S. Department of Interior, Contract No. AA551-CT-9-32, 1981.

2. Kantha, L.H., A.F. Blumberg, H.J. Herring, and G.L. Mellor, The Physical Oceanographic and Sea Surface Flux Climatology of the South Atlantic Bight, Report No. 70, Dynalysis of Princeton, Prepared for Bureau of Land Management, U.S. Department of Interior, Contract No. AA551-CT-9-32, 1981.

3. Blumberg, A.F. and G.L. Mellor, Circulation Studies in the South Atlantic Bight with Prognostic and Diagnostic Numerical Models, Report No. 71, Dynalysis of Princeton, Prepared for Bureau of Land Management, U.S. Department of Interior, Contract No. AA551-CT-9-32, 1981.

4. Blumberg, A.F., H.J. Herring, L.H.Kantha, and G.L. Mellor, South Atlantic Bight Numerical Model Application--Executive Summary--, Report No. 72, Dynalysis of Princeton, Prepared for Bureau of Land Management, U.S. Department of Interior, Contract No. AA551-CT-9-32, 1981.

These reports were made available to the author through the efforts of Mr. Eric Vernon, Office of Marine Affairs.

In summary, there is a need for additional coastal wind buoy station data and for improved knowledge of the current circulation pattern offshore north of Cape Hatteras.

CHAPTER 5

Summary and Conclusions

A brief history of the state-of-the-art in oil spill modeling has been presented in Chapter 2, along with an outline review of the fundamental problem development as stated in mathematical terms. It has been shown that the major processes which have greatest influence on impacts resulting from oil spills are advection, spreading, dispersion and evaporation, but that all of these processes are not necessarily active in all cases.

A review and classification of various models as they are published in the open literature is presented in Chapter 3. Detail reviews for each modeling effort are presented in the Appendix. For each modeling effort, the name or description of the model is presented along with the primary reference(s) and corresponding abstract(s). Reviewer's comments are also presented.

Chapter 4 contains an analysis establishing the criteria for evaluating oil spill models for use in North Carolina waters. This is followed by an evaluation of leading model candidates for each of the regions into which North Carolina waters may be classified.

It is concluded that the most appropriate models for use in each of the regional classifications of North Carolina waters are as follows:

Inland waters and estuaries:	Delaware Bay Model, Puget Sound Model and Riverspill.
Nearshore areas:	DRIFT, URI (Georges Bank), DPPO (Garver and Williams).
Offshore areas:	SLIKFORCAST and NWS/NOAA, when completed and validated.

RECOMMENDATIONS

As a result of this study, a number of findings and observations stand out which could easily be formulated into a set of recommendations. Rather than present a formal set of recommendations (which always reflect the biases of the author), the nature of the study is such that it is believed to be more appropriate to simply present the most important observations and let the reader form his (or her) own recommendations. These are as follows:

1. For North Carolina regions, there are two major deficiencies which inhibit application of the more sophisticated models (including those now available and under development) in order to realize maximum benefits. One of the deficiencies has to do with the data base (climatic and oceanographic) which is not sufficiently fine in order to make detailed coastal evaluations of oil spill impacts with reasonable confidence. The other has to do with the lack of detailed knowledge concerning resource inventories (both living and

non-living) and their exposure to various oil spills.

2. As a general observation, both short-term and long-term weathering processes are very poorly understood. This will require a deliberate and sustained research effort at the national level.

3. None of the models reviewed treat the problem of continuous spills in a rigorous manner. All of them make some assumptions which introduce errors into the analysis.

4. There are a large number of models available and under development. It seems more prudent to adapt existing models to new situations rather than embark on a new model development program. This is true even for the nearshore zone where, in general, most models are inadequate. Adaptation of existing models to North Carolina waters still remains a challenging task, however.

5. It is unlikely that any one model can be developed or adapted that has general applicability to a wide variety of situations. It is more likely that a single <u>family</u> of models can be developed,

all with similar procedural characteristics, to meet this need. Therefore, the attempt to develop or to find a single model to meet all needs is probably a fruitless endeavor.

6. As a by-product of this study, it was observed that there is a tremendous communication (or understanding) gap between various factions of different communities concerning the matter of oil spills and their impacts. This includes both federal and state administrators and decision makers, scientific community, industrial community, local community leaders, concerned populace and various state and local politicians.

References

(In addition to those documented in text and appendix)

Bishop, J.M., Editor, Proceedings of Workshop on Government Oil Spill Modeling, Wallops Island, Virginia, November 7-9, 1979.

Fay, J.A., "The Spread of Oil Slicks on a Calm Sea," Oil on the Sea, Edited by D.P. Hoult, Plenum Press, New York, pp. 53-63, 1969.

Fay, J.A., "Physical Processes in the Spread of Oil on a Water Surface," Proceedings of Joint Conference on Prevention and Control of Oil Spills," Sponsored by API, EPA, USCG, Washington, D.C., June 15-17, 1971.

Huang, N., "A Simple Model of Ocean Surface Drift Current," Proceedings, Workshop on the Physical Behavior of Oil in the Marine Environment, Princeton, N.J., May 8-9, 1979.

Madsen, O.S., "Wind Driven Currents in an Infinite Homogeneous Ocean," Journal of Physical Oceanography, 1977.

Murray, S.P., "Turbulent Diffusion of Oil in the Ocean," Limology and Oceanography, Vol. 27 (5), pp. 561-660, 1972.

Stolzenbach, K.D., O.S. Madsen, E.E. Adams, A.M. Pollack and C.K. Cooper, A Review and Evaluation of Basic Techniques for Predicting the Behavior of Surface Oil Slicks, Report No. 222, MIT, Cambridge, Massachusetts, 1977.

APPENDIX

This appendix contains summaries for each of the modeling efforts identified during the course of this investigation. The original publications, which describe and provide details on the modeling efforts, have been collected and reviewed in all but three cases. For each effort, the summaries list the model name or description followed by the primary reference(s) and by the author's own abstract or one synthesized by the reviewer. The reviewer's own concise comments follow the abstract.

In the cases of the three exceptions (BOSTM, USC/API, and MOST), the abstract is not given and the reviewer's comments are based on the numerous comments provided by other reviewers or isolated comments appearing in the open literature. The BOSTM and USC/API models have been reviewed comprehensively by Stolzenbach, et.al.(1977). Unfortunately, in spite of a deliberate and dedicated search by several of the area librarians, the primary references appropriate for these three models could not be obtained in a reasonable period of time. In one case, the reference was simply out-of-print and in another case, permission to release the reference due to proprietary restrictions has not yet been obtained.

Finally, the 1981 Oil Spill Conference is scheduled for release in September 1982 and will contain additional material relevant to these models.

The order in which the modeling efforts are presented is a historical one with the earliest developed models appearing first.

Model Name or Description

U. S. Navy

Reference

Webb, L.E., R. Taranto and E. Hashimoto, "Operational Oil Spill Drift Forecasting Seventh U.S. Navy Symposium on Military Oceanography, Annapolis, Maryland, 1970

Abstract

Recent incidents of large scale oil pollution have had catastrophic effects on the ecology, recreation and wild life resources of coastlines and coastal waters and caused worldwide public opinion to be very sensitive to this problem. Fleet Weather Centrals should have the capability to provide movement forecasts for oil spills from naval vessels or other sources, identifying the area of maximum threat and permitting containment action to be taken most efficiently. A tentative method is presented using surface current parameters based on operational data available at most Navy Fleet Weather Centrals.

