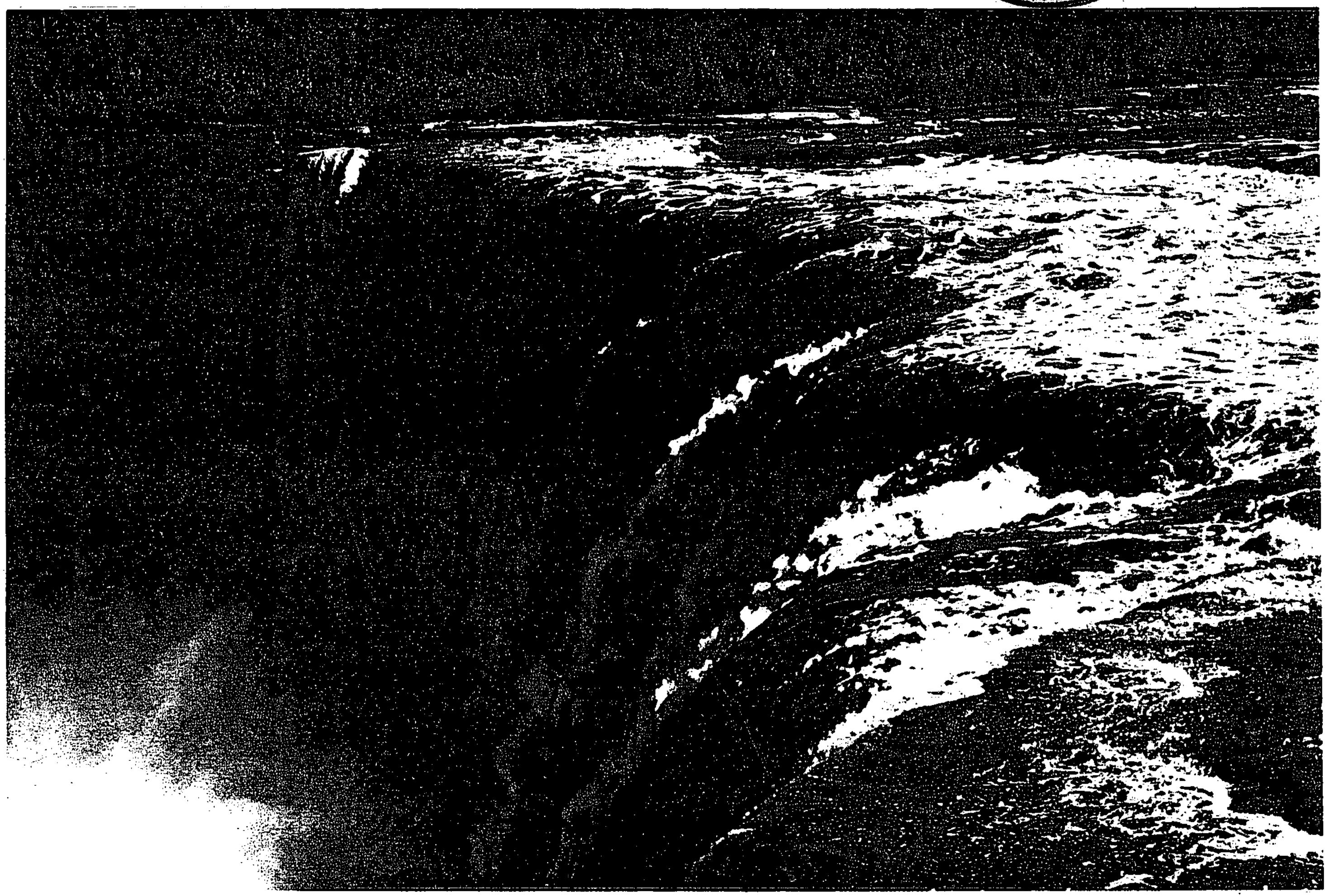
Development of an Oil Spill Model for the St. Lawrence River



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Development of an Oil Spill Mode for the St. Lawrence River

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Abstract

The use of modelling to simulate the behaviour of spilled hydrocarbons under varying natural conditions is improving man's understanding of his environment. This report reviews some of the history of oil spill modelling and discusses many of the factors that must be considered in plotting the behaviour of bunker crude oil on the water surface. The report then goes through the steps taken in developing an oil spill simulation model for the St. Lawrence River.

Résumé

En modélisant le comportement d'une nappe d'hydrocarbures dans diverses conditions naturelles, l'homme apprend à mieux connaître son environnement. Le présent rapport étudie certains modèles élaborés jusqu'ici et traite de maints facteurs qui doivent être considérés pour prévoir l'évolution d'une nappe de pétrole brut à la surface de l'eau. Le rapport décrit ensuite les étapes requises pour élaborer un modèle de déversement dans le Saint-Laurent.

List of Symbols

$A(m^2)$ - area of oil spill in metres squared

Δ - density ratio of oil and water

- $(\rho_w - \rho_o) / \rho_w$

C_t - wind velocity in the x direction at time t.

G,g - acceleration due to gravity, 32.2 ft/sec/sec or 9.8 m/sec/sec

K_B - the Blokker spreading constant for an oil type (min^{-1}) (is about 30,000 for gasoline, 15,000 for a light crude and about 10,000 for lubricating oil)

K_{2i} - coefficient for initial gravity spread

K_{2v} - coefficient for viscous spread

K_{2t} - coefficient for surface tension spread

L - the length of a rectangular slick (cm)

ρ_w - the oil density (gm/cm^3)

ρ_o - the water density (gm/cm^3)

r_i - radius of spill during initial gravity spread

r_v - radius of spill during viscous spread

r_t - radius of spill during surface tension spread

R_{iv} - theoretical radius of spill at gravity to viscous spread

R_{vs} - theoretical radius of spill at viscous to surface tension

R_f - final stable radius of spill

SG_o - the specific gravity of oil

SG_w - the specific gravity of water

t - time during spreading process (min)

T_{iv} - theoretical time when spill changes from gravity to viscous spreading

T_{vs} - theoretical time when spill changes from viscous to surface tension spread

T_f - final time required to reach stable conditions

V - the volume of the spill (cm^3) (usually initial or at time of consideration)

W - the width of a rectangular slick (cm) restricted to W the width of a narrow channel

W_t - water velocity in the x direction at time t

X_t - vectorial velocity on an oil slick in the x direction at time t

ν - kinematic viscosity of water

ρ - oil density

δ - spreading coefficient

π - constant pi

Q_t - the diameter of the slick at time t (cm)

1. INTRODUCTION

Oil spill modelling has been carried out by a large number of investigators in recent years (1, 4-11). This activity can be explained by the increasing concern over the numbers and impacts of oil spills on the marine and coastal environments. In addition, the modelling activity has been made possible by the availability of data on the behaviour of oil on water - data that was almost unavailable 10 years ago. It is now possible to choose from a large number of approaches to the mathematical modelling of oil on water.

The models that have been developed are usually designed to fulfill certain needs. One of these needs is to provide predictive capability, that is, to be able to predict the movement of oil in the environment, to determine the possible impacts of the oil, to design countermeasure systems, activities and priorities in the event of a spill, or to assess the best location for facilities such as tanker ports. In more recent years it has also become possible to perform real-time modelling, that is, to run a spill model during a spill both to predict the movement for some time in advance as well as to confirm immediate positions of the slick.

