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Review of Existing Oil Spill Trajectory Scenario Models

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Regional and headquarters establishments of Ocean Science and Surveys ceased publication of their various report series as of December 1981. A complete listing of these publications and the last number issued under each title are published in the *Canadian Journal of Fisheries and Aquatic Sciences*, Volume 38: Index to Publications 1981. The current series began with Report Number 1 in January 1982.

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Ces rapports contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles mais que l'on ne trouve pas normalement dans les revues scientifiques. Le sujet est généralement rattaché aux programmes et intérêts du service des Sciences et Levés océaniques (SLO) du ministère des Pêches et des Océans.

Les rapports techniques peuvent être considérés comme des publications à part entière. Le titre exact figure au-dessus du résumé du chaque rapport. Les résumés des rapports seront publiés dans la revue Résumés des sciences aquatiques et halieutiques et les titres figureront dans l'index annuel des publications scientifiques et techniques du Ministère.

Les rapports techniques sont produits à l'échelon régional mais sont numérotés et placés dans l'index à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page de titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Les établissements des Sciences et Levés océaniques dans les régions et à l'administration centrale ont cessé de publier leurs diverses séries de rapports depuis décembre 1981. Vous trouverez dans l'index des publications du volume 38 du *Journal canadien des sciences halieutiques et aquatiques*, la liste de ces publications ainsi que le dernier numéro paru dans chaque catégorie. La nouvelle série a commencé avec la publication du Rapport n° 1 en janvier 1982.

Canadian Technical Report of

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REVIEW OF EXISTING OIL SPILL TRAJECTORY SCENARIO MODELS

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ABSTRACT

Davidson, L.W. and Lawrence, D.J. 1982. Review of existing oil spill trajectory scenario models. Can. Tech. Rep. Hydrogr. Ocean Sci. 9: iv + 60 p.

The general descriptions of many scenario type models are presented, documenting the physical processes considered, the types of input required, the form of output, the hardware configuration and access details. Comparative summaries are also presented. A concluding review details the range of methods and parameter values employed to model each physical process, and identifies the preferred method or value for each. Additional inclusions are the objectives of the Working Group on Oil Spill Trajectory Modelling and a membership list, a glossary of relevant modelling terms, and a copy of "Draft Guidelines for Offshore Surface Oilspill Scenario Models". The latter document, following extensive review by the group, is being applied to all Canadian waters by DEMR and DINA.

RÉSUMÉ

Davidson, L.W. and Lawrence, D.J. 1982. Review of existing oil spill trajectory scenario models. Can. Tech. Rep. Hydrogr. Ocean Sci. 9: iv + 60 p.

On presente la description générale de nombreux modèles de type scénario en donnant des précisions sur les processus physiques étudiés, les types d'entrée nécessaires, la forme des dorties, la configuration des matériels et sur les modalités d'accès. Sont également présentés des résumés comparatifs. En conclusion, on fait une synthèse détaillée des méthodes et des caleurs de paramètre employées pour modéliser chaque processus physique, en idiquant la méthode ou valuer préférée pour chacun.

Sont joints au document les objectifs et la composition du groupe de travail sur la modélisation des trajectoires de déversements de pétrole, un glossaire de modélisation et un exemplaire du "Draft Guidelines for Offshore Surface Oil Spill Scenario Models". Ce dernier document, après étude poussée par le groupe de travail, est utilisé pour toutes les eaux canadiennes par le MEMR et par le MAIN.

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1. INTRODUCTION

Motivated by a general scientific interest and by the increasing level of hydrocarbon exploration activity in the Canadian Frontier offshore, a "Working Group on Oil Spill Trajectory Modelling" was convened in August 1978 under the direction of the federal Department of Energy, Mines and Resources. A core of government personnel representing Energy, Mines and Resources, Environment, Fisheries & Oceans, and Indian and Northern Affairs, as well as representatives of private consulting firms have participated from the inception of the group. Additional personnel, principally from the consulting and industrial sectors have participated in the group's latest activities. A list of members is included as Appendix A.

The terms of reference of the group, as developed at a meeting between Dr. J. McTaggart-Cowan, Dr. G.K. Sato and Mr. P. Vandall on 30 July 1979 were:

a) examine and assess historical or scenario type models especially those developed by FENCO, NORDCO, Shell - E & P Forum and the U.S. Geological Survey;

b) develop an operational real-time model;

c) establish an archive of test data incorporating information from well documented spills;

d) determine data and research requirements;

e) determine resources required to carry out tasks identified.

Because oil spill scenario models are vital to the environmental assessment and contingency planning processes, the main activity of the group to the present time has been to review the detailed operations of numerous oil spill scenario models. This review paper presents the summarized details of such analyses.

2. GENERAL NATURE OF OIL SPILL TRAJECTORY MODELS

For purposes of the present discussion, an oil spill model is defined as a computerized sequence of calculations designed to predict some aspects of the behavior of oil spilled on the surface of water. This broad definition allows inclusion of both marine and river environments, and accommodates models which give consideration to the motion (advection), the spreading, the diffusion, and the weathering of spills. Attention is generally restricted to surface behavior.

The working group has concentrated initially on scenario-type oil spill models, which are not be be confused with so-called real-time models. The purpose of a scenario model is generally to provide an overview to potential spill behavior in the pre-spill stage. Such models are frequently employed as contingency planning tools in designing frontier development programs. Scenario models attempt to predict mean (or most probable) and extreme answers, for a given spill site, to such questions as:

- What is the likely speed and direction of slick motion?
- What are the probable shore impact points?
- What volume of oil is expected ashore?
- What combination of environmental (wind, wave, current, etc.) conditions generates the most severe spill scenario? How frequently do such conditions occur?

To be of greatest value in planning potential countermeasure operations and in assessing potential threat to biological stocks, such predictions are required on at least a seasonal, if not a monthly basis.

Real-time models on the other hand are operational tools to be employed at the time of an actual spill event. These models make use of most-recently observed wind, current and sea state conditions in conjunction with wind, current and sea state forecasts, to forecast the behavior of spilled oil generally some tens of hours into the future. As a general rule, the scale of resolution for the geographical area of interest would (initially at least) be smaller.

A distinction must be drawn between the two basic types of scenario models - deterministic and statistical. The differences relate not so much to the mechanisms of the model as to the nature of wind and current data input to the model. A deterministic scenario model employs actual data as input to the advection aspect of its calculations. These data may possibly be modified to be made more representative of the site under considerations, but the root of the input is a measured time series of values. Deterministic scenario model mechanics are such that input of a given data series will always yield the identical predicted output. Thus to gain statistical significance in the interpretation of output, deterministic models must be run on a variety of input data sets or must group predictions by some appropriate time average (such as monthly). In contrast, the statistical variety of scenario model employs some volume of measured data as a standard or guide to creating a synthetic input data set. This approach is most commonly encountered with wind input. The synthetic data, generated by some statistical process (Monte Carlo simulation, Markov chain, etc.) employing a random number function, are then input to the scenario model. Each iteration of the model commencing with a specific set of parameters, fixed except for the random seed, will generate a distinctly different predicted output. Such models must be run a sufficient number of times to assure statistical significance in the interpretation of the output data.

The following section presents a review of various scenario models encompassing both the deterministic and statistical varieties.

3. METHOD OF MODEL REVIEW

A standardized form has been developed to allow quick intercomparisons of the key features of the models reviewed. Tables (Appendix B) present details of the following scenario models:

TABLE	MODEL NAME	AGENCY
B.1	AES	AES, Downsview
B.2	Arctic Sciences Ltd.	Arctic Sciences Ltd.
B.3	Canmar/Dome Spill Tracking	Canmar/Dome
B.4	FENCO/Marsan	FENCO (Nfld.) Ltd. André Marsan et Assoc. Inc.
B.5	Seaconsult-Hydrospace	Seaconsult Limited Hydrospace Marine Services Ltd.
B.6	Hydrospace	Hydrospace Marine Services Ltd.
B.7	MARTEC Trajectory	MARTEC Limited
B.8	NORDCO	NORDCO
B.9	SLIKTRAK	Shell International

TABLE	MODEL NAME	AGENCY
B.10	St. Lawrence River	Fisheries & Oceans
B.11	USCG	U.S. Coast Guard
B.12	USGS Risk Analysis	U.S. Geological Survey
B.13	Rand 3D Oil Spill	Rand Corp.