The surface current parameters influencing oil spill drift used in this proposed forecast method are permanent currents, wind drift, geostrophic and tidal currents. A basic operational forecast using the vector sum of the pertinent parameters is presented. Modifications of the basic forecast method due to the location of the spill (open water, restricted water) are explained. The method presented should provide an acceptable forecast as an aid in effective control or containment of oil spillage.

Reviewer's Comments

This is one of the earliest models proposed and is a very simple advection-only model. The advection is taken to be the vectorial sum of the various currents which are assumed to consist of permanent geostrophic, tidal and wind-drift types. This model is one of those reviewed by Stolzenbach, et.al. (1977).

Model Name or Description

Warner, Graham, Dean (WGD) Model

Reference

Warner, J.L., J. W. Graham and R. G. Dean, Prediction of the Movement of an Oil Spill on the Surface of the Water," Paper No. 1550 Preprint of the Fourth Annual Offshore Technology Conference, Houston, Texas, May 1972

Abstract

A calculation procedure is described to represent the displacement of a surface oil spill under the action of time-varying surface wind stress components; predictions using this technique are carried out for the 1970 Arrow spill in Chedabucto Bay, Nova Scotia.

The procedure presented is based on a convolution integral of the x- and y- components of a time-varying wind stress and is approximated in summation form for computer application. For an impulsive wind stress, it is demonstrated that the summation form is in agreement with an analytical solution by Fredholm.

The Arrow oil spill occurred on 4 February, 1970 and during the first week of March, oil was observed on the beaches of Sable Island some 120 miles Southeast of the spill location. Meteorological data in the form of reduced geostrophic winds have been published by Neu. These winds were utilized to predict the oil spill trajectory based on: (1) a surface velocity equal to 3% of the wind speed and aligned with the wind direction, and (2) a surface velocity determined from the convolution procedure presented in this paper. It was found that the convolution procedure predictions provided better agreement with the available information relating to the spill transport to Sable Island. The importance of an adequate description of prevailing surface currents and vertical eddy viscosity is illustrated.

Reviewer's Comments

This model has been reviewed by Stolzenbach, et.al. (1977) who notes that this is purely an advection model since it neglects spreading, dispersion and other processes such as evaporation. The model does not provide for inclusion of coastline boundaries; therefore, its application is

limited to far offshore regions where wind induced currents dominate the movement mechanisms. The model has been applied to the Arrow oil spill (Nova Scotia) where, after calibration via the eddy viscosity parameter, the measured trajectory was satisfactorily simulated.

Model Name or Description

Narragansett Bay (or Premack and Brown) Model

Reference

Premack, J., and G.A. Brown, "Prediction of Oil Slick Motions in Narragansett Bay," Proceedings of the Joint Conference on Prevention and Control of Oil Spills, American Petroleum Institute, Washington, D.C. 1973

Abstract

In the development of meaningful oil spill contingency plans, it is of great value in establishing the response to a spill emergency to have predictions of oil slick motions once the spill occurs. In an attempt to evaluate some of the present technical literature on oil spill motion, a calculation was made for the oil spill motion which occurred in Narragansett Bay in September, 1960, when the tanker P.W. Thirtle ran aground and emitted about 24,000 barrels of Bunker C oil over a 12 hour period before the successful abatement of the source was completed.

The existing literature on oil slick spreading was reviewed and the work of Fay was chosen to represent the slick's spreading characteristics. The existing literature on the oil slick drift was reviewed and the work of Teason, et.al., was used to establish the drift motion under the influence of current and wind actions. An available numerical hydrodynamic model of Narragansett Bay was used to calculate the current characteristics in the vicinity of the spills during the period of interest. Appropriate wind data were combined with current data in order to obtain the important hydrodynamic and meteorological conditions. Since no comprehensive theory exists at the moment for oil slick spreading and drift, a simple model was taken in which the 24,000 barrels were emitted from the source in the form of 12 hourly discharges of 2000 barrels each. These individual spills were then handled on the basis of the available spreading theory and the drift motion calculated as described above. Although this is a crude approximation, it does give an estimate of the location and area magnitude of the spreading as a function of time after the spill.

The predicted results were compared with documentation of this spill as presented in the Providence Journal. The overall slick motion as calculated by this procedure was in good agreement with the arrival times of the spill in Newport Harbor and other places in Narragansett Bay and with the overall surface area involved

in the spill. This example of the calculation of the oil slick motion in an estuary at least gives some confidence to oil spill contingency planners that numerical calculations can be made for use in planning response and abatement to spills.

Reviewer's Comments

This model has been reviewed by Stolzenbach, et.al., (1977) who note that this model treats advection (both wind and current) and spreading. Advection due to wind is considered to be directed at a wind drift angle of 20° clockwise from the wind vector. The modified wind induced motion is then added vectorially to the tidal currents and both are superimposed on the slick spreading. Spreading is treated via Fay's (1971) equations. The model does treat the case of spills that occur with time (as contrasted with instantaneous spills). This is accomplished via a uniform discretization of the oil spill volume. However, the resulting subspills are treated independently of each other via simple superposition. That is, the spill-spill interaction effect is neglected. The model has been applied in one case to the Thirtle oil spill where some limited comparisons have been made.

Model Name or Description

Tetra Tech, Incorporated

Reference

Wang, S., and L. Huang, "A Numerical Model for Simulation of Oil Spreading and Transport and Its Application for Predicting Oil Slick Movement in Bays." Tetra Tech, Inc., Sponsored by U.S. Coast Guard Research and Development Center.

Abstract

A computer model for simulating oil spreading and transport has been developed. The model can be utilized as a useful tool in providing advance information and this may guide decisions for an effective response in control and clean-up once an accidental spill occurs.

The spreading motion is simulated according to the physical properties of oil and its characteristics at the air-oil-water interfaces. The transport movement is handled by superimposing the spreading with a drift motion caused by winds and tidal currents. By considering an oil slick as a summation of many elementary patches and applying the principal of superposition, the model is capable of predicting the oil size, shape, and movement as a function of time after a spill originates.

Field experiments using either cardboard markers or soybean oil to simulate a spill were conducted at the Long Beach Harbor. Computer predictions showed good agreement with the field tracers. In order to accommodate the model in local port offices, two hardware candidates are proposed.

Reviewer's Comments

This model considers the combined effects of advection and spreading. The numerical scheme that is employed is intended to simulate the simultaneous effects of advection, spreading and dispersion. Both wind and tidal current advection are considered. The differential spatial effects are modeled by use of elemental cells. However, the procedure is based on a linear

superposition of subspills (in the spatial sense) and the effect of neighboring subspills is not considered. In other words, during each time step an individual cellular subspill is considered to react independently of its neighbors. This is considered to be a serious weakness by Stolzenbach, et. al.(1977), who has reviewed this procedure and who also points out that the numerical dispersion that results from this approach is not directly related to any physical dispersion.