At the present time, there is a large amount of concern within the scientific community regarding the applicability of certain models, their validity, etc. The authors of this paper have reviewed many of these arguments and counter arguments and believe that many of the problems are due simply to the fact that many models are designed for specific situations and needs. It is felt that the best model is one which predicts realistically but which is best suited to the end user's needs and situations.

2. THE FACETS AND PROBLEMS OF SPILL MODELLING

Anyone undertaking the design of an oil spill model is immediately confronted with a number of basic problems:

a. Needs of the end user.
b. The geographic situation in which the model will be used.
c. The level of input data which is available.
d. The level of accuracy required by the end user.
e. The number and kind of output parameters required by the end user.
f. The manner in which the end user will, or intends to, employ the model.

The failure to gear oil spill models to the situation and the end-users needs, it is believed, has led to a mistrust of the oil spill modelling process in general. Much of the discussion on spill modelling has been more a comparison of situations than a comparison of the benefits of one approach versus another. It is important to review some of the issues that often are overlooked at the design stage of the model.

2.1 Micro Versus Macro Modelling

Most spill models can be divided into one or two categories - "micro" and "macro".

Micro models are those applicable to areas of small geographic coverage, e.g., a harbour, a bay or a river. These models are characterized by the relatively large amounts of high-accuracy input data. The predictive ability of the model usually is required to encompass several miles or several hours at the greatest extent. Correspondingly, the level of accuracy demanded is usually high. Macro models are those which cover large areas - e.g. the entire coastal waters of a country. Typically these models are designed to operate with significantly less input data than the micro class of models to derive wind and current influences on a slick. The prediction accuracy required of macro models is typically far less than required for a micro model. Comparison of the fine details of micro and macro models will usually not be a fruitful exercise - simply because of the large differences between the two models. Presumably the physical factors that influence oil spills are the same in both situations; however, the procedure whereby current and wind data are derived for input to the model, the treatment of the data, and the resulting precision of the models, are often quite different.

2.2 Real-Time Versus Scenario Models

Some discussion has taken place as to whether or not models should be real-time or scenario models. It would appear that the only differences between the two would be computer hardware and software availability, user preference or need and the level of data availability. Presumably a model of either type would be identical for the same region or situation.

2.3 Levels of Input

Considerable discussion has taken place in the past few years on the level of current and wind information that is required for a model. The question, perhaps, should not be what is the minimum but what data are available and accessible. It would appear that a spill modeller would always have less data than he really would like and thus usually "makes do" with those data that are available. Perhaps the problem is really whether or not there are enough data to make modelling worthwhile in a particular instance. Situations of this sort probably exist in certain regions of the arctic where wind and current data are simply not available and, model or no model, the trajectory of an oil slick is anyone's guess.

2.4 Levels of Inclusion

In the past few years, a large number of proponents have claimed that a spill model is not a model at all unless it includes provision for oil behaviour such as evaporation, dissolution, sedimentation, dispersion, etc. The merits of these inclusions cannot be disputed. However, if the end user only requires trajectories over a short distance or short period of time, the inclusion of these "extra" features will probably not benefit him to any great extent while increasing the cost and difficulty of both creating and using the model.

In many cases, the only information that is desired from a spill model is simply, given a spill of x size and these environmental conditions, where will it go and approximately how long will it take to get there.

The inclusion of factors such as evaporation become important in macro models where there is sufficient time between a given spill origin and destination to appreciably alter the results, for example, if 50% of the product evaporates in the considered time span.

2.5 Testing of the Model

The most serious shortcoming of most of the modelling exercises to date has been the lack of testing. One review of the spill modelling[1] revealed that only a very few of the many models were ever tested on real spills. Furthermore, most of those tested used spills that had occurred long periods of time before the models were developed. The validity of this type of "hind-casting" has to be questioned because many of the spills examined were not well-documented.

The authors contend that the most important property of any model is its ability to predict actual situations. Testing the model should then be part of the model design process. Perhaps there are two reasons why this has not been so in the past: lack of communication between operators and the scientific community and the lack of tools to test models using other than real spills. The latter is no longer a real problem since "spill cards" and "spill tracking buoys" are now available[2].

2.6 Physical Description Versus Correlation

Modelling has proceeded from two different approaches: one using basic physical descriptions to develop mathematical descriptions of the behaviour of the environment (theoretical) and the other by correlating observations of the behaviour of oil in the environment with factors such as wind and current (empirical). Many of the models currently used have components of both approaches. It is felt that the important issue is whether a model can really predict oil spill behaviour. Furthermore, the complexity of the situation does not allow one to derive a complete oil spill model from fundamental principles at the present time.

3. THE BASICS OF SPILL BEHAVIOUR IN THE ENVIRONMENT

In this section the basic problems of oil spill behaviour in the environment will be examined. The assumption will be made that one can uncouple the forces acting on spilt oil, describe them and then proceed again to put some of these points together to form a concept of oil behaviour in the environment. Figure 1 illustrates some of the behaviour patterns of oil in the environment.