The review presentation proceeds with a comparative summary of scenario models in terms of wind input, current input, wave input, advection parameters, dispersion, spreading, weathering, risk analysis, software language, hardware, and operational status (Appendix C). The concluding summary (Section 5) documents the range of techniques and values employed for each process or parameter, and indicates the preferred method or value in each case. A further appendix (D) is a glossary providing definitions for technical terms appearing in this paper. Finally, the DEMR/RMB document "Draft Guidelines for Oil Spill Scenario Models", following extensive review by the group, is reproduced (Appendix E) as submitted to the Joint Government/Industry Task Force on Oil Spill Contingency Plan Guidelines.

4. INTERCOMPARISON METHODS

The following table summarizes our perception of the methods, problems and progress to date.

	METHOD	ADVANTAGES	DISADVANTAGES	WORKING GROUP PROGRESS
(a)	Theoretical, i.e., review and pass judgement on the processes included and the methods used to model them.	Easiest to do and to update for new models.	Many of the constants are empirical and not well established, particularly for oil weathering.	This document contains summaries of the range of methods used and concensus of the preferred technique.
(b)	Run all models on the same set of wind and current data, either simulated or real.	Easy to control and vary parameters.	The relative strengths of wind, current and turbulence will affect model performance.	Initially supported resulting in FENCO/Hydrospace proposal to do the intercomparison. The idea has been since rejected due to lack of funds and a realization that the results would probably depend on the subtleties of the data series used.
(c)	Evaluate wind data source and manipulation techniques.	Addresses most basic difference between various models.	Subjective. To do a thorough evaluation would require actual handling of data. Difficult to avoid site specific conclusions. Expensive.	AES contract will partially address this problem and determine appropriate wind input for Hibernia region. Still remaining are problems of the differences of real vs. simulated winds particularly in regard to the extremes of trajectory excursion, and of the use of shore base winds for modelling

4. - CONT'D.

METHOD	ADVANTAGES	DISADVANTAGES	WORKING GROUP PROGRESS
			well offshore. Advice from AES meterologists is now under consideration.
(d) Do a field experiment, measuring wind and surface current and probably using some kind of drifter to simulate oil slick movement.	Has real world values of all the empirical constants.	Expensive due to logistics, hard to measure surface currents, hard to simulate horizontal dispersion and oil losses due to vertical dispersion and evaporation.	Slightly outside the group's mandate, but BIO (Elliott and Lawrence) are proceeding with a proposal and logical sequence of testing to develop suitable drifters.

5. RECOMMENDED METHODS OF MODELLING VARIOUS PHYSICAL PROCESSES

5.1 Advection

Range of methods or values: the common approach is to advect single or multiple oil particles over a short time step by vectorially combining wind generated and residual current generated displacements. It is assumed that the wind generates a current which advects the oil. This wind induced current is modelled with a magnitude of some 2-4% (the wind reduction factor) of the wind speed and a direction to the right of the wind direction (northern hemisphere) at a deflection angle of 0-40°. The residual current is regarded as the total current less any local wind effects, and is variously allowed to contribute 50-100% of its magnitude to the advection computation.

Discussion: to model advection properly, one has to understand the various scales of oceanographic variability. To interpret the variability found in current measurements, one needs to understand the various processes going on. If successful, then one may be able to use the variability in the generally much longer data records of sea level, atmospheric pressure or winds to predict the variability in the currents over a much longer period. Consider, then, the following processes:

(a) Tides - the excursion is usually small (<10 km) except in regions such as the Bay of Fundy and Hudson Strait. However nonlinearities and friction can generate steady residuals and thereby large displacements. Tidal currents and tidal residuals are fairly easily modelled and predictable since the astronomical driving forces are known exactly and field verification for the currents requires only a relatively short data set.

(b) Inertial motion - this is found in all regions, it is episodic, being generated whenever there is an abrupt change in the forcing. On the Scotian Shelf, the motion is strong in winter when storms are intense. Typical amplitudes are 30 cm/s, with horizontal coherences of 50 km (Petrie and Smith, 1977). This results in circular motion with a diameter of only about 6 km. This motion would only need to be considered for short term predictions (several days) and could be modelled relatively easily if wind fields were well known.

(c) Meteorological events - wind or atmospheric pressure records on the east coast show a considerable spectral energy peak in the band of about 2-7 days. There is a corresponding peak in most current meter records. However the currents show a very low horizontal coherence, probably because the response is governed by small scale topographic features (Smith and Petrie, 1982). Winter spectra from Scotian Shelf current meter records of several months duration give displacements of at most 10 km at the 10 day period, although individual storm events would greatly exceed this. It will be very difficult to model such currents and thereby get reliable estimates of means and extremes. A start has been made (Beardsley and Haidvogel, 1981) on the Mid Atlantic Bight (Cape Hatteras to southern end of Nova Scotia) using vertically integrated and linearized equations in a homogeneous ocean driven by atmospheric pressure and wind stress fluctuations and damped by quadratic bottom stress. The transient response time in the shallow regions was found to be small (~10 hours) so that the storm driven current should be quasi-steady.

(d) External Forcing

(1) Gulf Stream eddies - these are largely born in the deep waters south of Nova Scotia shelf and then drift slowly west and south or are reabsorbed. Energy can radiate from them and has been detected as oscillations at the shelf edge (Louis, Petrie and Smith, 1981). The characteristic periods are long (10-30 days). Spectral estimates from moored current meters give average displacements of 10-40 km. Individual events can produce considerably larger displacements, as confirmed by Lagrangian drifter buoys. The shelf response to eddies can be very complicated. Satellite sea surface temperature maps have shown large tongues of cold water being drawn off the shelf. Predictions of the birthdates of future eddies are nearly impossible, however since several years of maps exist, estimates are becoming possible of historical birth rates. One still has the problem of the resultant response of the waters near the shelf edge to the eddies and whether this can be given in any kind of meaningful average sense. Needler (1980) speculates that similar instabilities in the Labrador Current might result in similar occurrences there.

(2) Estuarine outflow - the St. Lawrence River and the rivers of Hudson Bay are major sources of fresh water. There is a strong annual signal, dominated by the spring runoff peak. It results

in a quasi-steady flow along the shelves, with displacements of order 8 km/day. While the flow may not yet be modelled very well, it is of such large scale that it has been well traced and mapped.

(e) Direct wind forcing - The local winds drive the surface layer directly, and most oil trajectory models parameterize this process with simple 3.5% factor. The only advantage of this approach is its simplicity. It requires that the complexity of shelf wide response to atmospheric pressure and wind forcing events be relegated to the 'residual current' field which usually means that because of the paucity of data, most of the variance in this process is neglected. Even the use of the single value, 3.5%, for the wind factor has severe limitations. It has evolved empirically from experience at various oil spills, but even so, the wide range of values used by various modellers (1-6%, Stolzenbach et al., 1977) indicates the scatter in the data. Recent experimental data (Ambjörn, 1981) indicates that while 3.5% is appropriate for the very surface film, the value falls off rapidly with vertical integration (1.9% for 1 cm, 1.3% for 10 cm). The major spills in eastern Canadian waters have been of Bunker-C oil, which always forms lumps not surface slicks. There is also evidence that even with crude oil in warm water, the surface slick is of very small spatial extent and that large nearly neutrally buoyant lumps are formed (IXTOC blowout, Gulf of Mexico). In any model, the shape of the velocity profile in the surface boundary layer will be very sensitive to the variation of eddy viscosity with depth. There is no agreement yet on an appropriate formulation (see discussions by Ambjörn, 1981, Madsen, 1977, Huang, 1979). More theoretical and experimental work is required to determine regional and seasonal variations.

In summary then, a variety of processes contribute to the advection of oil. Each process has a characteristic range of time and space scales. Stolzenbach et al. (1977) have displayed this aspect, but for wind forcing only. The importance of a given process cannot be stated absolutely, but will depend on details of the spill and its location: e.g. if oil can reach an environmentally sensitive area in one day then tides and inertial motions may matter if of sufficient amplitude, if it takes 2-10 days storm events may matter, while only for longer periods might true residual currents matter.

5.2 Diffusion (horizontal)

Range of methods or values: Fickian. Random Walk.