The model considers only instantaneous spills, but, because of the fact that each cellular subspill is considered to be "new" at the beginning of each time step, there is no reason, in principle, why time-dependent spills could not be considered.

The model is intended for use where spreading and advection are the dominant processes. Therefore, its application is limited to mostly enclosed water bodies such as harbors and bays and protected near-shore areas having relatively short time and length scales. To derive maximum benefit, it is further limited to those situations where detailed environmental data is available.

The model has been field tested and an example using Long Beach harbor (San Pedro Bay) is illustrated. Some five different simulated spills using tracers were conducted to validate the model. A computer code is included in the Appendix of the above reference.

Model Name or Description

Council on Environmental Quality (CEQ)

Reference

Stewart, R.J., J.W.Devanney, III, and W. Briggs, Section III, "Oil Spill Trajectory Studies for Atlantic Coast and Gulf of Alaska," Primary, Physical Impacts of Offshore Petroleum Development, Massachusetts Institute of Technology, Sea Grant Program, MITSG 74-20, Report to Council on Environmental Quality, April, 1974

Abstract

Oil spills can be transported many miles from the site of an accident by the action of wind, waves and currents. The purpose of this study is to obtain insight into the likely behavior of oil spill trajectories emanating from each of the thirteen potential Atlantic Outer Continental Shelf (OCS) production regions and each of the nine potential production areas in the Gulf of Alaska as identified by the U.S. Geological Survey. In addition, the likely behavior of oil spills emanating from three potential nearshore terminal areas, Buzzards Bay, Delaware Bay and Charleston Harbor are examined in greater detail. Major emphasis in all of these analyses is placed on the probability of a spill coming to shore, the time to shore and in the case of the terminal (areas) analyses, the wind conditions at the time the spill first reaches shore.

Reviewer's Comments

This model has been reviewed in detail by Stolzenbach, et.al, (1977). It is essentially an advection model with two versions. One version can be applied to nearshore areas and the other version is intended for application to offshore areas. Advection by wind, tidal currents and 'residual' currents are considered. Application of the model requires a knowledge of the tidal currents, residual currents (in the case of the offshore version) and wind measurements appropriate for the region under study.

Model Name or Description

U.S. Coast Guard (New York Bight)

Reference

Miller, M.C., J.C. Bacon and I.M. Lissauer, A Computer Simulation Technique for Oil Spills Off the New Jersey-Delaware Coastline, DOT U.S. Coast Guard, Washington, D.C. 1975

Abstract

Predictions for the movement of oil slicks and their impact implications along the shoreline of New Jersey and Delaware were determined for two potential deepwater ports and two potential drilling sites. A hydrodynamic numerical model for the New York Bight area was coupled with a wind generating model to produce temporal patterns of concentration of oil. Shoreline impact determinations were made for the four spill sites for the average winter storm conditions and average summer high pressure systems generated by the model.

Reviewer's Comments

This model has been reviewed by Stolzenbach, et.al.(1977), who points out that many details are lacking in the report. The model consists of essentially a numerical hydrodynamic system which utilizes a wind field generating submodel to predict fluid particle velocities. The latter, in turn, are employed to yield the oil spill trajectories.

Model Name or Description

Batelle Oil Spill Transport Model (BOSTM)

Reference

Ahlstrom, S.W., A Mathematical Model for Predicting the Transport of Oil Slicks in Marine Waters, Batelle Pacific Northwest Laboratories, Richland, Washington, 1975

Abstract (not available)

Reviewer's Comments

This model has been reviewed by Stolzenbach, et.al. (1977) and numerous references to it appear in the open literature. From these reviews and citations, it appears that the model treats advection, spreading and dispersion but does not treat weathering. The CAES model appears to be based on the BOSTM model with the addition of weathering so that the CAES comments also apply to the BOSTM model.

Inherent in the Discrete Parcel Random Walk method is the assumption that each parcel (subspill) behaves independently of the other parcels. Stolzenbach, et.al. (1977) points out that this assumption has not been proven and that it gives rise to a numerical dispersion which may not be realistic. Moreover, the model employs some arbitrary empirical factors whose origin is uncertain.

Model Name or Description

Delaware Bay (Wang, Campbell, Ditmars) Model

Reference

Wang, H., J.R.Campbell, and J.D. Ditmars, Computer Modelling of Oil Drift and Spreading in Delaware Bay, CMS-RANN-1-76, Ocean Engineering Report No. 5, University of Delaware, Newark, Delaware, 1976

Abstract

A generalized two-dimensional model and an interactive computer code for the determination of the oil slick dispersion are presented. The model considers two mechanisms to dominate, spreading and dispersion. Drifting refers to the drift of the center of mass of the slick and is influenced by winds, water currents and the earth's rotation (Coriolis force). Spreading refers to the spread of the oil slick with respect to its center of mass and a function of first, a gravitational force; second, a viscous force; third, a diffusion process. Relevant details and user options of the computer code are discussed. An important adjunct of the computer code is the capability for interactive graphics. This paper concludes with a comparison between this model and field data taken in Delaware Bay.

Reviewer's Comments

This model has been reviewed by Stolzenbach, et.al. (1977) who notes that this is the only model that includes the effect of advection due to waves. The model treats advection due to wind and current also, as well as spreading dispersion. Spreading is treated by using a modified approach to Fay's (1971) equations. The first two phases (gravity-inertia and gravity-viscous) are treated unchanged. However, in lieu of the third phase (viscous-surface tension), the modellers substitute a

Fickian diffusion relation which requires evaluation of a dispersion coefficient. The authors state that the reason for this substitution lies in the fact that while the third phase exists in the case of small scale laboratory experiments, its existence is questionable in the prototype (or field) experiments. Therefore, the influence of dispersion completely dominates behavior beyond the second phase. The model results have been compared with some field tests of drifting as carried out in Delaware Bay.

Model Name or Description

U.S. Coast Guard (New York Harbor)

Reference

(a) Lissauer, J.M., "A Technique for Predicting the Movement of Oil Spills in New York Harbor," U. S. Coast Guard Research and Development Center, Groton, Connecticut (1974)

(b) Kollmeyer, R.C., and M.E. Thompson, "New York Harbor Oil Drift Prediction Model," Proceedings of the Joint Conference on Prevention and Control of Oil Spills, American Petroleum Institute, Environmental Protection Agency, and U. S. Coast Guard, Washington, D.C. (1977)

Abstract (Reference (b))

An operational predictive oil slick movement model is developed and applied to New York Harbor. This computer simulation employs hourly tidal currents for all stages of the tide as input data, combined with river flow and continuous wind data to predict oil slick movement. Slick spreading and transport is accomplished using a conservative form of the diffusion/advection equation. The shape of the slick as well as its possible separation into multiple slicks due to current divergence is predicted. Time steps on the order of three minutes and grid spacing of 200 meters allow short term, small scale slick position and shape predictions to facilitate quick response for location of sites for containment or cleanup activities. Hindcasting features allow for possible source location of the initial spill.