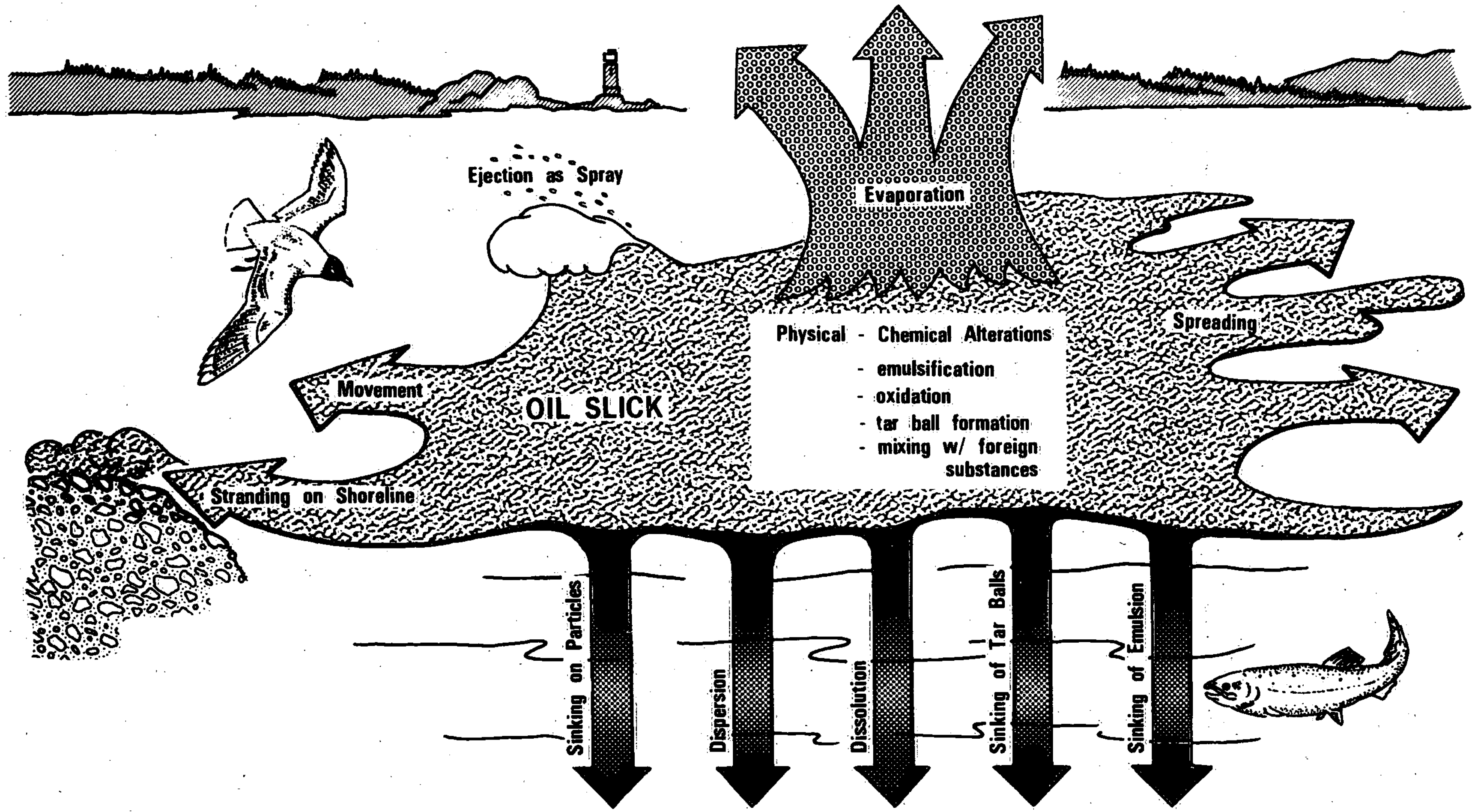


Figure 1. Diagrammatic summary of the changes occurring to oil in the marine environment.

3.1 Spreading

When oil reaches a water surface it rapidly spreads to form a slick only millimetres thick. This rate of spreading is very much related to the properties of oil as well as to the temperature of the water surface. Several models have been proposed to describe spreading as will be discussed later.

3.2 Movement with Surface Current

Intuitively an oil slick should move at the full rate of the water on which it is resting. This surface current is, however, very difficult to measure, since the very top layer, for example, 1 cm, is not a depth that can be measured with the typical current meter. Nevertheless, cards, etc. have been used to measure this velocity.

The situation is more typically that of using existing velocity measurements for the full depth and relating these to the surface movement. The factor of .56 has often been used in river and estuary situations although there are many proposed vertical velocity distributions[1].

3.3 Effect of Wind

Several investigators have reported correlation between wind velocity and movement of an oil slick[1]. The reported values vary between 2 and 5%, the mode and average of these generally being considered to be 3% of wind velocity. In addition to the velocity vector there is also the "Coriolis force", the deflection caused by the earth's rotation. In the northern hemisphere this phenomenon deflects oil to the right. Many of the same investigators, as noted above, have also attempted to include the deflection angle. The results vary from 0.3° to the left to 13.2° to the right (in the northern hemisphere). The results of these have high standard deviations and thus a simple rule for Coriolis deflection does not appear to be available.

The information as presented above allows us to present a simplified model or scheme to prescribe the movement of oil on water (Figure 2). Indeed this information is all that is used in many simplified models.

3.4 Effect of Tides

The modelling of oil spill movement in tidal areas is much more complex than in non-tidal areas. The effect of tide in many areas is to move the entire system back and forth with the tidal cycle. In addition to the oscillatory behaviour, tidal waters often have peculiar boundary layers, and temperature and velocity profiles. Some spill models have attempted to take these factors into consideration but much work has yet to be done[1].

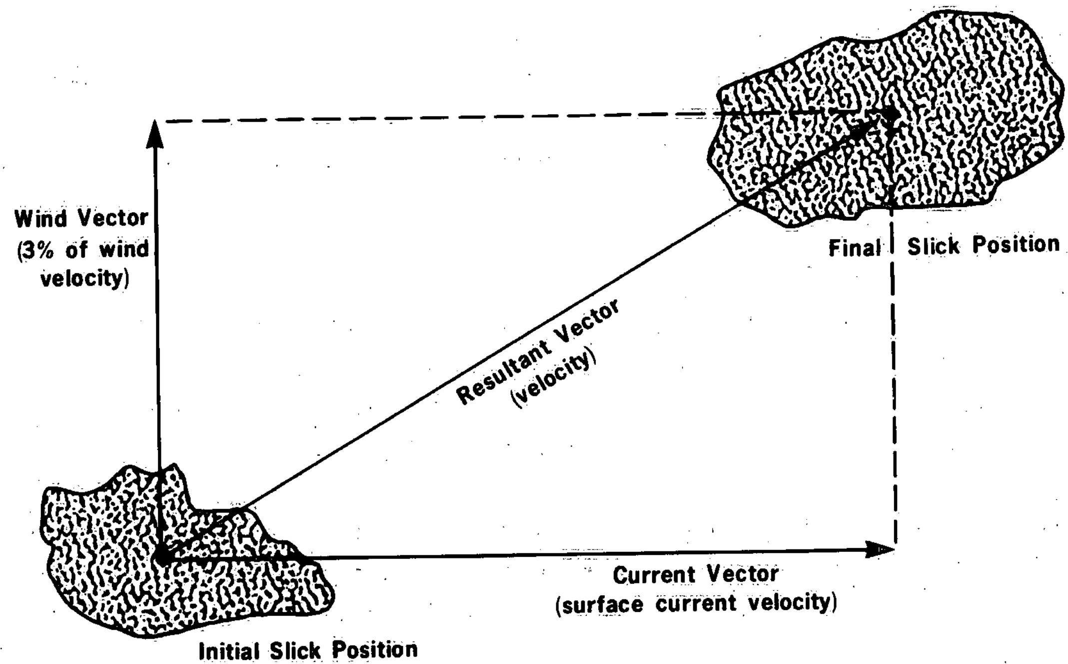


Figure 2. Diagrammatic representation of oil slick transport modelling.

3.5 Effect of Waves

Several investigators have noticed that the presence or absence of waves affects the movement of oil on water. To date there is no adequate mathematical model to describe this effect[1].

3.6 Effect of Water-in-Oil Emulsions

Many of the models that have been developed take into account the density and viscosity of oil, factors which have been shown to affect the spreading and movement of oil. One effect that sometimes becomes important is the formation of water-in-oil emulsions - these emulsions commonly referred to as "chocolate mousse" have a density close to water (i.e., heavier than oil) and a much greater viscosity than oil alone. If oil forms an emulsion in a spill situation, its spreading rate is greatly reduced and the thickness of the slick (actually the formation of lumps or areas of emulsion) changes. No model that is known to the authors incorporates this factor and the process itself is poorly understood. The problem is a complex one: some oils form emulsions, other do not. A large amount of work has to be performed on the process itself before the behaviour can be incorporated into a spill model.

3.7 Losses of Oil

Several models now incorporate the loss of oil by evaporation, dissolution, retention on shorelines, sedimentation, sinking, etc. Evaporation has usually been considered to account for the greatest loss of product. Cormack and Nicols[3] reported losses of up to 21% in the first 7½ hours when conducting an experimental spill using light crude oil in the North Sea. Several models now incorporate evaporation[1,4]. Loss of petroleum product through dissolution into the water column has proven to be a more difficult behaviour to model; however, several investigators have modelled this facet of oil spill behaviour and some have even included the modelling of distribution of hydrocarbons in the water column[1,4]. The loss of petroleum product by retention on shoreline also has been modelled[1]. This task has proved to be fairly straightforward with those models that incorporate boundary conditions (shoreline, shallows). The problem has been that many models do not incorporate boundary conditions with the result that the model not only lacks realism but also cannot take into account landfall conditions.

Sedimentation of oil on particles can result in considerable loss of oil. In a recent film "Black Tide", on the AMOCO CADIZ spill, the estimate of over 25% loss to sedimentation processes was presented. Little work on including this process in spill models has been done to date[1].