Suggested method or values: The explicit modelling of this process is regarded as non-essential as the small effect will generally be insignificant in comparison to inherent variability introduced by winds and currents. In confined regions or near shorelines the magnitude of this effect must at least be estimated. Note that the partition of energy between advection and diffusion is somewhat artificial since no spectral gap is generally present. The energy allotted to diffusion and therefore its relative importance depends on the time scale of interest.

5.3 Diffusion (vertical)

Range of methods or values: Blaikley et al. (1977).

Suggested method or values: Modelling of this mainly sea state dependent process is considered essential although no preferred technique has been identified. It is expected that this process could account, under severe conditions, for transfer of some tens of percent of slick volume into the water column. The ultimate goal is to model subsurface concentrations and behavior.

5.4 Spreading

Range of methods or values: Fay (1971)

Suggested method or values: Spreading analysis, while required for near shore or confined regions, is not absolutely required in the standard offshore scenario case. Recent work (Mackay et al, 1979a) merits investigation.

5.5 Evaporation

Range of methods or values: Mackay et al (1977, 1979a, 1980), Kreider (1971) Wang et al (1976).

Suggested method or values: After Mackay et al (1980). Use evaporative analysis for known or anticipated oil type to develop look-up table based on time, wind speed and water temperature. Evaporation should continue throughout entire simulation unless a minimum volume remaining cutoff is explicitly justified.

5.6 Dissolution

Range of methods or values: Percentage of evaporation after Moore et al (1973).

Suggested method or values: Modelling of this process is considered non-essential as it accounts at most for a loss of a few percent of total spill volume.

5.7 Emulsification

Range of methods or values: Proportional to vólume present and dependent on sea state, temperature and oil type. Mackay and Leinonen (1977), Blaikley et al (1977).

Suggested method or value: Again the modelling of this process is considered necessary, but a recommended approach is not available. Research indicates that processes of evaporation, spreading, diffusion and most probably advection are affected by emulsification. The current work of Mackay is to be monitored, eg. Mackay et al, (1979b).

6. BIBLIOGRAPHY

AHLSTROM, S.W., 1975. A Mathematical Model for Predicting the Transport of Oil Slicks in Marine Waters. Battelle Pacific Northwest Laboratories, Richland, Wash., 70 pp.

AMBJÖRN, C., 1981. An Operational Oil Drift Model for the Baltic. Proc. Conf. on Mechanics of Oil Slicks, 7-9 Sept. 1981, Paris, France. 167-178.

AUDUNSON, T., V. DALEN, J.P. MATHISEN, J. HALDORSEN and F. KROGH, 1980. SLIKFORCAST - A Simulation Program for Oil Spill Emergency Tracking and Long Term Contingency Planning. Paper submitted to Petromar '80, Monaco, May 1980.

BEARDSLEY, R.C. and D.B. HAIDVOGEL, 1981. Model Studies of the Wind-Driven Transient Circulation in the Middle Atlantic Bright. Part 1: Adiabatic Boundary Conditions. J. Phys. Oc. 11 (3) 355-375.

BLAIKLEY, D.R., G.F.L. DIETZEL, A.W. GLASS and P.J. VAN KLEEF, 1977. SLIKTRAK- Computer Simulation of Offshore Oil Spills, Cleanup, Effects and Associated Costs. Proc. Joint Conf. on Prevention and Control of Oil Spills, Amer. Petrol. Inst., March 8-10, 1977, New Orleans, La., pp. 45-52.

FAY, J.A., 1971. Physical Processes in the Spread of Oil on Water Surface. Proc. Joint Conf. on Prevention and Control of Oil Spills, Amer. Petrol. Inst., June 15-17, 1971, Washington, D.C. pp. 463-467.

HUANG, N.E., 1979. A Simple Model of Ocean Surface Drift Current. Workshop on Physical Behaviour of Oil in the Marine Environment. Princeton University. 8-9 May 1979. pp. 6.19-6.34.

KREIDER, R.E., 1971. Identification of Oil Leaks and Spills. Proc. Joint Conf. on Prevention and Control of Oil Spills, Amer. Petrol. Inst., June 15-17, 1971, Washington, D.C., pp. 119-124.

LOUIS, J., B.D. PETRIE and P.C. SMITH, 1981. Observations of Topographic Rossby Waves at the Continental Margin off Nova Scotia. J. Phys. Oc., in press.

MACKAY, D. and P.J. LEINONEN, 1977. Mathematical Model of the Behaviour of Oil Spills on Water with Natural and Chemical Dispersion. Fisheries and Environment Canada, Environment Protection Service, Economic and Technical Review Report EPS-3-EC-77-19. 84 pp.

MACKAY, D., I. BUIST, K. HOSSAIN, A. KISIL, R. MASCARENHAS and S. PATERSON, 1979a. Oil Spill Processes and Models. In: Proceedings of the Arctic Marine Oil Spill Program Technical Seminar, March 1979, Edmonton, Alberta. Fisheries and Environment Canada, Environmental Emergency Branch. pp. 87-100.

MACKAY, D., I. BUIST, R. MASCARENHAS and S. PATERSON, 1979b. Experimental Studies of Dispersion and Emulsion Formation from Oil Slicks. Workshop on Physical Behavior of Oil in the Marine Environment. Princeton Univ. 8-9 May 1979. pp. 1.17-1.40.

MACKAY, D., S. PATERSON and S. NADEAU, 1980. Calculation of the Evaporation Rate of Volatile Liquids. Proc. Nat. Conf. on Control of Hazardous Materials Spills, Louisville KY, USA, May 1980. pp. 361-368.

MADSEN, O.S., 1977. A Realistic Model of the Wind-Induced Ekman Boundary Layer. J. Phys. Oceanog. 7: 248-255.

MOORE, S.F., R.L. DWYER and A.M. KATZ, 1973. A Preliminary Assessment of Environmental Vulnerability of Machias Bay, Maine, to Oil Supertankers. Mass. Inst. Tech. Rept. MIT-SG-73-6.

NEEDLER, G.T., 1980. Oceanographic Variability in the Operating Environment. Proc. 9th Env. Workshop on Offshore Hydrocarbon Development, Fairmont, B.C. 4-7 May 1980. Special publ., Arctic Institute of N. America, Univ. Calgary.

PETRIE, B. and P.C. SMITH, 1977. Low Frequency Motions on the Scotian Shelf and Slope. Atmosphere 15 (3): 117-140.

SMITH, P.C. and B. PETRIE, 1982. Low Frequency Circulation at the Edge of the Scotian Shelf. J. Phys. Oceano., in press.

STOLZENBACH, K.D., O.S. MADSEN, E.E. ADAMS, A.M. POLLACK and C.K. COOPER, 1977. A Review and Evaluation of Basic Techniques for Predicting the Behaviour of Surface Oil slicks. R.M. Parsons Lab, MIT, Tech. Report 222 (also MITSG-77-8).

SYDOR, M., 1978. Study of the Two-Dimensional Model of the St. Lawrence River. Proc. of Workshop on Oil Spill Modelling, Toronto, 7-8 Nov., 1978. Eds. D. Mackay and S. Paterson, U. of Toronto. Publ. EE-12, Inst. for Env. Studies, U. of Toronto, Ont. M5S 1A4. pp 93-141.

WANG, H., W.C.YANG and C.P. HWANG, 1976. Modelling of Oil Evaporation in an Aqueous Environment. Dept. Civil Eng. and Coll. Mar. Studies, Univ. of Delaware, Ocean Eng. Rept 7. possibly also see Yang and Wang, 1977.

YANG, W.C. and H. WANG, 1977. Modelling of Oil Evaporation in an Aqueous Environment. Water Res. 11: 879-887.

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APPENDIX B

SCENARIO OIL SPILL MODEL SUMMARIES

TABLE B.1 SCENARIO OIL SPILL MODEL SUMMARY FORM

Model Name: AES

Development Agency: AES, Downsview

Reviewed by: D.J. Lawrence Date: August 13, 1980

Methods:

Advection winds - due to Madsen (1977), assuming vertical eddy viscosity α depth

current - no

Diffusion (horizontal) - random walk (dist α $(K_x \Delta t)^{\frac{1}{2}}$, direction random) Ahlstrom (1975)

Weathering: Spreading - Due to Fay (1971)

Evaporation - Dependent on oil component, air temperature, wind speed (after Mackay and Leinonen, 1977)

Dissolution -

Vertical Diffusion -

Emulsification - amount α volume of non volatile oil in slick (15%/day for low sea states, 45%/day for high sea states) Mackay & Leinomen (1977), Blaikley et al. (1977).