Reviewer's Comments

Reference (a) has been reviewed by Stolzenbach, et.al. (1977). Reference (b) is an update and an enhancement of the work begun by Lissauer (1974). Advection is by wind, tidal currents and fresh water inflows from the Hudson River. In reference (a), spreading followed Fay's (1971) model. However, in reference (b), spreading

follows Murray's (1972) turbulent diffusion approach. Both approaches require a moderate amount of field data under a variety of conditions in order to calibrate the model. Stolzenbach, et.al. (1977) notes that although the model can be applied to other harbors, estuaries and bays, its usefulness is hampered by the data requirements including knowledge of the fresh water inflows. He also points out that the accuracy drops off in areas close to shore.

As reported in reference (b), the model has been extensively calibrated by a physical model (U.S. Waterways Experiment Station, Vicksburg, Mississippi) and by numerous observations in New York Harbor. Both the time step interval and grid size appear to be small enough to minimize numerical errors but error analysis has not been conducted.

Model Name or Description

USC/API

Reference

(a) Kolpack, R.L., N.B. Plutchak and R.W. Stearns, Fate of Oil in a Water Environment, Phase II - A Dynamic Model of the Mass Balance for Released Oil, Chapter 19, "Settling", American Petroleum Institute, Publication No. 4313, Washington, D.C. 1977.

(b) API, Publication No. 4212

(c) API, Publication No. 4213

(The above publications are out-of-stock)

Abstract (not available)

Reviewer's Comments

This model has been reviewed by Stolzenbach, et.al. (1977). It is known that the model includes advection, spreading and weathering with particular attention on the weathering processes.

Model Name or Description

SLIKFORCAST (with OILSIM and SLIKTRAK)

Reference

(a) Audunson, T., V. Dalen, J.P. Mathisen, J. Haldorsen and F. Krogh, "SLIKFORCAST - A Simulation Program for Oil Spill Emergency Tracking and Long Term Contingency Planning," Exploration and Production Forum, London, England, 1980

(b) Det Norske Veritas, et.al., OILSIM - Oil Spill Simulation Model Phase 1, Veritas Report No.77-441 Det Norske Veritas Research Division, Norway, 1977

(c) Blaikley, D.R., G.F.L. Dietzel, A.W.Glass, and P.J. Vankleef, "SLIKTRAK - A Computer Simulation of Offshore Oil Spills, Cleanup, Effects and Associated Costs, Proceedings of the 1977 Oil Spill Conference, American Petroleum Institute, Environmental Protection Agency and U.S. Coast Guard, 1977

Summary (Reference (a))

The oil spill simulation program Slikforcast is an integrated program system where the main components are a deterministic oil spill simulation program, a statistical oil spill simulation program, a hydrodynamical model for tidal currents, a data preprocessor, and various output routines. Wind data and data on residual currents must be supplied from outside sources. The wind data may be from (i) meteorological wind models with winds on a gridded net; (ii) from time series of wind from one or several observational stations; (iii) from statistical wind data from given locations. The data preprocessor is used to arrange the data on a unified format suitable for the simulation models.

Simulation of oil spill drift and fate may be carried out using either the deterministic or statistical model or using the two simulation models in a coupled mode. In the latter case, the results from the deterministic simulations are used as starting conditions for the statistical model. This permits oil spill forecasting both on a short term and long term basis. The deterministic model is interactive allowing for continuous updating of the simulation results against field observations.

The program package may be used both for contingency planning and for oil spill forecasting and hindcasting during an emergency situation. Great care has been taken to obtain a general program structure suitable for implementation in different geographical regions of interest. The access to sufficient and relevant ambient data and boundary conditions is, however, paramount to the quality of the simulation results.

Abstract (Reference (c))

The reasons are introduced for the development of a siumlator sufficiently simple to enable weather data normally acquired for E & P operations to be used. "SLIKTRAK", developed by Shell, applies a slick description and combat concept, developed within the E & P forum for well blowouts in the North Sea, but applicable to other areas. This concept includes costs for cleanup, damages and effects of phenomena such as evaporation and natural dispersion. These factors are based on industry experience and vary primarily with sea conditions.

The computer program simulates the continued creation of an oil spill and applied weather data to predict movements of each day's spillage for successive days at sea and quantities of oil left after each day until the oil either disappears or reaches a coastline.

Cumulative probability curves for the oil volumes cleaned up, oil arriving at specified shores, total costs, etc., are produced by random selection of input variables such as well location, weather data, the possibility of well bridging, etc., and repetition of simulated spill incidents over a large number of cycles. Trace plots of individual spills may also be generated.

In association with the E & P Forum's position as technical advisers to the North West European Civil Liability Convention for Oil Pollution Damage from Offshore Operations, a study based on the North Sea areas has been made. These results and further developments of the program are discussed.

Reviewer's Comments

References (a), (b) and (c) described a main program and two subroutines for simulating oil spills, respectively. Reference (b) deals with deterministic

trajectory analysis. Reference (c) is the subroutine that deals with the statistical trajectory analysis. This is a general oil spill simulation program designed specifically for accidents (particularly blowouts) in the North Sea but it is intended for application to different geological areas. It simulates wind from measurements or from historical data. It also simulates dispersion into the water column and evaporation but does not simulate biodegradation and photooxidation because these are very slow relative to other phases. This oil spill simulation model is not designed for and not sufficiently accurate for detailed coastal effect evaluation. However, both short term deterministic and long term probabalistic oil spill forecasts are possible.

Model Name or Description

MOST

Reference

Paily, P.P., and B.N. Rao, MOST-The Model for Oil Spill Transport, Hazelton Environmental Laboratory, Northbrook, Illinois, 1978

Abstract (not available)

Reviewer's Comments

This model treats advection, spreading and dispersion but no weathering. Both wind drift and surface currents are apparently treated. Spreading is treated by Fay's (1971) approach combined with diffusion. The model has been applied to the BRAVO blowout (North Sea) but apparently overestimated the slick size.

Model Name or Description

Deepwater Ports Project Office (DPPO) Model
(LOOP, Inc., and SEADOCK, Inc.)
Also referred to as SEADOCK Model

References

(a) Williams, G.N., R. Hann and W.P. James, "Predicting the Fate of Oil in the Marine Environment," Proceedings of the Joint Conference on Prevention and Control of Oil Spills held in San Francisco, California. American Petroleum Institute, Washington, D.C., 1975.

(b) SEADOCK Deepwater Port Final Environmental Impact Statement, Volume III. Prepared by Arthur D. Little, Inc., Cambridge, Massachusetts,

(c) LOOP Deepwater Port License Application, Volume I. Prepared by Arthur D. Little, Inc., Cambridge, Massachusetts.

(d) Garver, D.R. and G.N. Williams, "Advancement in Oil Spill Trajectory Modelling," Proceedings of Oceans '78, Marine Technology Society, Washington, D.C., 1978,

Abstract

The continuing increase in offshore crude oil production and transportation is presently coupled with widespread concern over protection of the environment. This has led to interest by members of the petrochemical community in the development of suitable methods for quickly predicting the probable transport path and coastal impact time of a possible oil spill in the offshore environment. An oil slick simulator of the stochastic trajectory type has been enhanced in an effort to provide such methods.

In particular, four areas will be addressed. First, both the Fay radial spreading equations and a long-term dispersive algorithm are now provided. Additionally, the slick may now assume an elliptical shape. Secondly, wind and current forcing functions may now be generated with the use of Markov state transition matrices as well as through the use of input time histories. Thirdly, the model will adaptively calculate coefficients for the transport equations in an attempt to correct for deficiencies in the particular equations used. Finally, the model will now execute in a real-time mode with an on-line computer terminal to allow tracking to occur during an actual spill.