3.8 Variation in Parameters

There may be considerable variation in parameters over even short periods of time. Winds, for example, frequently display a direction origin and velocity distribution similar to a Poisson distribution. Similarly, the variance in other parameters has been studied and has been incorporated in spill models[1].

4. COMMON MODELS

In the following section a review of the more common models is presented. The review is descriptive rather than critical. Those readers wishing a critical review are referred to reference 1. Other reviews of models have been written for those who wish to compare models more extensively (1, 5-9).

4.1 Spreading Models

4.1.1 Blokker's Model

Blokker[12, 13] developed empirical relationships for the spreading of various types of oil on water. These relationships are based on the assumption that the rate of spreading decreases exponentially with reduction in slick thickness.

Circular Oil Slick

$$Q_t^3 - Q_o^3 = \frac{24}{\pi} K_B \, (SG_w - SG_o) \, \frac{SG_o}{SG_w} \, V_t \qquad \text{(i)}$$

Rectangular Oil Slick

$$L_t^2 - L_o^2 = 4 \, K_B \, (SG_w - SG_o) \, \frac{SG_o}{SG_w} \, \frac{V_t}{W} \qquad \text{(ii)}$$

where:

Q_t = the diameter of the slick at time t (cm)

K_B = the Blokker constant (min^{-1})

(is about 30 000 for gasoline, about 15 000 for a light crude and about 10 000 for lubricating oil)

t = the time during the spreading process (min)

V = the volume of the spill (cm^3)

(usually initial or at time of consideration)

SG_o = the specific gravity of oil

SG_w = the specific gravity of water

L = the length of a rectangular slick (cm)

W = the width of a rectangular slick (cm)

(presuming it is in a narrow channel and fairly constant)

The Blokker model was tested on a few occasions with generally inconclusive results. Jeffery[14] performed a study of a spill of light Iranian crude oil in the North Atlantic. During a 4-day period, the spill was monitored and the Blokker constant found to vary over a factor of 3.

4.1.2 Fay's Model

Fay[15,16] developed a spreading model based on the premise that the gradual spreading of an oil mass on calm water is caused by the combined effects of the potential energy of the oil mass (due to gravity) and the difference in surface tension of the oil and water. The spreading process is modelled as consisting of three phases depending on the dominant force in that phase:

a) inertial spread - gravity is the predominant force

b) viscous spread - the potential energy (due to gravity) is dissipated in overcoming viscous forces

c) surface tension spread - surface tension is the dominant force and causes further spreading of the oil.

Both one-dimensional and axisymmetric equations were developed by Fay. Fay's spreading model has been used extensively in spill models and also has been tested in simulated and real situations with generally favorable results[1]. This model is further described in a later section.

A number of other spreading models were developed, many of these being variations on Blokker's and Fay's models. The majority of these models are not used to any great extent nor have they been tested[1].

4.2 Transport Models

The difference in most models lies in the transport portion of the spill model. The variances arise from differing concepts of the surface transport of oil slicks as well as being artifacts of the data available to the modellers, that is, many modellers develop a transport model on the basis of the input data available to them. Transport models are reviewed below in terms of the general types which have been developed.

4.2.1 Basic Uncoupled Model

Most of the models that have been developed employ the basic concepts of vector addition of the wind, current, and spreading forces as illustrated in Figure 2. Many of these models have been used by Schwartzberg(17,18), Wang(19), Cole(20), Bien(17) and others(6), where:

$$\vec{X}_t = \underset{a}{.03}\,\vec{W}_t + \underset{b}{.56}\,\vec{C}_t$$

a - As noted in Section 3 of this report, the wind coupling factor has been found to vary but 3% of wind velocity is generally used as an average value. Many investigators have adjusted their values to suit their own area of coverage. This is quite reasonable, since in sheltered areas, such as on a river, winds are not measured near the surface and thus a smaller value for this factor is appropriate.

b - The factor of .56 as used here is typically the factor used by many investigators when using currents of depths 5 m or greater(1). Again many investigators have adjusted this factor to suit their own particular needs.

The use of this simplistic model for the transport-portion of spill modelling is widespread. In addition to the simplicity of the model, there are advantages in that the wind and current parameters can be quickly adjusted to suit actual field observations and experimental data.

4.2.2 Probabilistic Models

Presuming that the movement of oil is partly random process, usually dependent on its position, a number of investigators have employed probabilistic transport models, some of which include spreading phases(1,21,24). These models typically use stochastic processes such as time series, random walk and Markov chain models. Many of these models have not been tested with actual or experimental spills. As a class of models, they suffer from several disadvantages: lack of identifiable correspondence to physical processes, difficulty in calibration and lengthy computation time requirements.

5. DEVELOPING THE ST. LAWRENCE RIVER SPILL MODEL

5.1 Simulating Flow Distribution in the St. Lawrence River

A prerequisite of the oil spill model for the St. Lawrence River was a comprehensive flow distribution analysis of the river. This was largely available as a result of an undertaking of a joint federal-provincial study group from 1974 to 1978 which was studying flow distribution in a series of reaches on the river. The model used to generate the currents was a two-dimensional hydrodynamic simulation model developed by Rand Corporation[25]. After being modified to meet study needs, the model effectively generated a velocity vector field on a grid varying in size from 110 to 1760 metres. The velocity field can best be described by Figure 3.

The hydrodynamic model required as basic input: water depths at the intersecting grid points, water surface elevations and discharges at open boundaries, and field measurements for calibration purposes[26,27,28]. After the calibration stage of the individual river reaches, the resultant velocity vector fields were used as part of the data input to the oil spill model. The velocity field effectively reduced the degree of uncertainty in the oil spill simulations by providing a forcing function when wind forces were negligible.

One of the important features of incorporating the water velocities as oil spill modelling input was the fact that the Coriolis effect is taken into account in the hydrodynamics. This factor reduces greatly the angle adjustments used by various models to handle this effect.

5.2 The Oil Spill Simulation Model

The basic governing equations, from which this oil simulation model has evolved, are those developed by James A. Fay[15,16] under laboratory conditions for which theoretical constants play a major role. Refinements to these equations and constants are made only where actual spills and their properties are available for a more comprehensive analysis.

As described in his research, Fay has established equations for three types of motions that consecutively act on the oil until a final stabilized slick size is reached. These forces are gravity, viscous spread, and surface tension.

5.3 Theoretical Considerations of the Fay Model

The initial force of gravity, acting upon the spill, is a vertical force, which becomes translated into a horizontal force by the very nature of oil itself. The floating oil film creates an unbalanced motion on the surrounding water surface as it thins outwardly until a point is reached when the film thickness, its gradient, and the difference in density between oil and water diminishes substantially. At this stage, the oil film is still thick but the force of gravity has greatly decreased. The radius of two-dimensional spread is