Biodegradation -

Scenario mode - Up to 500 parcels are tracked.

Input Data:

Wind - at grid points (5x5 array, Δ127 km used in Beaufort Sea tests) obtained in real time from AES Computerized Prediction Support system wind module.

Current - No.

Waves - No.

Output:

Position of each oil parcel after n time steps plotted.

Model Useage:

Beaufort Sea
Contract issued to convert model from real time to scenario mode.

TABLE B.1 - CONT'D.

Software:

Language - Fortran IV # Lines - Core req'd. -

Documentation - Prediction of Motion of Oil Spills in Northern Canadian Waters by H.S. Sahota and S. Venkatesh, Canadian Meteorological Research Rept. # 1/79 & Toronto Workshop 1978 pg. 35-49, 51-83.

Available from - AES, 4905 Dufferin Street, Downsview, Ontario M3H 5T4

Hardware:

Computer Type -

Peripherals -

Graphics -

Operational Status:

Where is Model - AES; Edmonton, Downsview

What Data Required -

Who to Contact - S. Venkatesh (416)667-4849

TABLE B.2 SCENARIO OIL SPILL MODEL SUMMARY FORM

Model Name: ASL

Development Agency: Arctic Sciences Ltd. (for AMOP)

Reviewed by: J.R. Marko Date: March 13, 1980

Methods:

Advection winds - 3.5%, 0°

current - 100%

Diffusion (horizontal) - Fickian

Weathering: Spreading - Fay (1971)

Evaporation - Kreider, 1971, 45% over 1st 2 days

Dissolution -
{combined losses, Blaikley, et al. (1977)
Vertical Diffusion -

Emulsification -

Biodegradation -

Scenario mode - Batch release at bottom, every time step

Input Data:

Wind - at any desired grid spacing, from real or synthetic data.

Current - 9 km grid, based on average values of 35m deep current records and accumulated drogued-drifter trajectories.

Waves - No.

Output:

Trajectories and representation of oil batch configurations.

Model Useage:

Scenario development in Eastern Parry Channel for deepwater blowouts. Compared with oil follower buoy tracks.

Software:

Language - FORTRAN IV # lines - ≈ 700 Core req'd. - 83K (octal)

Documentation -

Available from - Arctic Sciences Ltd.
9860 W Saanich Road, RR # 2, Sidney, B.C. V8L 3S1

TABLE B.2 - CONT'D.

Hardware:

Computer Type -	Sperry Rand 1106
Peripherals -	Printer, Techterm Terminal
Graphics -	Calcomp, Tektronix

Operational Status:

Where is Model -	Arctic Sciences Ltd., Sidney, B.C.
What Data Required -	Current grid, wind grid, spill parameters, diffusivity
Who to Contact -	J.R. Marko, Arctic Sciences Ltd. (604)656-0177

TABLE B.3

SCENARIO OIL SPILL MODEL SUMMARY FORM

Model Name: CANMAR OIL SPILL TRACKING

Development Agency: CANMAR/DOME

Reviewed by: Bill Pistruzak Date: May 13, 1980

Methods:

Advection winds - 3% and 20°

current - No

Diffusion (horizontal) -

Weathering: Spreading -

Evaporation - By look up table for C_{11}-C_{16}

Dissolution -

Vertical Diffusion - 6% loss/6 hours

Emulsification -

Biodegradation -

Scenario mode -

Input Data:

Wind - Single Site, hourly

Current - No.

Waves - No.

Output:

1. Line printer map indicating daily position of oil and concentrations.
2. Printout of daily conc. of oil on shore.
3. Optional printout of positions, conc. of oil.
4. Final histogram of oil that has gone ashore.

Model Useage:

Operational: track, predict motion of oil spill determine conc. of oil; after t_o {Used in Beaufort Sea}

Historical: hindcasting where oil would have impacted

TABLE B.3 - CONT'D.

Software:

Language - FORTRAN   # Lines - 426   Core req'd. - 26K

Documentation -

Available from - CANMAR

Hardware:

Computer Type - Honeywell 60/6000

Peripherals - Line Printer

Graphics -

Operational Status:

Where is Model - In Calgary and Arctic Weather Centre-Edmonton

What Data Required - Spill date, location (lat-long)

Who to Contact - W.M. Pistruzak or P.K. Devenis (403)266-7622

TABLE B.4

SCENARIO OIL SPILL MODEL SUMMARY FORM

Model Name: FENCO-Marsan Scenario Model

Development Agency: FENCO (Nfld.) Ltd., André Marsan et Associés Inc.

Reviewed by: L.W. Davidson Date: August 28, 1979

Methods:

Advection winds - Three simultaneous wind reduction factors, generally 0.30, .035 and .040. Fixed Coriolis angle-generally 10° or 20°.

currents - rotation or speed enhancement/reduction is allowed generally 20° rotation shoreward and multipliers of 0.5, 1.0 and 1.5 on speed.

Diffusion (horizontal) -

Weathering: Spreading -

Evaporation -

Dissolution -

Vertical Diffusion -

Emulsification -

Biodegradation -

Scenario mode - Seed value for wind simulator varied within each set of ≈ 100 runs.

Input Data:

Wind - long time-series processed to extract speed, directional frequency and directional persistency statistics. These are maintained in simulated wind time-series generated by model.

Current - Seasonal residual current grids generally relevent to three or four month interval.

Waves - Not considered separately.

Grid size optional. Have used 1 nm to 20 nm.

Output:

1. trajectory plots
2. trajectory endpoint distributions in space and time
3. trajectory coordinates if requested

TABLE B.4 - CONT'D.

Model Useage:

Scenario development for contingency planning. Altered versions have been used in forecast and hindcast situations.
Used for Kurdistan spill (C-CORE)

Software:

Language - FORTRAN # Lines - Roughly 300 Core req'd. - 512K

Documentation -

Available from - proprietary/FENCO (Nfld.) Ltd.

Hardware:

Computer Type - IBM 370/158

Peripherals - VUCOM 4 in-house terminal

Graphics - CALCOMP 960 belt plotter

Operational Status:

Where is Model - St. John's, Nfld.

What Data Required - Time-series winds, current grids

Who to Contact - F. Beaumont (709)754-1400

TABLE B.5

SCENARIO OIL SPILL MODEL SUMMARY FORM

Model Name: Seaconsult - Hydrospace

Development Agency: Seaconsult Ltd.
Hydrospace Marine Services

Reviewed by: L.W. Davidson Date: July 28, 1980

Methods:

Advection winds - reduction factor and Coriolis angle

currents - factor adjustable 50-150%

Diffusion (horizontal) -

Weathering: Spreading -

Evaporation - Function of time, wind, water temp, slick thickness and component vapor pressure. Wang et al. (1976), modified as per Mackay (pers comm)

Dissolution - As fraction of evaporation. Moore et al. (1973)

Vertical Diffusion - Dependent on sea state (and therefore wind). Blaikley et al. (1977)

Emulsification -

Biodegradation -

Scenario mode - Simultaneous advection of up to 31 day lots to simulate continuous source.

Input Data:

Wind - For Canadian East Coast, historical time series are adjusted with speed coefficients to match speed statistics of local modelled areas.

Current - Seasonal residual grids in use are being updated with acquisition of new data annually.

Waves - Inferred from wind speed.

Output:

Trajectory plots for each one month series of day lots, plus printed statistics which include (for each day lot), position, elapsed time, path length, mean speed, time of 95% loss of light fractions and total % volume remaining. Additional shore impact summary gives min, max, and mean % volumes ashore and earliest, latest and average time to shore.

TABLE B.5 - CONT'D.

Model Useage:

Scenario development for contingency planning purposes, Canadian East Coast.

Software:

Language - FORTRAN   # Lines - 850   Core req'd. - 256K

Documentation -

Available from - Seaconsult Ltd., Suite 200, 194 Duckworth St., St. John's, Nfld., A1C 1G6

or

Hydrospace Marine Services, Box 13187, St. John's, Nfld. A1B 4A4

Hardware:

Computer Type - IBM 370/158

Peripherals - Tape drives, teletype 43 terminal

Graphics - CALCOMP 960 belt plotter

Operational Status:

Where is Model - St. John's, Newfoundland

What Data Required - Historical wind time-series, seasonal residual current grids, water temperature, oil parameters.