Reviewer's Comments

Stolzenbach, et.al. (1977) reviewed reference (a) above which is referred to as the SEADOCK model as well as predecessor reports to references (b) and (c) which he refers to as the DPPO model. Actually, all four references taken together constitute a continuing effort to predict the probable transport path and coastal impact time of an oil spill occurring in the offshore region. Reference (d) describes the most recent enhancements to this model but, unfortunately, many of the details are not provided. Therefore, some details are assumed to be similar to those reported in references (a), (b) and (c).

The model objectives dictated the need to follow a probabalistic approach, but the model incorporates various levels of deterministic elements. In addition, an option exists for operating the model in a deterministic mode. The Fay (1971) equations are used for modeling spreading and advection is modeled for both wind and current by using the available data for the region. Garver and Williams state that although the vector combination approach to slick advection is poorly supported, the behavior of actual oil spills does not justify the use of a more rigorous modeling method. They do, however, use a weighted average approach to evaluate the proportionality constants and provision is made to incorporate new values as more data becomes available.

An algorithm for modeling long-term dispersion is provided. This algorithm is based on a very limited number of observations but does permit the slick to assume an elliptic shape. In addition, the subsurface transport processes are modeled.

The movement of the slick is tracked for a specified duration of time via employment of actual data (if measured) or of simulated data (based on a Markov chain model) if data is not available. Thus, the model is suitable for both environmental assessment and planning studies as well as for operational purposes during emergencies and clean-up. The latter is known as the adaptive tracking feature.

Certain submodels that account for weathering and degradation of the slick are also included. These follow the first order model of Moore, Dwyer and Katz (1973) for evaporation and dissolution and arbitrary empirical functions for emulsification and sedimentation.

In summary, this model represents a very comprehensive approach to the problem of predicting oil spill trajectories in the offshore region and even though many of the submodels are elementary, the fundamental stochastic approach is will justified.

Model Name or Description

University of Rhode Island (URI) Georges Bank

Reference

Cornillon, P.C., M.L. Spaulding, and K. Hansen, "Oil Spill Treatment Strategy Modeling for Georges Bank," Proceedings of the 1979 Oil Spill Conference, Los Angeles, California, American Petroleum Institute, Environmental Protection Agency, and U.S. Coast Guard.

Abstract

As part of a larger project assessing the environmental impact of treated versus untreated oil spills, a fates model has been developed which tracks both the surface and subsurface oil. The approach used to spread, drift and evaporate the surface slick is similar to that in most other oil spill models. The subsurface technique, however, makes use of a modified particle-in-cell method which diffuses and advects individual oil/dispersant droplets representative of a large number of similar droplets. This scheme predicts the time-dependent oil concentration distribution in the water column, which can then be employed as input to a fisheries population model. In addition to determining the fate of the untreated spill, the model also allows for chemical treatment and/or mechanical cleanup of the spilled oil. With this capability, the effectiveness of different oil spill control and removal strategies can be quantified.

The model has been applied to simulate a 34,840 metric ton spill of a No. 2-type oil on Georges Bank. The concentration of oil in the water column and the surface slick trajectory are predicted as a function of time for chemically treated and untreated spills occurring in April and December. In each case, the impact on the cod fishery was determined and is described in detail in a paper by Reed and Spaulding presented at this conference.

Reviewer's Comments

This model considers spreading, advection dispersion and evaporation. Spreading is based on a modified version of Fay's (1971) theoretical development.

Ocean currents were simulated by averaging estimates obtained from a long-term study of surface drifter returns. The model envisions that detail information from ocean surface transport or continental shelf circulation studies will be available as input. Advection is then simulated by the vectorial addition of ocean and wind-induced currents. Evaporation is simulated by application of a numerical solution to the procedures developed by Wang, Yang and Hwang (1976).

The subsurface transport of the dispersed oil is simulated by a three-dimensional mass transport equation which is solved by a "quasi Monte Carlo technique." Although it is stated that extensive model testing was performed in order to assure that the sub-process models correctly interfaced with one another, it appears that the model contains a mixture of numerical as well as physical dispersion.

The model has been applied to four different versions of a simulated spill. Unfortunately, there are no comparisons with field observations.

Model Name or Description

Puget Sound Model

Reference

Karpen, J., and J. Galt, "Modeling of Oil Migration in Puget Sound," Proceedings of Oceans '79, Marine Technology Society, Washington, D. C.

Abstract

The oil migration is simulated with a mixed Lagrangian-Eulerian model. The movement of the oil is modeled with Lagrangian point masses or Lagrangian elements (LE). Time dependent dispersion is applied to the individual LE's. Eulerian current and wind fields are used to advect the LE's.

Several scenarios for hypothetical spills in the Straits and upper Puget Sound are shown. The model accurately predicted the migration of the diesel oil spill at Ancortes, Washington.

The model is general enough so that submodels from currents and winds developed for other regions can be easily integrated into the simulation.

Reviewers Comments

A model named the Puget Sound Model was reviewed by Stolzenbach, et.al (1977), but the model described in the above reference is an entirely different one than that reviewed by Stolzenbach. The model simulates advection and the combined effects of spreading and dispersion. Spreading, using the theoretical approach developed by Fay (1971) was not employed. Instead the available data was used to determine a spill length scale as a function of time. The spill length corresponding to the spill size was then used in a modified random walk scheme to simulate

the combined spreading and dispersion. It is stated that this approach is comparable to diffusion by continuous movements for discrete particles or Fickian diffusion. The advection for wind and tidal currents are then superimposed on the combined spreading and dispersion.

Most of the data used in the regression equations to determine the spill length, size and time relations do not consider spill rates. There is some question how this technique can be used in situations where spill rate is an important factor. Also, there may be other factors (i.e., boundary conditions) that effect the spill length-time relationship.

Model Name or Description

Canadian Arctic Environment Service (CAES)

Reference

Venkatesh, S., S.H. Sahota and A.S. Rizkalla, "Prediction of the Motion of Oil Spills in Canadian Arctic Waters," Proceedings of the 1979 Oil Spill Conference, Los Angeles, California, American Petroleum Institute, Environmental Protection Agency, and U.S. Coast Guard (1979)

Abstract

An oil spill movement prediction model operating as part of a real-time Environmental Prediction Support System for the Canadian Beaufort Sea has been developed. The present version of the model considers spills only in open waters, that is, the sea surface is considered to be ice free. The model has been partially verified with data obtained from oil simulation experiments conducted in the Bay of Fundy, off the coast of Canada during the months of August and September 1978. With the use of observed winds, the model-predicted locations of "Orion" buoys used to simulate the motion of oil on water, agreed fairly well with their observed locations. These verification tests also pointed out the need for high resolution surface wind forecasts—essential data for computing wind-driven water currents which move the oil.