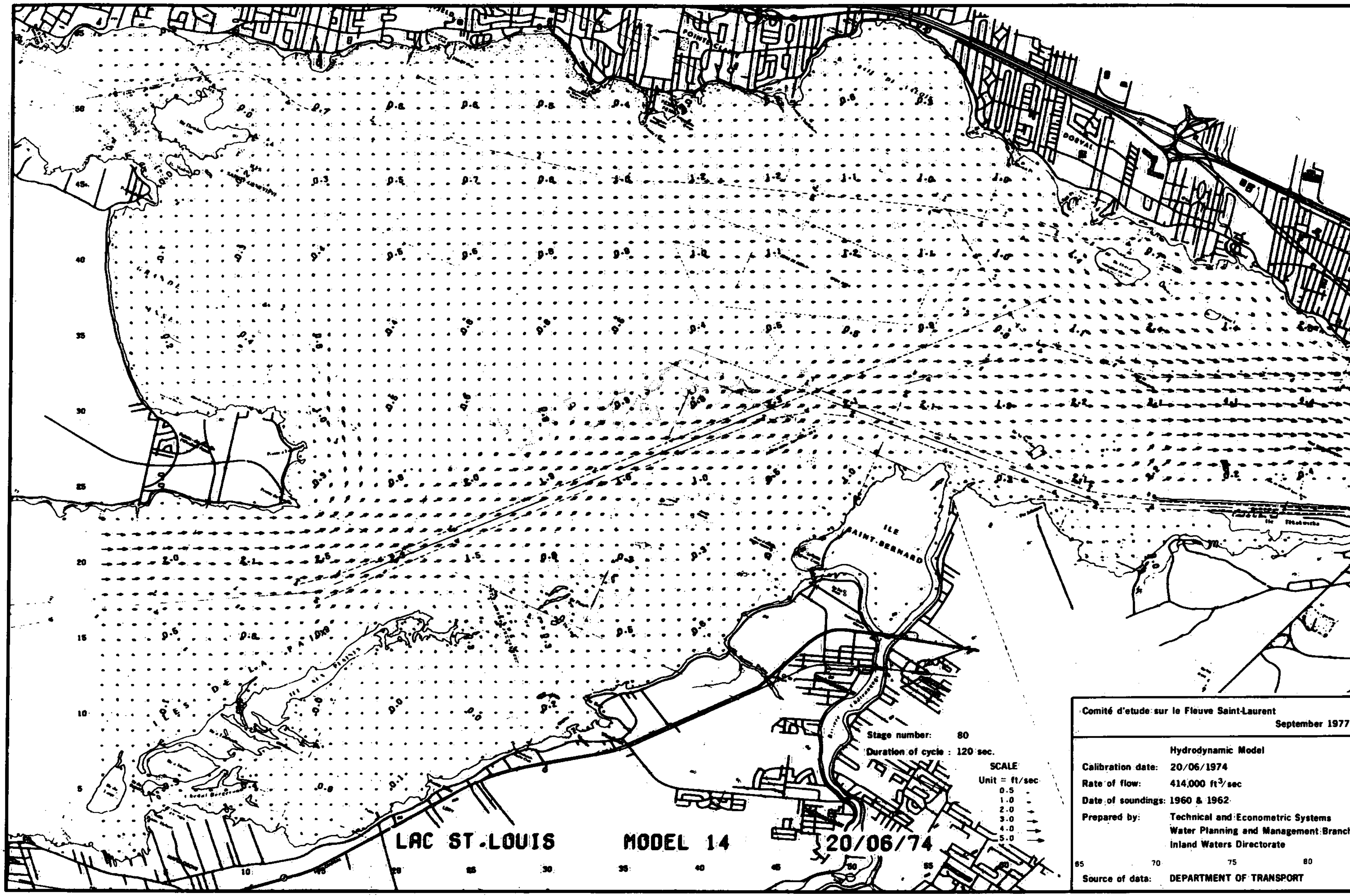


Figure 3. Velocity vector field for the St. Lawrence River at Lac St. Louis - June 20, 1974.

given by the following formula:

$$r_i = K_{2i} \ (\Delta \cdot G \cdot V \cdot t^2)^{\frac{1}{4}} \quad (1)$$

The second phase of oil slick growth is caused by the imbalanced forces that exist between the water-air interface and the sum of the surface tensions at the oil-air and oil-water interfaces. The net difference is a force that causes the leading edge of the oil to move outwards. This force is also a function of the film thickness, and has been appropriately named a viscous spreading force.

The resulting equation was found to be:

$$r_v = K_{2v}(\Delta \cdot G \cdot V^2 \cdot t^{3/2} / \nu^{1/2})^{1/6} \quad (2)$$

The final stage is characterized by the fact that the oil eventually reduces to molecular thickness and that the energy available is dissipated by heat. Also the surface and potential energies are reduced to a negligible value causing a further increase in oil slick size.

The resulting layer of oil is assumed to be of molecular thickness as the oil slick is assumed stabilized. The equation governing this phase of the spill is given as:

$$r_t = K_{2t}(\sigma^2 t^3 / \rho^2 \nu)^{1/4} \quad (3)$$

The final area of the circular spill, as estimated by laboratory studies and related to field observations, is represented by the following equation:

$$A(m^2) = 10^5 [V(m^3)]^{3/4} \quad (4)$$

The next step was to determine the times at which each phase transition was assumed to occur. This was done by equating equations (1) and (2), and solving for t as the unknown. The same procedure was carried out for equations (2) and (3), and finally equations (3) and (4). The following equations resulted:

- gravity to viscous tension phase:

$$T_{iv} = \left(\frac{K_{2v}}{K_{2i}}\right)^4 \cdot \left(\frac{V}{\Delta \cdot g \cdot \nu}\right)^{1/3} \quad (5)$$

$$R_{iv} = \left(\frac{K_{2v}}{K_{2i}}\right)^2 \cdot \left(\frac{\Delta \cdot g \cdot V^5}{\nu^2}\right)^{1/12} \quad (6)$$

- viscous tension to surface tension phase:

$$T_{vs} = \left(\frac{K_{2v}}{K_{2t}}\right)^2 \cdot (\Delta \cdot g \cdot \nu)^{1/3} \cdot \left(\frac{\rho}{\sigma}\right) \cdot V^{2/3} \quad (7)$$

$$R_{vs} = \left(\frac{K_{2v}^{3/2}}{K_{2t}^{1/2}}\right) \cdot \left(\rho \cdot \frac{\Delta \cdot g \cdot V^2}{\sigma}\right)^{1/4} \quad (8)$$

- surface tension to final stable phase:

$$T_f = \left(\frac{R_f^4 . \rho^2 . \nu}{\sigma^2 \; K_{2t}^4}\right)^{1/3} \quad (9)$$

$$R_f = \left(\frac{10^5 . V^{3/4}}{\pi}\right)^{1/2} \quad (10)$$

By solving the above equations and using the empirical coefficients derived, it is possible to construct a graph which relates the extent of the spill to quantity of oil spilled. In Table 1, the radii for progressively larger spills are shown after an interval of one minute and then for longer durations using the corresponding coefficients suggested by Fay.

TABLE 1

GRAPHICAL SUMMARY SHEET

Size of Spill (Barrels -.Petroleum, U.S.)

Radii in yards - Time in minutes

Size of Spill (barrels)	1	10	10^2	10^3	10^4	10^5
Radius of slick after 1 min.	6.7	11.9	21.2	37.8	67.1	119.4
Duration of spill T_{iv}	1.2	2.5	5.4	11.7	25.2	54.4
Radius after T_{iv}	7.2	18.9	49.5	129.3	337.4	880.5
Duration of spill T_{vs}	3.	12.	54.	250.	1163.	5397.
Radius after T_{vs}	8.8	27.8	87.9	277.9	878.7	2778.9
Duration of spill T_f	62.	197.	622.	1967.	6220.	19668.
Radius after T_f	97.8	232.2	550.5	1305.6	3095.9	7341.6
In above K_{2i} = 1.14 K_{2v} = 1.45 K_{2t} = 5.7						
Duration of spill T_{vs}	15.	71.	331.	1538.	7140.	33145.
Radius after T_{vs}	13.8	43.7	138.3	437.4	1383.4	4374.7
Duration of spill T_f	209.	660.	2086.	6597.	20859.	65953.
Radius after T_f	97.9	232.2	550.5	1305.6	3095.9	7341.6
In above K_{2i} = 1.14 K_{2v} = 1.45 K_{2t} = 2.30						

A graphical representation has been included to simplify the above and is shown in Figure 4.