Who to Contact - L.W. Davidson (709)722-7023

TABLE B.6

SCENARIO OIL SPILL MODEL SUMMARY FORM

Model Name: Hydrospace

Development Agency: C.J. Noll

Reviewed by: C.J. Noll Date: August 28, 1979

Methods:

Advection winds - 3.5%, 0-20°

currents - 100%

Diffusion (horizontal) -

Weathering: Spreading -

Evaporation - } done by separate program, for discussion purposes. Methods:
Evaporation - Wang et al. (1976)
Dissolution - } Dissolution - Moore et al. (1973)

Vertical Diffusion -

Emulsification -

Biodegradation -

Scenario mode - Varied starting day, common duration.

Input Data:

Wind - For Labrador area uses spatially varying time-series based on SSMO, drillship and pressure chart data.

Current - Monthly residual currents input on grid.

Waves - Not considered.

Output:

1. Trajectories for each day.
2. Arrival time to shore.
3. Location of shore impact.

Model Useage:

Risk Analysis, Labrador Shelf, 2° grid.

TABLE B.6 - CONT'D.

Software:

Language - FORTRAN # Lines - 200 Core req'd. - 193K

Documentation -

Available from - Hydrospace Marine Services, Box 13187, St. John's, Nfld. A1B 4A4

Hardware:

Computer Type - IBM 370/158

Peripherals -

Graphics - CRT, Hard Copy

Operational Status:

Where is Model - Hydrospace Marine Services

What Data Required - Spatially varying wind time-series and monthly current grids.

Who to Contact - B. Lukeman (709) 726-4300

TABLE B.7

SCENARIO OIL SPILL MODEL SUMMARY FORM

Model Name: MARTEC

Development Agency: MARTEC LIMITED

Reviewed by: M. Coolen Date: June 3, 1981

Methods:

Advection winds -. reduction factor & Coriolis angle adjustable.

currents - 100%

Diffusion (horizontal) - No.

Weathering: Spreading -

Evaporation - As a function of elapsed time formerly using a lookup table, now (1981) computed using slick thickness, wind speed, temperature, and oil properties (Audunson et al., 1980)

Dissolution -

Vertical Diffusion - As per SLIKTRAK (function of time and sea state).

Emulsification -

Biodegradation -

Scenario Mode - Follow each day lot released until: (1) outside grid; (2) at shoreline; (3) at desired elapsed time; or (4) amount of oil below % cutoff.

Input Data:

Wind - Historical time-series manipulated by model preprocessor to give reduction to 10 m level and express wind in daily displacements.

Current - Uses monthly residual current grids.

Waves - Average of available data or generation of wave data from wind by Beaufort scale.

Other - Air temperature, averaged daily or monthly.

Output:

Magnetic tape and/or hard copy plus trajectory plots.
Output includes start date, time after start, oil location, spill area, spill thickness, quantity of oil remaining (total and fractions)

Model Useage:

Scenario development.

TABLE B.7 - CONT'D.

Software:

Language - FORTRAN IV # Lines - Core req'd. -

Documentation -

Available from - MARTEC Ltd., 1526 Dresden Row
Halifax, Nova Scotia B3J 3K3

Hardware:

Computer Type - CDC 6400

Peripherals - Tape Drives

Graphics - Plotter

Operational Status:

Where is Model - Halifax

What Data Required - Historical time series winds, monthly residual current grids, mean wave climate (optional), air temperature.

Who to Contact - M. Coolen, MARTEC Ltd. (902) 425-5101

TABLE B.8 SCENARIO OIL SPILL MODEL SUMMARY FORM

Model Name: NORDCO

Development Agency: NORDCO (C.J. Noll)

Reviewed by: G.J. Purcell Date: October 1, 1980

Methods:

Advection winds - 3-3.8% reduction, 0-20° Coriolis

currents - 100%

Diffusion (horizontal) -

Weathering: Spreading -

Evaporation - As a function of time, wind, water temperature, thickness (modified Fay), and component vapor pressure. Wang et al. (1976).

Dissolution - as a fraction of evaporation. Moore et al. (1973)

Vertical Diffusion -

Emulsification -

Biodegradation -

Scenario Mode - Variable duration and starting date.

Input Data:

Wind -
Current - } Data bases from various sources (SSMO, CMC, NODC)

Waves - Predicted from winds by model.

Output:

Trajectories, arrival times, shore impact with graphics

Model Useage:

For risk analysis and contingency planning. Can be used in real time mode.

Software:

Language - FORTRAN # Lines - 500 Core req'd. - 64K

Documentation -

Available from - NORDCO, P.O. Box 8833, St. John's, Nfld. A1B 3T2

TABLE B.8 - CONT'D.

Hardware:

Computer Type - PDP 11/34 under RSX-11M real time system

Peripherals - Disks, tapes, printers, terminals, Talos digitizer for gridded input.

Graphics - Tektronix soft & hard copy.

Operational Status:

Where is Model - NORDCO

What Data Required - Winds, currents, sea and air temperature.

Who to Contact - NORDCO, (709) 754-2401

TABLE B.9

SCENARIO OIL SPILL MODEL SUMMARY FORM

Model Name: SLIKTRAK

Development Agency: Shell International Petroleum Mij (SIPM) on behalf of E.&P. Forum

Reviewed by: P.E. Vandall Date: October 9, 1979

Methods:

Advection winds - 2-4% Reduction, 5-30° Coriolis Deflection (15° Avg)

currents - 50-60% Reduction.

Diffusion (horizontal) -

Weathering: Spreading -

Evaporation - Function of time and wave conditions. Specified for each oil type and temperature of region.

Dissolution -

Vertical Diffusion - Based on wave conditions and time (determined from work by Warren Springs Labs and Norwegian Petroleum Directorate).

Emulsification -

Biodegradation -

Scenario Mode - For each trajectory, starting day for wind is chosen at random. Values for other parameters can be picked at random from within their ranges or be fixed.

Input Data:

Wind - One time-series (two years) (in grid units/day) used for entire grid. Coriolis deflection applied before or after input.

(Grid Size optional but 20 km used for North Sea)

Current - Seasonal (up to 4) residual current grids (tide and wind removed). In grid units/day for each grid square.

Waves - Coded values are used for vert. diffusion, evaporation, and cleanup cost estimates based on equipment limitations.

Other - Parameters controlling processes above, cost and bridging probability, range of efficiency of cleanup.

TABLE B.9 - CONT'D.

Output Data:

1. Total spill costs (primary & secondary cleanup and shore pollution).
2. Trajectories for each day lot of oil released.
3. Arrival time to shore (minimum) and quantity involved.

Model Useage:

Risk analysis, cost anlysis and clean up strategy formulation. Has been used in North Sea, and on Grand Banks.

Software:

Language - FORTRAN # Lines - Core req'd. -

Documentation - SLIKTRAK - a Computer Simulation of Offshore Oil Spills, Cleanup, Effects and Associated Costs. D.R. Blaikley, G.F.L. Dietzel, A.W. Glass and P.J. vanKleef, Pg. 45-52. Proc. of 1977 Oil Spill Conference.

Available from - Shell Canada Resources Ltd., Calgary

Hardware:

Computer Type - Univac 1110

Peripherals - Printer, three tape drives

Graphics -

Operational Status:

Where is Model - Shell Canada Resources Ltd., Calgary

What Data Required - Two year wind time-series, seasonal residual current grids, wave tables, cost related parameters.

Who to Contact - L.R. Hunter (403) 232-3410

TABLE B.10

SCENARIO OIL SPILL MODEL SUMMARY FORM

Model Name: St. Lawrence River Oil Spill Model

Development Agency: Department of Environment

Reviewed by: M. Sydor Date: October 9, 1979

Methods:

Advection winds - Direction given normal distribution about measured values: 18% probability of being outside $\pm \pi/2$, 0% outside $\pm\pi$.

currents - Components given normal distribution about measured values: 18% probability outside ± 5%, 0% probability outside ± 10%.

Diffusion (horizontal) -

Weathering: Spreading - Fay (1971)

Evaporation -

Dissolution -

Vertical Diffusion -

Emulsification -

Biodegradation -

Scenario mode - A spill is represented by up to 1000 parcels of oil. Each is tracked until lost to a shoreline or trapped in small bays.

Input Data:

Wind - Real or forecast point sources.

Current - Computed 2-D (St. Lawrence 2-D model) (Leendertse) 99X99 grid

Waves - No.