Reviewer's Comments

This model uses the numerical technique known as the Discrete Parcel Random Walk method. This method is identical to that used by Ahlstrom (1975). In a sense, this model is an adaptation of Ahlstrom's model (BOSTM). Spreading follows Fay's theory. Of the weathering processes, only evaporation and emulsification are considered because of their predominance in the first few days of slick formation. Treatment of both evaporation and emulsification

follows the procedures developed by Mackay and Leinonen (1977). Advection is considered to be due only to wind-induced surface currents and is based on the work of Madsen (1977). The expression for steady surface drift becomes a very simple relation.

The computational method assumes that the sub-spills act independently of each other. Therefore, the effect of neighboring subspills is neglected as is the spill-spill interaction effect. The model has been applied to four separate simulation experiments conducted in the Bay of Fundy.

Model Name or Description

Riverspill

Reference

Tsahalis, D.T., "Contingency Planning for Oil Spills: Riverspill - A River Simulation Model," Proceedings, 1979 Oil Spill Conference, Los Angeles, California, American Petroleum Institute, Environmental Protection Agency, and United States Coast Guard (1979)

Abstract

A simulation model, Riverspill, has been developed for the prediction of transport, spreading, and associated land contamination of oil spills on rivers. The effects of volume and type of oil, use of Oil Herder or not, type, location, and time of occurrence of the oil spill, geometry, and hydrographic characteristics of the river and wind speed and direction are taken into account. The model is capable of operating in either deterministic or stochastic mode. When the model is used in the deterministic mode, it predicts the path and associated land contamination of a specific oil spill as a function of time. When the model is used in the stochastic mode, it estimates the probability that an oil spill will be transported into a specific region after an accidental discharge within another specified region. In the present study, the model is specifically applied to the lower Mississippi River. However, the model is general and can be applied to any river. The predictions of the model are in very good agreement with the observed behavior of actual oil spills on the Mississippi River.

Reviewer's Comments

This model was developed specifically for river flows. Spreading follows Fay's (1971) theory, in which all three regimes are modeled. Advection due to wind and current is modeled by some derived relationships which depend on the direction of the wind velocity vector relative to the current vector. Some experimentally determined coefficients

are employed in the derived relationships. Cross flows (i.e., secondary) are also considered. The model has been applied to two accidents on the Mississippi River. The agreement between observed and model predicted deposition sites ranged from good to excellent.

Model Name or Description

National Weather Service (NWS) Model

References

(a) Hess, K.W., " The National Weather Service Oil Spill Motion Forecasting Program," Workshop on the Physical Behavior of Oil in the Marine Environment, Princeton, University, Princeton, New Jersey, May 8-9, 1979

(b) Hess, K.W., and C.L. Kerr, "A Model to Forecast the Motion of Oil on the Sea, Proceedings of the 1979 Oil Spill Conference, Los Angeles, California. American Petroleum Institute, Environmental Protection Agency and U.S. Coast Guard, Washington, D.C. 1979

Abstract (From Reference (a) Text)

The purpose of this model is to provide an operational method to forecast the movement of oil spilled in the ocean. The model utilizes the National Weather Service (NWS) meteorological forecasting capabilities to provide scientific prediction of the medium or long-range (up to 5 days) future oil behavior. In this time range, oil motions are strongly influenced, if not dominated, by wind effects (wind stress, wind-driven ocean currents, wind waves and evaporation). Forecasting using numerical models of the atmosphere give better results for this time range than the use of either a statistical (climatology) or a presistence approach.

The present model does not use the trajectory and point-mass simplifications of oil behavior; instead a two-dimensional approach is employed to predict the spatial variation of oil thicknesses. The oil spill model consists of three major segments, relies heavily on finite difference techniques and is driven by output of NWS atmospheric models. The three separate parts are: (1) a model of the atmospheres near-surface planetary boundary layer, (2) a dynamic model of the upper mixed-layer of the ocean, giving surface currents, and (3) a dynamic model of two-dimensional variable thickness oil distribution on the sea. In general, the first two segments provide input to the third in the form of stresses at the upper and lower oil boundaries. The most important simplifications of the present model are neglect of tide and wave effects and absence of weathering. Reference (b) provides additional details on this model which is under continuing development.

Abstract (From Reference (b))

A model to forecast the motion of oil spilled on the surface of water was established by combining separate models for the motion of oil, the motion of water, and the motion of air. The model for the motion of oil is based upon the hydrodynamic equations as they apply to oil on water. This model requires information at both the lower and upper boundaries of oil. At the oil lower boundary, the information is obtained from a model for the motion of water. This model is formulated by combining Ekman dynamics and continuity for the upper mixed layer of the sea. At the oil upper boundary, a model for the motion of air provides the required information. This model is based upon an analysis of output obtained from one of the National Weather Service's multi-level atmospheric models. A number of case studies demonstrate the features of the separate models and the composite oil spill model.

Reviewer's Comments

This is a very comprehensive model which takes advantage of the operational wind forecasts made available by the National Weather Service. Separate models for the motion of oil, water and air are combined into a composite model which is undergoing continuing development and improvement. The model has been applied in preliminary form to the Argo Merchant spill. The model results in comparison with observations indicate the potential applications and limitations of this model. The model approach appears well suited for making real time forecasts of oil motion in locations far offshore and especially where wind is the dominant driving force.

Model Name or Description

U.S. Coast Guard (Long Island Sound)

Reference

Kollmeyer, R.C., "Long Island Oil Spill Drift Prediction Model," Proceedings of Workship on Government Oil Spill Modeling, November 7-9,1979, Wallops Island, Virginia, NOAA, Washington, D.C. February 1980

Abstract

Because of the sensitive nature of the Long Island area and the complex nature of the surface currents in the Sound, the On-Scene Coordinator (OSC) must be able to predict oil spill trajectories accurately in order to deploy cleanup equipment and to protect sensitive areas. Present oil spill movement prediction models are inadequate for this need and are not readily accessible to the OSC.

The goal of the project is the production of a real-time prediction model that will forecast the movement and spread of an oil spill in Long Island Sound. Upon command, the model will, for a given period, produce a time series of charts displaying the location, shape and concentrations of the oil spill.

The model will be constructed on the computer facilities provided by the Department of Computer Science, U.S. Coast Guard Academy. Captain R.C. Kollmeyer will be the overall project coordinator. A close liaison will be maintained among all interested and contributing units. At present, the following Coast Guard units are involved:

1. Coast Guard Academy
2. Commander, CG Group, Long Island Sound
3. USCG Research and Development Center, and
4. USCG Oceanographic Unit.

The oil drift mechanisms to be modeled will include the following:

1. predicted tidal currents,
2. Stokes drift, considering both duration and fetch limitations
3. leeway of oil slick caused by the wind, and
4. wind drift currents of the surface layer.

A relatively sophisticated computer graphics output is desired in the form of segment maps showing the spill, its location, areal size, and concentration gradients. These maps would be produced on a time basis, showing the oil spill's predicted location every 15 minutes from the time of the spill.

The preparation of the tidal current data set will include the use of overlays for the NOS tidal current charts to allow their transfer to the model matrix. A scaling program (inverted smoothing) will then determine the currents for all other points on the matrix for each of the 13 current charts available. Currents along the shore boundaries will be made zero unless other information is available.

A planned program of verification and testing will be developed as part of the model completion. Procedures will be proposed by which small oil spills in Long Island Sound may be monitored and used in a hindcast mode. In addition, a testing program will be drafted that would use oil drift simulators which can be tracked and compared with model predictions.