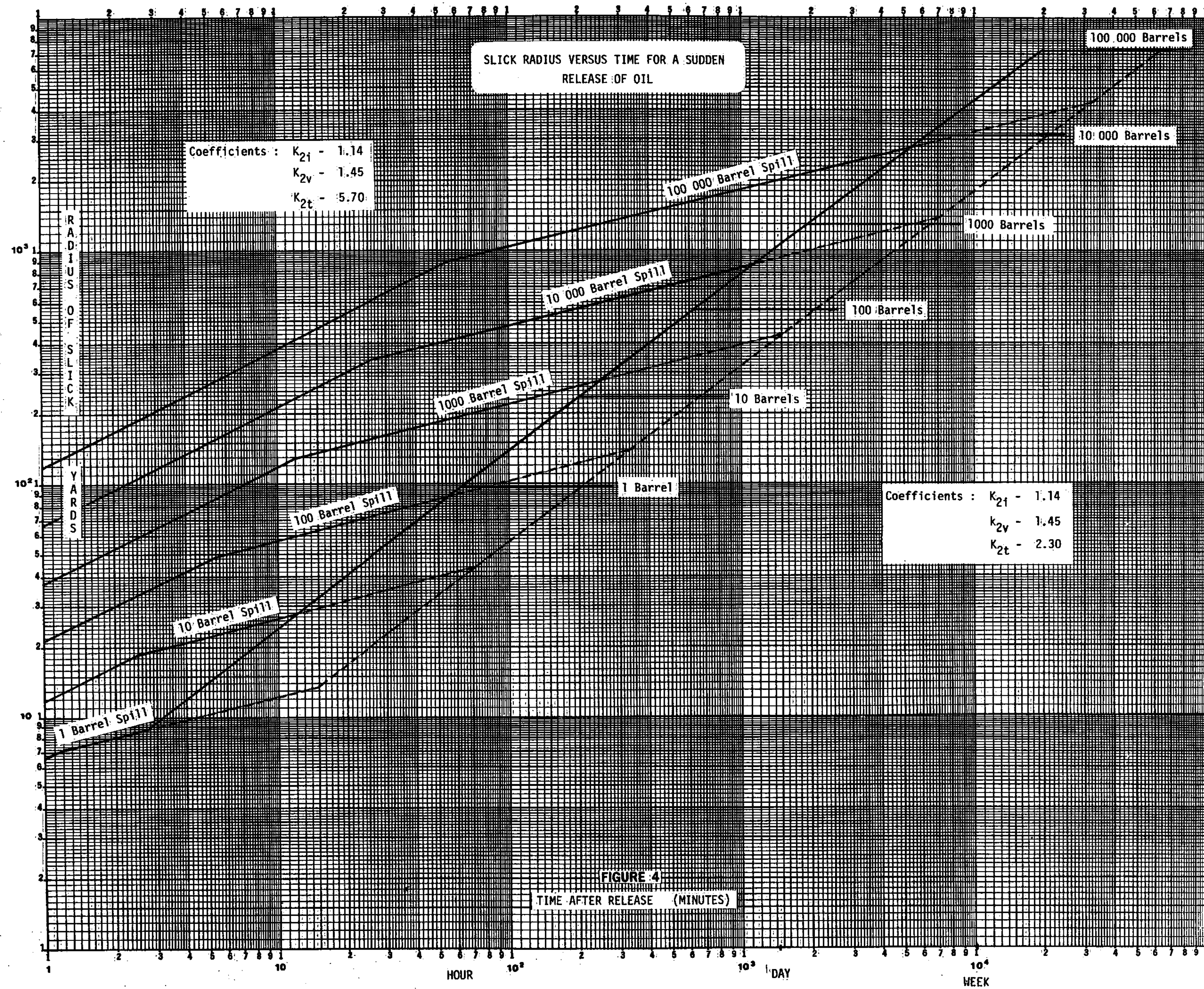


Figure 4. Slick radius versus time for a sudden release of oil.

The next step was to determine the rate of movement outwards from the centre of the continuous spill. Differentiating the radius with respect to time yields a rate of change or the outward velocity of the oil's leading edge during a spill. The resulting equations are as follows:

- where $\frac{dv}{dt}$ = rate of change of oil; $\frac{dr}{dt}$ = velocity of leading edge

$$\frac{dr_i}{dt} = K_{2i} \ (\Delta \cdot g \cdot)^{1/4} \cdot \left(\frac{V^{1/4}}{2t^{1/2}} + \frac{t^{1/2}}{4V^{3/4}} \cdot \frac{dv}{dt}\right) \quad (11)$$

$$\frac{dr_v}{dt} = K_{2v} \left(\frac{\Delta \cdot g}{\nu^{1/2}}\right)^{1/6} \cdot \left(\frac{V^{1/3}}{4t^{3/4}} + 1/3 \cdot \frac{t^{1/4}}{V^{2/3}} \cdot \frac{dV}{dt}\right) \quad (12)$$

$$\frac{dr_t}{dt} = K_{2t} \left(\frac{\sigma^2}{\rho^2 \nu}\right)^{1/4} \cdot \frac{3}{4t^{1/4}} \quad (13)$$

Once the rate of spill with respect to time can be estimated, the velocity of oil at the leading edge of the spill can also be estimated.

It can also be seen that simple manipulation of these formulas can be used to reflect spills occurring from or confined by rigid boundaries such as shorelines and wharves.

If, for example, a spill occurs from a wharf, one-half the circle would be eliminated from the spill site, and the same volume of oil would occupy one-half the area. By a simple relationship the volume can be divided by the reduction in the circular area to reflect the effect of this condition.

The following simple relationship would be applied:

$$V \alpha V / (100\text{-\% area reduced}) \quad (14)$$

5.4 <u>How does the Model Deal with Oil Spill Volume?</u>

The oil in the model is represented by a number of individual particles. Each particle represents a certain quantity of oil spilled. The maximum number of particles is presently set at one thousand. This means a 100 000 barrel spill will give each particle a value of 100 barrels.

The additional feature of assigning each particle a given volume is to be able to determine the volume of the spill at any particular moment. The size of each particle computed by the model is used as a guide in determining the minimum distance the oil can go before coming into contact with the river shoreline or any other obstruction in the water course.

The quantity of oil represented by each particle is maintained throughout the simulation. This quantity is reduced by loss to the shoreline, or by becoming trapped in small bays or channels. The oil particles can lose a certain amount due to evaporation, aging and other factors, but these are not presently considered in the model.

The model uses each particle in the system, if it still represents a quantity of oil, to compute the centre of gravity (C of G) of the entire spill. After each time step, each particle is assigned a direction outward from the centre of gravity. At the same time, the velocity of the particles outward from the centre is computed. Furthermore, a non-stationary grid is superimposed on the spill with a smaller grid size. The model computes the number of oil particles in each grid in order to determine if the oil can move in its designated direction.

Under normal conditions, an oil particle cannot move into a gridsquare containing a larger quantity of oil than that found in the gridsquare from which the particle is to move. In other words, the forces acting on the oil particle can be counteracted by existing oil already occupying a specific area. This reduces the chance of oil moving in a direction that would reduce the size of spill unless driven by even greater forces such as wind or water currents.