Output:

Trajectories, printouts and Tektronix plots.

Model Useage:

St. Lawrence River - Cornwall to below Quebec City.

TABLE B.10 - CONT'D.

Software:

Language - FORTRAN   # lines - 2000   Core req'd. - 150K (octal)

Documentation - Sydor, Proc. Workshop on Oil Spill Modelling, Toronto (1978) p. 121-141

Available from - Dept. of Environment

Hardware:

Computer Type - CDC Cyber 74

Peripherals - Printer, Teckterm terminal

Graphics - Tektronix, CALCOMP

Operational Status:

Where is Model - EMR, Cyber 74, Ottawa

What Data Required - Hydrographic charts, point source winds, current model output

Who to Contact - M. Sydor, WPM/DOE, Ottawa (819) 997-2359

TABLE B.11

SCENARIO OIL SPILL MODEL SUMMARY FORM

Model Name: USCG Model

Development Agency: U.S. Coast Guard Research & Development Center

Reviewed by: V.R. Neralla Date: October 9, 1979

Methods:

Advection winds - 3.5% (N.Y. case used 2% + leeway)

currents - Based on tides and river outflow, 100%

Diffusion (horizontal) - No (yes for New York Harbour)

Weathering: Spreading - Fay (1971)

Evaporation -

Dissolution -

Vertical Diffusion -

Emulsification -

Biodegradation -

Scenario mode -

Input Data:

Wind - National Weather Service Charts.

Tides - Tide Tables (East Coast of North and South America, 1973)

Current - Offshore - derived from special publication 1400 series, published by the Naval Oceanographic Office.
- U.S. Coast Guard Oceanographic Unit (CGOCEANO) developing a coastal atlas from available near shore data.

River Flow - Continuous recording gauge data from the U.S. Geological Survey.

Output:

Drift position charts at desired intervals.

Model Usage:

Site specific (New Jersey - Delaware Coastline, New York Harbour)

TABLE B.11 - CONT'D.

Software:

Language - Focal   # lines -   Core req'd. -

Documentation - Lissauer (1974) NTIS # AD 786 627
Stolzenbach et al (1977) MIT Report 222, p. 5-25+

Available from - I.M. Lissauer (203) 445-8501
U.S. Coast Guard Research and Development Center
Avery Point, Groton, Connecticut 06340 U.S.A.

Hardware:

Computer Type -

Peripherals -

Graphics -

Operational Status:

Where is Model - U.S. Coast Guard Research and Development Center

What Data Required - Meteorological, Oceanographic, tidal and river flow

Who to Contact - U.S. Coast Guard Research and Development Center, Avery Point, Groton, Connecticut 06340, U.S.A.

TABLE B.12

SCENARIO OIL SPILL MODEL SUMMARY FORM

Model Name: USGS Risk Analysis

Development Agency: U.S. Geological Survey

Reviewed by: D.J. Lawrence Date: June 2, 1981

Methods:

Advection winds - 3.5%, 20°

currents - 100°

(Horizontal) - Not in model. Discussed in S. Calif. Report. Several Graphs given of slick width versus time.

Weathering: Spreading - Not in Model. Discussed in S. Calif. Report. Toxicity much reduced by 4 days.

Evaporation -

Dissolution -

Vertical Diffusion -

Emulsification -

Biodegradation -

Scenario mode - Up to 500 spills/season can be modelled, with random seeding of Markov wind simulator, from up to 100 launch sites.

Input Data:

Wind - Simulation of time-series using lag 1 Markov with vector transition probability matrices based on long term observed data (3 hourly; S. Calif. case, 8 direction and 5 speed classes, 4 seasons, 5 years)

Current - Prescribed at grid points (2.4 km, based on mean monthly geostrophic and drift card data for S. Calif. case, but in general can be polygonal). Can also accept data from numerical ocean models.

Waves - No.

Output:

I: Probability of oil spill as function of volume at sites and along routes.

II: Monte Carlo simulation of spill trajectories and plots.

III: Assessment of probability of impact of oil on biological, recreational and other resource areas.

TABLE B.12 - CONT'D.

Model Useage:

Incremental risk analysis for proposed Continental Shelf lease sales: 4 Atlantic coast sites, Southern Calif., Florida West Coast, Gulf of Alaska. Ref: USGS Water Resources Investigations # 78-80, for S. Calif. case. 10 sites done up to Nov. 1979, planning 4 more/year up to 1983 at least.

Software:

Language - IBM FORTRAN IV/H   # Lines -   Core req'd. - 800 K bytes.
Programs - 21

Documentation - Offshore technology Conf. 1979, paper 3607.
USGS Open-File Report 80-687 "The Oil Spill Risk Analysis Model of the USGS"

Available from - Kenneth Lanfear (703)860-6730, possibly by late spring, 1980. Will follow release of report documenting the system.

Hardware:

Computer Type - IBM 370 Model 155

Peripherals - Tape Drives, Disk (2000 tracks), digitizer

Graphics - Plotter

Operational Status:

Where is Model - USGS

What Data Required - Wind vector transition matrices, oil spill rates, grid locations of sensitive areas, currents at grid points.

Who to Contact - Richard A. Smith, Systems Analysis Group Reston, VA (703)860-6927
Kenneth J. Lanfear, Environmental Modelling Group Reston VA. (703)860-6730

TABLE B.13 SCENARIO OIL SPILL MODEL SUMMARY FORM

Model Name: RAND 3-D OIL SPILL

Development Agency: Rand Corp.

Reviewed by: D.J. Lawrence Date: June 11, 1981

Methods:

Advection winds -

currents -

Diffusion(horizontal) -

Weathering: Spreading -

Evaporation -

Dissolution -

Vertical Diffusion -

Emulsification -

Biodegradation -

Scenario mode -

Input Data:

Wind - Stochastic, transitional matrix from theory of synoptic climatology and field data.

Current - 3-D non homogenous model with coastal boundaries and option of ice cover. Tides included. Ice formation involves heating, cooling and salt rejection. Ice-ice interactions modelled by non linear viscous second order dynamics in coastal regions.

Output:

Model Useage:

Eastern Bering Sea. Ref: A 3-D Oil Spill Model With and Without Ice Cover. S.K. Liu and J.J. Leendertse, abstract accepted for IAHR Symposium, 4-7 Sep. 1981, Paris.

Software:

Language - # Lines - Core Req'd. -

Documentation -

Available from -

TABLE B.13 - CONT'D.

Hardware:	
Computer Type -	
Peripherals -	
Graphics -	
Operational Status:	
Where is Model -	
What Data Required -	
Who to Contact -	J.J. Leendertse, Rand Corp. Santa Monica CA USA 90406

APPENDIX C

COMPARATIVE SUMMARY OF SCENARIO MODELS

OIL SPILL MODEL CHARACTERISTICS	(1) AES	(2) ARCTIC SCIENCES LTD.	(3) CANMAR/DOME
ADVECTION PARAMETERS: Wind reduction factor Coriolis angle Current Contribution	uses Madsen, 1977. (vert eddy viscosity α depth)	3.5% 0° (adjustable) 100%	3% 20°
DIFFUSION (horiz):	random walk dist $\alpha(K_x \Delta t)^{\frac{1}{2}}$	Fickian	
OIL: Spreading Evaporation Dissolution Vertical Diffusion Emulsification Biodegradation	Fay (1971) dependent on oil component, air temp & wind. Mackay & Leinonen (1977) amt α volume, rate α sea state	Fay (1971) 45% over 1st 2 days Kreider (1971) } combined losses } Blaikley et al (1977)	 look up table for C_{11}-C_{16} 6% loss/6 hrs.
WIND FIELD: Obs. (O)/Synth(S) #sites(j)/grid(jxk) Comments	 O or predicted 5x5 (Δ127 km) from CPSS wind module usually interpolated to finer grid	 O or S jxk	 O 1
RESIDUAL CURRENTS: #sites(n)/Grid(nxm) Comments		 n x m (Δ9km) from current meters & drifters	
WAVES: Obs.(O)/Synth(S) Used for			
Other input data:			
RISK ANALYSIS: Shore Fouling Ecological Damage Cost Analysis			 histogram
SOFTWARE: Language	Fortran IV	Fortran IV	Fortran
HARDWARE: Computer type Graphics type Machine location	 Downsview & Edmonton	 Sperry Rand 1106 Calcomp, Tektronix Victoria, B.C.	 Honeywell 60/6000 no Calgary&Edmonton
OPERATIONAL STATUS: Time for new region Comments	 designed for real time mode, being adapted for scenario mode		