Reviewer's Comments

The above reference simply describes a program being undertaken to develop a model with certain specific goals and features. It likely will be similar to the model developed by USCG for New York Harbor.

Model Name or Description

SPILSIM

References

(a) Pickett, R.L., "A Surface Oil Spill Model for the Great Lakes, Proceedings of the Workshop on Government Oil Spill Modeling, November 7-9, 1979, Wallops Island, Virginia NOAA, February 1980

(b) Boyd, J. D., "A Surface Spill Model for the Great Lakes," Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan, 1979

Abstract (Edited from Reference (a))

This model was developed as an operational forecast model for the movement of surface-pollutant spills on the Great Lakes with special emphasis on oil spills. Oil spills are of particular concern because of their environmental impact and the substantial quantities of oil transported on the Great Lakes, both as cargo and as fuel. The Great Lakes Environmental Research Laboratory (GLERL) undertook this modeling effort because a number of models were being developed for oceanic spills but none were being developed for those on the Great Lakes. The resulting model, SPILSIM, is a batch oriented model derived form oil spill models from the Canada Center for Inland Waters (CCIW) and NOAA's Pacific Marine Environmental Laboratory (PMEL). It predicts the movement of an insoluble surface spill anywhere within the Great Lakes, given spill size and location and surface currents and winds in the area of interest. Modifications to make the model interactive are straightforward.

Reviewer's Comments

This is a simple model that simulates advection by wind and currents.

Model Name or Description

Environmental Data and Information Service (EDIS) Model

Reference

Bishop, J.M., A Climatological Oil Spill Planning Guide, No. 1, The New York Bight. NOAA, Washington, D.C., 1980

Abstract

Over the past 4 years, the Environmental Data and Information Service (EDIS) of NOAA has developed a multiple trajectory oil spill model. The model is based on the archived wind and current data available within EDIS's National Climate Center (NCC) and National Oceanographic Data Center (NODC). The model was originally designed for assessment of possible environmental impact due to construction of a deepwater port off the Texas coast, but has been used effectively in the Argo Merchant and Compeche oil spills for a rapid estimate of the impact areas. The successful use of this model for climatological assessments of large ocean spills leads to the conclusion that this type of climatological forecasting technique should be a part of our overall response to major oil spills.

Although the utility of this approach has been shown in these two examples of large open-ocean oil spills, a better application of this climatological (Type I) model is in contingency planning (prespill resource allocation). In this mode, one can map most probable impact zones over known local resources (biological or economic). Such a use has been initiated in a recent EDIS publication produced for use by the 3d Coast Guard District contingency planners, couples key environmental data (both physical and biological) with climatological oil spill trajectory forecasts.

Reviewer's Comments

This model is an enhancement of the DPPO model but in an empirical-simplified direction rather than in the fundamental-comprehensive direction taken by Garver

and Williams (1978). Advection due to wind and current is determined using measured data. These, in turn, are coupled with Fay's spreading theory to predict the spill trajectories.

Model Name or Description

Particle-In-Cell (PIC) Model

Reference

Tingle, A.G., "Perturbation Analysis of the New York Bight," Proceedings of the Workshop on Government Oil Spill Modeling, November 7-9, 1979, Wallops Island, Virginia, NOAA, Washington, D.C., February 1980.

Abstract

The physical transport of pollutants, their modification by the coastal food web, and transfer to men are problems of increasing complexity on the continental shelf. In an attempt to separate cause and effect, a computer modeling technique is applied to problems involving the transport of pollutants as one tool in assessment of real or potential coastal perturbations. Approaches for further model development of the biological response within the coastal marine ecosystem are discussed. Our present perturbation analyses consist of 1) a circulation submodel, 2) a simulated trajectory of a pollutant particle within the flow field, and 3) a time-dependent wind input for each case of the model. The circulation model is a depth-integrated, free surface formulation that responds to wind stress, bottom friction, the geostrophic pressure gradient, the coriolis force, and the bottom topography. The transport diffusion model is based on Lagrangian mass points, or "particles" moving through a Eulerian grid. The trajectories of material moving on the surface and in the water column are computed. It has the advantage that the history of each is known. With these models, we have been able successfully to: 1) reproduce drift card data for determining the probabilities of a winter oil spill beaching within the New York Bight, 2) analyze the source of floatables encountered on the south shore of Long Island in June 1976, and 3) predict the trajectory of oil spilled in the Hudson River after it had entered the New York Bight Apex. For future analyses, the shallow water model can be modified or replaced with a numerical model that contains a more sophisticated parameterization of the physical circulation. Also, the particle-in-cell model can be modified to explicitly include chemical reactions and interactions with the biota. A model should be used in the context of the level of resolution or aggregation that is known about the ecosystem and the management decision to the made. Models are used also as an aid in selecting situations that merit further analysis with more comprehensive ecological reasoning.

Reviewer's Comments

This model is based on a numerical hydrodynamic model of the area under study. One of the difficulties in applying models of this type to other regions is the determination of the model boundaries and treatment of the boundary cells (free, fixed, no-slip, reflecting). A disadvantage in the use of models of this type is the required cost of computation—even on the largest, most sophisticated computers.

Model Name or Description

The U.S. Geological Survey Oil Spill Trajectory Analysis (OSTA) Model

Reference

Samuels, W.B., "The USGS Oil Spill Trajectory Analysis Model," Proceedings of the Workshop on Government Oil Spill Modeling, November 7-9, 1979, Wallops Island, Virginia, NOAA, Washington, D. C., February 1980.

Abstract

The USGS oil spill trajectory analysis model (OSTA) is used to calculate the probability of oil spills occurring and contacting environmental resources and sections of the coastline. A grid system is superimposed on the study area with a maximum of 480 miles on a side. The dimension of the grid cell is variable depending on the size of the study area. Locations of environmental resources proposed and existing lease tracts, and oil transportation routes (pipeline and tanker) are determined by their positions in the model's grid system. Data from different map projections can be digitized and fitted into the model's grid system by coordinate conversion subroutines. A maximum of 31 categories of resources and up to 100 segments (2 different sets) of the coastline can be included in the analysis.

Oil spills are simulated in a Monte Carlo fashion. Typically, 500 simulated oil spills are launched per season from each launch point (platform location, pipeline, or tanker route). Spills are transported by monthly currents and by winds sampled from wind transition matrices. These matrices, composed of 41 wind velocity states, are based on historic wind records. They are constructed for each season for up to six wind stations. Surface ocean currents are incorporated in a deterministic manner by representing monthly current fields in the model's grid system. The spill movement algorithm consists of computing the vector sum of a wind and current vector for successive 3-hour increments. Each grid cell in the path of the spill is checked for the presence or absence of each environmental resource. Spill movement ends in one of three ways: 1) the spill contacts land, 2) the spill decays at sea, or 3) the spill moves off the map.

Conditional probabilities of contact are reported for 3-, 10-, and 30- day travel times. Oil spill occurrence is treated as a Poisson process, in which the exposure variable is the volume of oil produced or transported. Scenarios outlining proposed oil production and transportation are constructed for various alternatives. The overall risks are determined by combining spill occurrence probabilities. Recent applications of the model have been: Sale 55 (Northern Gulf of Alaska, Sale 53 (Northern and Central California), and Sale 46 (Kodiak Island).