5.5 Effects of Existing Shorelines or Boundaries

The shorelines are capable of absorbing oil at some predetermined volume per unit length. The manner in which this is done is to consider the shoreline as a continuous "picket fence" where each picket coming into contact with an oil particle can retain a pre-set quantity of oil.

The initial step in this approach is to first digitize the actual shoreline, retaining the land-water coordinates in a data file. This file is subsequently transformed into another file containing the boundary information for any given square. All points are examined with intermediate coordinates inserted between digitized coordinates at given, regular intervals. These 'intermediate' coordinates are normally less than 30.5 metres apart. The oil spill particles, each assigned a radius (with a predetermined minimum), at time 't', cannot pass through this picket fence.

In this manner, an oil particle which enters a square containing a land-water boundary is checked for the following:

1. Is the oil particle radius in contact with a picket?
2. Can the oil contained in the particle be fully absorbed by the shoreline (and therefore removed from the system)?

If the shoreline has absorbed all the oil it can, the particle is forced to remain where it is until other conditions force it away from the boundary.

Under such conditions as described above, a more realistic approach can be taken to resolve complex shoreline problems.

5.6 Random Effects used in the Model

Random effects were incorporated in the model in the wind and water velocity routines. This was carried out in a specific way on the basis of general expected errors in measured field data.

In the wind subroutine, the wind components were computed by taking the wind direction and allowing it to vary in such a way that the frequency distribution of the particle's direction forms a natural distribution curve. The properties of this curve restrict the movement to plus or minus one radian variation, and a probability of only 18% to fall outside the limits of one-half radian.

The water velocity vectors are each allowed to randomly vary by a maximum of plus or minus 10% in the same manner as described above. The chance to exceed the range of plus or minus 5% is an 18% probability. This range is assumed within the error normally accepted by those responsible for actual field measurements.

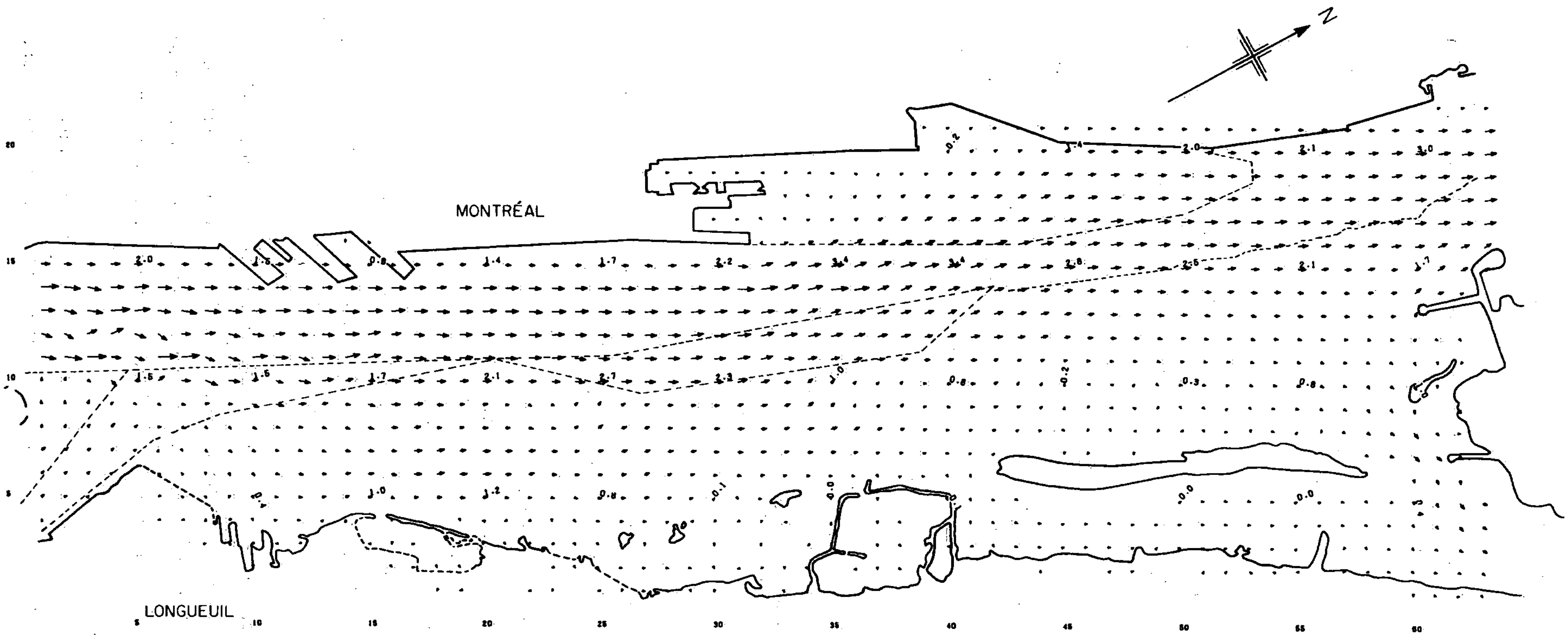
5.7 An Oil Spill Simulation in the Port of Montreal

In this simulation, an oil spill was assumed to have occurred from a ship just off the wharf in Montreal-East about 220 metres from the northern shoreline. The type of oil was Bunker C and the volume was 2860 barrels, with a constant spill rate over one-half hour. The spill was considered to have occurred during a calm day when no wind was recorded at the spill site. As such, the forces acting were only those of oil spread and water velocity.

The hydrodynamics were computed for a river discharge of 6655 m^3/sec and the date that the model was calibrated for was October 21, 1964. The velocities in the channel ranged from 0 to 0.3 m/sec along the south shore, and from 0.67 to 1.2 m/sec in the shipping channel. The graphical representation of the given flow are shown in Figure 5.

From the simulations, (Figures 6 to 9, output every 15 minutes) it can be seen that oil hits the northern shoreline shortly after one-half hour, and spreading continues with the assistance of the currents. It can also be seen that lower velocities in the northern area away from the main shipping channel tend to cause a "fan" effect of the oil in that area.

From these simulations, it is possible to estimate the time of travel, the areas most probably damaged, and the time necessary to react to rapidly moving spills along the river.



ÎLE STE. HELENE - ÎLES BOUCHERVILLE M-18

Stage number: 70

Duration of cycle : 120 sec.

SCALE

Unit = ft/sec

0.5
1.0
2.0
3.0
4.0
5.0
6.0

Comité d'etude sur le Fleuve Saint-Laurent	September 1977
	Hydrodynamic Model
Calibration date:	20/06/1974
Rate of flow:	414,000 ft^3/sec
Date of soundings:	1960 & 1962
Prepared by:	Technical and Econometric Systems Water Planning and Management Branch Inland Waters Directorate.
Source of data:	DEPARTMENT OF TRANSPORT

DATE RUN SEP. 01/77

Figure 5. Graphical representation of velocities in the St. Lawrence River at the Port of Montreal.