OIL SPILL MODEL CHARACTERISTICS	(4) FENCO/MARSAN	(5) SEACONSULT/HYDROSPACE	(6) HYDROSPACE
ADVECTION PARAMETERS:			
Wind reduction factor	3-4% (3 simultaneously)	3.5%	3.5%
Coriolis angle	10-20°	10° adjustable	0-20°
Current contribution	50-150% & rotation	100%	100%
Other			
DIFFUSION (horiz):			
OIL: Spreading			
Evaporation		Wang et al (1976) + mods from Mackay	Wang et al (1976)
Dissolution		as % of evaporation Moore et al (1973)	as % of evaporation Moore et al(1973)
Vertical Diffusion		dependent on sea state (wind) and time. Blaikley et al (1977)	
Emulsification			
Biodegradation			
WIND FIELD:			
Obs.(O)/Synth(S)	S	O	O
#sites(j)/grid(jxk)	1	1	j x k (Δ1°)
Comments		distant obs. used with speeds adjusted	from pressure charts
RESIDUAL CURRENTS:			
#sites(n)/grid(nxm)	n x m (1-20nm)	n x m	n x m (Δ2°)
Comments	from literature review	updated from available current meter data	monthly residual
WAVES:			
Obs.(O)/Synth(S)		S(from wind speed)	
Used for		vertical diffusion	
Other input data:		water temperature air temperature	
RISK ANALYSIS:			
Shore Fouling	% ashore/grid	many statistics	trajectory end points
Ecological Damage			
Cost analysis			
SOFTWARE: Language	Fortran	Fortran	Fortran
HARDWARE:			
Computer type	IBM 370/158	IBM 370/158	IBM 370/158
Graphics type	Calcomp 960	Calcomp 960	CRT, hard copy
Machine location	St. John's	St. John's	St. John's
OPERATIONAL STATUS:			
Time for new region	few days	few days	depends on wind data
Comments			

OIL SPILL MODEL CHARACTERISTICS	(7) MARTEC	(8) NORDCO	(9) SLIKTRAK
ADVECTION PARAMETERS: Wind reduction factor Coriolis angle Current contribution Other	 3.5% 10° adjustable 100%	 3-3.8% 0-20° 100%	 2-4% 5-30° (15° avg) 50-60%
Diffusion (horiz):			
OIL: Spreading Evaporation Dissolution Vertical Diffusion Emulsification Biodegradation	 Audunson et al (1980) based on time & sea state, Blaikley et al (1977)	 Wang et al (1976) as % of evaporation Moore et al (1973)	 based on time, seastate, oil type, temperature based on time & sea state, Blaikley et al. (1977)
WIND FIELD: Obs.(O)/Synth(S) #sites(j)/grid(jxk) Comments	 O 1	 O j x k	 O 1 2 year series
RESIDUAL CURRENTS: #sites(n)/grid(nxm) Comments	 n x m monthly residuals	 n x m	 nxm (20km, N.Sea) seasonal residuals
WAVES: Obs.(O)/Synth(S) Used for	 O, or S from wind evaporation, vertical diffusion	 S from wind	 O or S evaporation, vertical diffusion, cleanup cost factors
Other input data:	air temperature, daily or monthly		bridging probability, cleanup factors
RISK ANALYSIS: Shore Fouling Ecological Damage Cost Analysis	 volume	 Yes	 trajectory endpoints very extensive
SOFTWARE: Language	Fortran IV	Fortran	Fortran
HARDWARE: Computer type Graphics type Machine location	 CDC 6400 plotter Halifax	 PDP 11/34 Tektronix St. John's	 Univac 1110 Calgary
OPERATIONAL STATUS: Time for new region Comments			

APPENDIX C - CONT'D.

OIL SPILL MODEL CHARACTERISTICS	(10) ST. LAWRENCE RIVER	(11) USCG	(12) USGS Risk Analysis
ADVECTION PARAMETERS: Wind reduction factor Coriolis angle Current contribution Other	 100%	 3.5%, or 2% + leeway 100%	 3.5% 20° 100%
Diffusion (horiz):		for N.Y. Hbr. case	discussion & graphs only
OIL: Spreading Evaporation Dissolution Vertical Diffusion Emulsification Biodegradation	Fay (1971)	Fay (1971)	Discussion only
WIND FIELD: Obs.(O)/Synth(S) #sites(j)/grid(jxk) Comments	 0 1 direction given normal distribution	 0 ? NWS charts	 S 1 Markov
RESIDUAL CURRENTS: #sites(n)/grid(nxm) Comments	 99x99 calc, by 2 D num. model	 ? from NOO or USCG publications	 nxm (2.4 km) from geostrophic & drift cards
WAVES: Obs.(O)/Synth(S) Used for			
Other input data:		river flow from USGS gauges	
RISK ANALYSIS: Shore Fouling Ecological Damage Cost Analysis	 Trajectory endpoints	 Trajectory endpoints	 probabilities probabilities
SOFTWARE: Language	Fortran	Focal	IBM Fortran IV/H
HARDWARE: Computer type Graphics type Machine location	 CDC Cyber 74 Tektronix, Calcomp Ottawa		 IBM 370/155 Reston, VA
OPERATIONAL STATUS: Time for new region Comments	 few hours		Huge software system, 21 programs. Complete analysis takes 4 months

APPENDIX C - CONT'D.

OIL SPILL MODEL CHARACTERISTICS	(13) RAND 3D OIL SPILL		
ADVECTION PARAMETERS: Wind reduction factor Coriolis angle Current contribution Other			
Diffusion (horiz):			
OIL: Spreading Evaporation Dissolution Vertical Diffusion Emulsification Biodegradation			
WIND FIELD: Obs.(O)/Synth(S) #sites(j)/grid(jxk) Comments	 S Transition matrix		
RESIDUAL CURRENTS: #sites(n)/grid(nxm) Comments	 nxm 3-D model, with tides		
WAVES: Obs. (O)/Synth(S) Used for			
Other input data:	ice cover details		
RISK ANALYSIS: Shore Fouling Ecological Damage Cost Analysis			
SOFTWARE: Language			
HARDWARE: Computer type Graphics type Machine location			
OPERATIONAL STATUS: Time for new region Comments			

APPENDIX D

GLOSSARY

Advection:	Horizontal motion in a non-random fashion e.g. currents rather than turbulence.
AES:	Atmospheric Environment Service (of DOE)
AMOP:	Arctic Marine Oilspill Program (of EPS)
APOA:	Arctic Petroleum Operators Association
C-CORE:	Center for Cold Ocean Resources Engineering (Memorial University of Newfoundland)
CMC:	Canadian Meteorological Center
CPSS:	Computerized prediction support system. A set of programs for automated weather prediction, developed by AES.
Deflection angle:	Angle between wind generated surface current and the surface wind direction, due to Coriolis force.
DEMR:	Dept. of Energy, Mines and Resources (Ottawa)
DFO:	Dept. of Fisheries and Oceans (Ottawa)
DINA:	Dept. of Indian and Northern Affairs (Ottawa)
Dissolution:	The passing of oil into true solution in the water column.
DOE:	Dept. of Environment (Ottawa)
Emulsification:	One liquid is intimately dispersed in another in the form of droplets where diameter generally exceeds 10^{-4} mm. When water is in oil the oil is generally described as "chocolate mousse". Oil in water is generally invisible.
EPOA:	East Coast Petroleum Operators Association
EPS:	Environmental Protection Service (of DOE)
Evaporation:	Loss of oil from water surface into the air.
Fay spreading:	Spreading modelled using the algorithm due to Fay (1971).
Fickian Diffusion:	Diffusion that is assumed constant in time. Simple to model but not very realistic, especially for large scales.
Horizontal diffusion:	Spreading of the surface slick horizontally due to turbulence and shear in the water.

APPENDIX D - CONT'D.