Reviewer's Comments

This model uses a vectorial approach of wind and current to simulate advection. The use of input data is very similar to the DPPO model. The movement of the slick is tracked for a specified duration of time via employment of actual data or of simulated data (based on a Markov chain model) if real data is not available. This model has been used for environmental assessment in connection with a number of offshore lease sales (e.g., Alaska, Gulf of Mexico, Southern California and North-, Mid- and South Atlantic).

Model Name or Description

On-Scene Spill Model (OSSM)
Pacific Marine Environmental Laboratory
NOAA, Seattle, Washington

Reference

(a) Torgrimson, G.M., and J.A. Galt, "An On-Scene Spill Model for Pollutant Trajectory Simulation," Workshop on the Physical Behavior of Oil in the Marine Environment, Princeton University, Princeton, New Jersey

(b) Galt, J.A., and G.M. Torgrimson, "On-Scene Trajectory Modelling for the U.S. Response to the IXTOC-1 Blowout," Proceedings of the Workshop on Government Oil Spill Modeling, November 7-9, 1979, Wallops Island, Virginia, NOAA, Washington, D.C., February 1980.

Abstract

(a) The Pacific Marine Environmental Laboratory's Hazardous Materials Scientific Support Team (PMEL/HMSST) has developed a data management system for the rapid simulation of pollutant trajectories in the marine environment. The On Scene Spill Model (OSSM) has been designed to function at several different levels of complexity depending on user requirements and available environmental data. OSSM may be utilized as an environmental assessment tool to predict pollutant trajectories and coastal impact areas, given hypothetical pollutant spills. General cautions about interpreting the output are included. Planned modifications and additions to the existing program are listed. The data management system was used to document and predict pollutant trajectories during the PECK SLIP oil spill off the east coast of Puerto Rico on December 19, 1978.

(b) During the spill event associated with the IXTOC I well blowout, the U.S. National Contingency Plan was activated. In anticipation of this, the NOAA Hazardous Materials Response Project requested the Hazardous Materials Scientific Support Team (for physical processes) to supply trajectory information through the scientific support coordinator. This was done beginning June 12, 1979. During the summer, this plan required a variety of activities including: (1) collecting available

background information, (2) carrying out observational field programs, (3) coordinating data and information presented by other researchers (Federal, State and private) and (4) analyzing trajectories.

During the spill, trajectory models were used in basically three different forms. The first was in a long-term statistically controlled form (strategic) for planning call up and retirement of scientific or cleanup units. The second was a short-term localized forecast (tactical) for input into day-to-day planning. The third was in a receptor mode that identified danger zones that could impact scientific high-valued regions. This, in turn, was used to develop optimal mapping strategies for overflights.

The basic model for IXTOC I studies was a new version of OSSM (On-Scene Spill Model) incorporating a number of advanced features. In addition, several auxiliary programs to analyze circulation data were also used for the first time in a real spill situation. Both hindcasts and forecasts from the models have provided useful input to the overall response program.

Reviewer's Comments

This model is undergoing continuing development and improvement. The model is designed to be utilized as a real-time spill trajectory model. Advection is handled in vector fashion from both wind and current. Diffusion is currently modeled via a "Monte Carlo" approach to the governing diffusion equations. Other algorithms are being considered which would more accurately simulate spreading and diffusion. Additional details will be provided in the 1981 Joint Conference on Prevention and Control of Oil Spills which will be available in September, 1982.

Model Name or Description

DRIFT

Reference

Hunter, J.R., "An Interactive Computer Model of Oil Slick Motion," Oceanology International '80.

Abstract (from text)

An interactive computer model has been developed to predict the motion of an oil slick on the sea surface which is particularly suited to the shallow waters of the sea shelf. Wind-induced drift and spreading are considered to be the most important mechanisms in this motion. The wind-induced drift is modeled via an empirical relationship and the spreading, mixing and decay are modeled using Monte Carlo techniques.

The model has been applied to an area of Irish sea near Anglesey, U.K., and has predicted at least one recent spill successfully.

Reviewer's Comments

This model is a classical deterministic approach which incorporates the major mechanisms of importance to the prediction of the motion of an oil spill in the area for which it was designed. One of the underlying assumptions in this model is that spreading is caused by turbulence and lateral velocity shears. As a consequence, this model should not be used to predict oil spill behavior during early stages following the initial spill. The justification for the approach that has been employed is based on a few observations of very large spills wherein it was noted that spill diameter increases with the first power of time. With proper imput, the model appears to provide

reasonable predictions. However, for predictions nearshore, the model is very sensitive to errors in certain input information. Therefore, use of the model in an operational mode requires continuous updating of input information.

CEIP Publications

1. Hauser, E. W., P. D. Cribbins, P. D. Tschetter, and R. D. Latta. Coastal Energy Transportation Needs to Support Major Energy Projects in North Carolina's Coastal Zone. CEIP Report #1. September 1981. $10.

2. P. D. Cribbins. A Study of OCS Onshore Support Bases and Coal Export Terminals. CEIP Report #2. September 1981. $10.

3. Tschetter, P. D., M. Fisch, and R. D. Latta. An Assessment of Potential Impacts of Energy-Related Transportation Developments on North Carolina's Coastal Zone. CEIP Report #3. July 1981. $10.

4. Cribbins, P. S. An Analysis of State and Federal Policies Affecting Major Energy Projects in North Carolina's Coastal Zone. CEIP Report #4. September 1981. $10.

5. Brower, David, W. D. McElyea, D. R. Godschalk, and N. D. Lofaro. Outer Continental Shelf Development and the North Carolina Coast: A Guide for Local Planners. CEIP Report #5. August 1981. $10.

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7. Richardson, C. J. (editor). Pocosin Wetlands: an Integrated Analysis of Coastal Plain Freshwater Bogs in North Carolina. Stroudsburg (Pa): Hutchinson Ross. 364 pp. $25. Available from School of Forestry, Duke University, Durham, N. C. 27709. (This proceedings volume is for a conference partially funded by N. C. CEIP. It replaces the N. C. Peat Sourcebook in this publication list.)

8. McDonald, C. B. and A. M. Ash. Natural Areas Inventory of Tyrrell County, N. C. CEIP Report #8. October 1981. $10.

9. Fussell, J., and E. J. Wilson. Natural Areas Inventory of Carteret County, N. C. CEIP Report #9. October 1981. $10.

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14. Rogers, Golden and Halpern, Inc., and Engineers for Energy and the Environment. The Design of a Planning Program to Help Mitigate Energy Facility-Related Air Quality Impacts in the Washington County, North Carolina Area. CEIP Report #14. September 1982. $10.

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33. Sorrell, F. Yates and Richard R. Johnson. Oil and Gas Pipelines in Coastal North Carolina: Impacts and Routing Considerations. CEIP Report #33. December 1982. $10.

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35. Cribbins, Paul D. Coastal Energy Transportation Study, Phase III, Volume 4: The Potential for Wide-Beam, Shallow-Draft Ships to Serve Coal and Other Bulk Commodity Terminals along the Cape Fear River. CEIP Report #35. August 1982. $10.

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