IAHR:	International Association for Hydraulic Research
Markov chain:	time sequence created by a Markov process, but based on a finite number of discrete states. The transition probabilities for each state to every other are prescribed. Then, from a given initial state, a time sequence is generated with each point coming from the immediately previous point via the transition probability matrix.
Monte Carlo simulation:	A set of results is generated by having a random component in the system and repeating the calculation many times.
NODC:	National Oceanographic Data Center (USA)
NOO:	Naval Oceanographic Office (USA)
NWS:	National Weather Service (USA)
OSS:	Ocean Science and Surveys (of DFO)
OWS:	Ocean Weather Ship
Persistency:	Tendency of the wind to maintain its speed or direction over several sampling intervals.
Random walk:	At each time step the velocity components are taken from a velocity vector having constant magnitude but random, direction in two dimensions. (A Monte Carlo approach). Useful for modelling Fickian diffusion.
Real-time model:	designed to be used to produce a single trajectory, using observed or predicted winds and currents.
Residual current:	a current component that is neither tidal nor generated by the local wind.
Rig data:	data collected from an oil rig.
RMB:	Resource Management Branch (of DEMR)
SSMO:	Summary of Synoptic Meteorological Observations. A source of statistical offshore wind data.
Scenario model:	designed to be run many times with the same input data, with a random component in the wind signal or some other parameter being varied to generate a set of trajectories so that a statistical envelope can be obtained.
Spreading:	increase in the surface area of an oil patch due to gravity, as opposed to increase due to turbulence in the underlying water.

APPENDIX D - CONT'D.

Synthetic Data: an artificial time series having prescribed statistics.

Trajectory: path of a small particle of oil or the centroid of a large patch.

Vertical Diffusion: turbulent movement of the oil out of the surface slick and into the water column.

Weathering: processes that affect the physical and chemical properties of the oil.

Wind Reduction Factor: wind generated surface current speed ÷ surface wind speed (at 10 m height). Generally taken to be 3.5%. It is the simplest method of connecting surface wind and current, but does not allow for the inertia and friction of the system.

WPM: Water Planning Branch (of Inland Waters Directorate of DOE)

Symbols:

α - proportional to

K - diffusivity

APPENDIX E

DRAFT GUIDELINES FOR

OFFSHORE SURFACE OIL SPILL SCENARIO MODELS

As submitted to the Joint Government-Industry Task Force on Oil Spill Contingency Guidelines by RMB/DEMR.

Introduction

20 December 79

An oil spill trajectory analysis is required in the oil spill contingency planning process. Such an analysis can indicate if shoreline areas are threatened and can indicate the areal extent of threat to offshore biological resources. The former result is useful for planning for shoreline clean-up activities if required and such questions as the following can be answered:

a) What types of shoreline are threatened?

b) What are possible sites for a control centre for clean-up crews?

c) What logistics and equipment are required?

d) Is sufficient equipment available? Etc.

Information on the offshore areal extent will be required to assess the potential threat to biological resources. A knowledge of this threat can be used to answer the following questions:

a) Is there a time when the potential threat should restrict drilling operations?

b) Is there a time and place when the use of dispersants can be authorized and indeed encouraged?

c) When is the "do nothing" approach the preferred countermeasure tactic? Etc.

APPENDIX E - CONT'D.

In order to obtain meaningful answers to these types of questions an oil spill trajectory analysis must be carried out in an adequate fashion. The analysis needs to be based on the available theory and observations concerning oil spill dynamics and behaviour on the sea surface (sub-surface movement cannot be modelled adequately at this time because of the lack of data). The analysis also must be consistent in its complexity with regard to the quality and accuracy of data input as well as the capability to describe the dynamic forces on the oil spill. This concept suggests simple models which employ simple drift equations for the centre of mass of the spill with little or no computations on spill size or thickness. As well, since most surface current information as well as biological resource information is usually only accurate on the time scale of a month, monthly trajectory analyses are required. These analyses will also be required over all months of anticipated operation as well as the two months that follow. This will cover the situation that may arise with a blowout occurring in the last few days of an operation.

Input Data

(a) Wind Input

Ideally the data that should be used in these analyses is that which has been measured over the grid area for a long period of time. In most offshore areas, however, this information is not available. Four sources of data are generally used as substitutes for wind data; these are as follows: a) long-term measurements at shore-based stations; b) long-term geostrophic wind computations over the grid; c) long-term ocean weather ship data at a distant site; and, d) short-term measurements in the vicinity. All of these sources have their problems; however, since the anticipated drilling operations usually are taking place in a year not too far removed from past measurements, the preferred data set is d). The data from set c) is preferred next provided that the climatological variability at the weather ship is similar to the drilling location and that the data set c) can be massaged in some way to look like data at the drilling location. The data set b) is the next desirable set and is so because in the East Coast offshore area the atmospheric pressure contouring has been of poor quality. Usually the data set a) is the least desirable, because it has been shown that wind speeds offshore are higher than those measured at shore stations, offshore winds have more climatic variability in terms of wind direction (i.e. no local topographic effects) and offshore winds generally have higher persistence in terms of wind direction.

Whichever wind data set is chosen all wind speeds need to be reduced to the 10-metre level. Data is handled in a time series as with an actual series or a simulated time series. Simulated time series based on long-term statistics are preferred but need to ensure the directional and speed persistence normally found in the monthly raw data statistics. The use of mean wind statistics alone is not acceptable.

Markov and Monte Carlo techniques of simulation need to be used with care so that seasonal systematic changes in weather patterns are not distorted.

If variability of winds across the continental shelf is large, some provision for this fact needs to be made. In this case the grid size of the wind grid should be consistent with the knowledge of the spatial variability of winds. This suggests that grid size will vary with location of interest.

(b) <u>Current Input</u>

Mean monthly surface residual currents need to be employed. These currents will be by nature the mean total current minus wind and tidal effects. The values used should also be consistent with seasonal runoff cycles. The pattern of currents across the grid should be internally consistent with no points of convergence or divergence. The grid size of the current grid should also be consistent with the knowledge of the spatial variability of currents.

Model Mechanics

As was mentioned in the introduction the mechanics of the model should be simple and indicative of our knowledge and consistent with the quality of data input. Weathering in the form of evaporation and dispersion needs to be considered. It is suggested that a look-up table be established for the process of evaporation as well as that for dispersion. Entries in the table should be the percentage loss of oil from the sea surface due to the process for each time step. Values chosen from the table will be determined by environmental conditions, i.e. air and sea temperature, wave height, etc. as required. Data in the tables should be consistent with the work of T. Audunson, D.P. Hoult and D. Mackay. A sensitivity analysis will be required for at least one set of simulations.

Scenario model analyses should be provided on a monthly basis. The time series used internally for winds should be sampled at least once per day for offshore locations. Nearshore locations will require a much higher frequency. Proper selection of this frequency will depend on the proximity of the well site to shore. In any event a frequency less than one sample per day is considered unrealistic. Wind-induced sea surface drift generally occurs at an angle of 10° to the right of the wind direction and at a speed of 3.5% of the wind speed. These parameters should be used to simulate the sea surface drift due to the influence of wind. Coriolis deflection angle for wind reduction to surface drift should be 10° and the reduction factor should be 3.5%. Wave drift will be assumed to be incorporated into the wind reduction factor. Some sensitivity analysis needs to be performed for wind and current vectors.

In the case where actual time series are used, trajectories should be generated assuming a blowout could occur on any day within a month. In other words at least 30 tracks should be generated. In the case where simulated time series are used, trajectories should be generated for at least 50 or 60 simulations, preferably more. There should be at least one initialization date per month. The blowout analysis will determine the number of grid squares to be specified as the source.

Data handling and model specifications need to be described in detail and justified.

A pack ice model is required to examine the drift of oil confined within pack ice.

Output Data

(a) General

Two types of output are required, namely a map of all simulated tracks and statistics on the average and maximum oil spill speeds. The map of all tracks needs to indicate three other features: a) the most likely trajectories need to be identified, b) an envelope corresponding to those at which 90% of the carbon molecules up to C_{14} which are believed to be toxic fractions have been removed from the surface slick through weathering processes and c) an envelope outlining the ultimate limit of oil on the sea surface.

(b) Shoreline Impact

If an oil spill track in the analysis described above comes within a grid square containing some coastline, it should be assumed it will eventually come ashore. If shoreline contact is possible, the probability of this happening should be determined from the weather records along with the minimum and average time to shore, the mean, maximum and minimum percentage of oil remaining, and the sequence of weather events for each of these trajectories.

NOTE

Each sensitivity analysis is to be carried out with the model using the average values for all other variables. In other words only one parameter needs to be varied for each analysis.