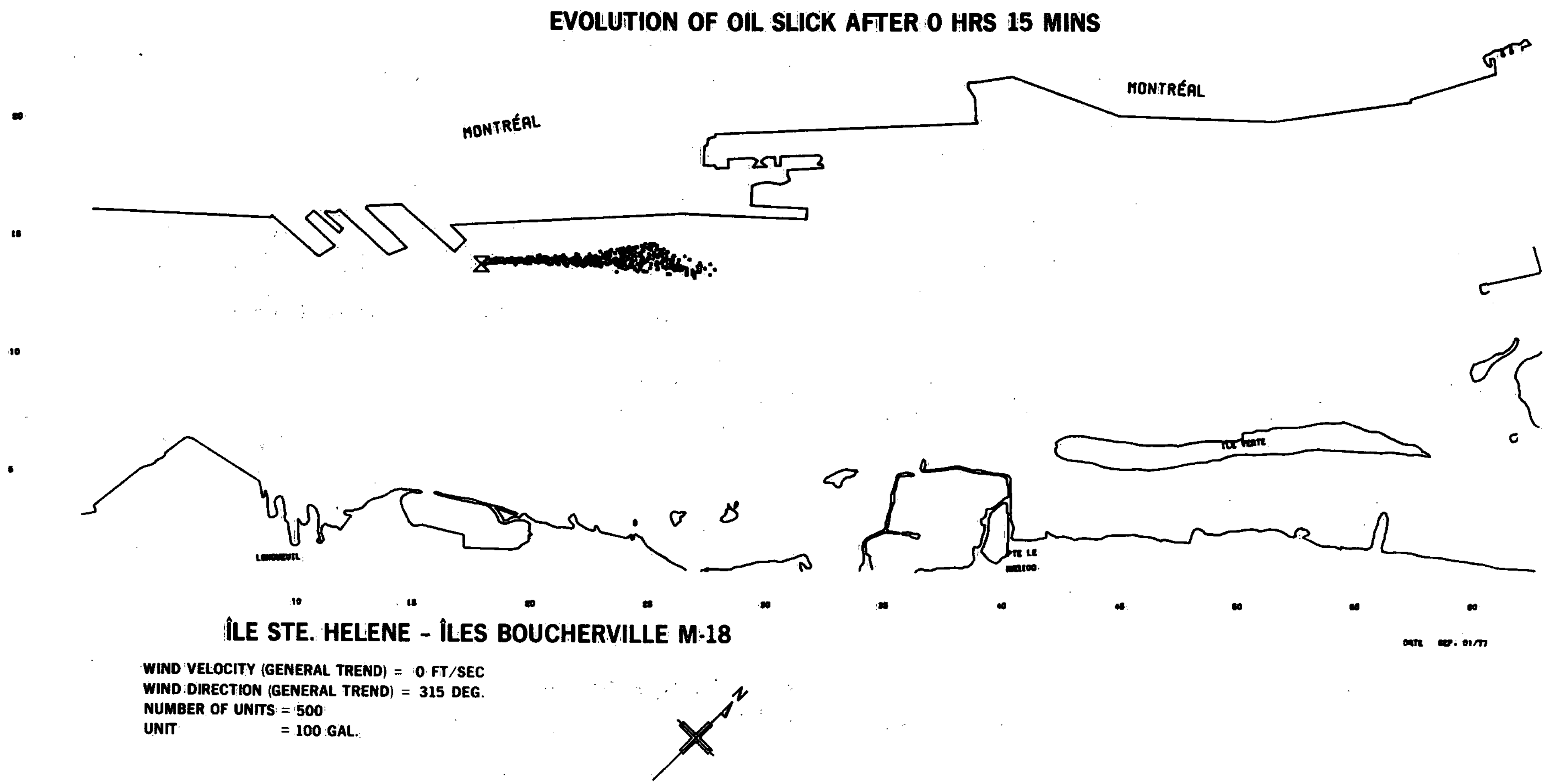


Figure 6. Port of Montreal oil spill, showing movement after 15 minutes.

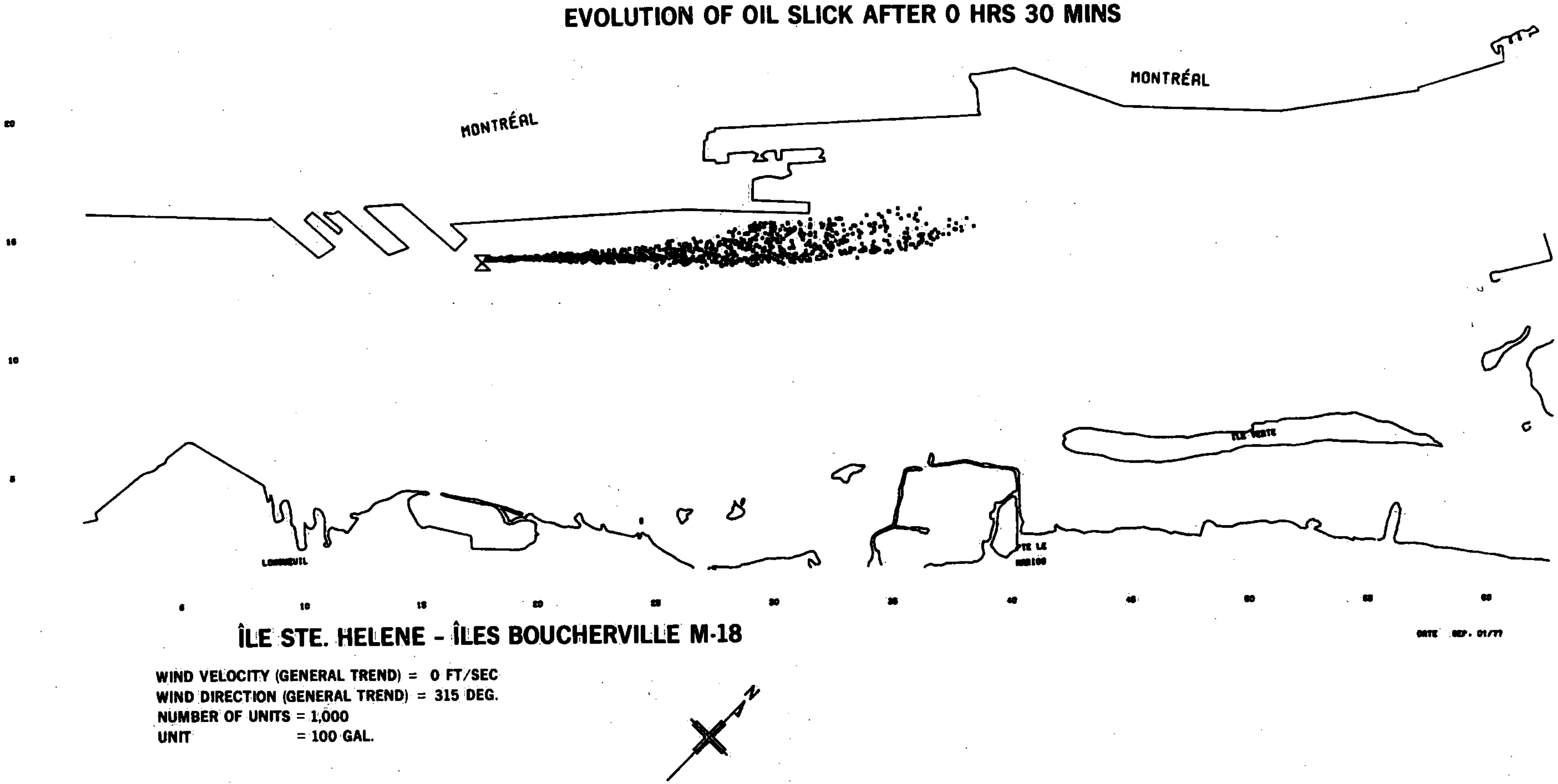


Figure 7. Port of Montreal oil spill, showing movement after 30 minutes.

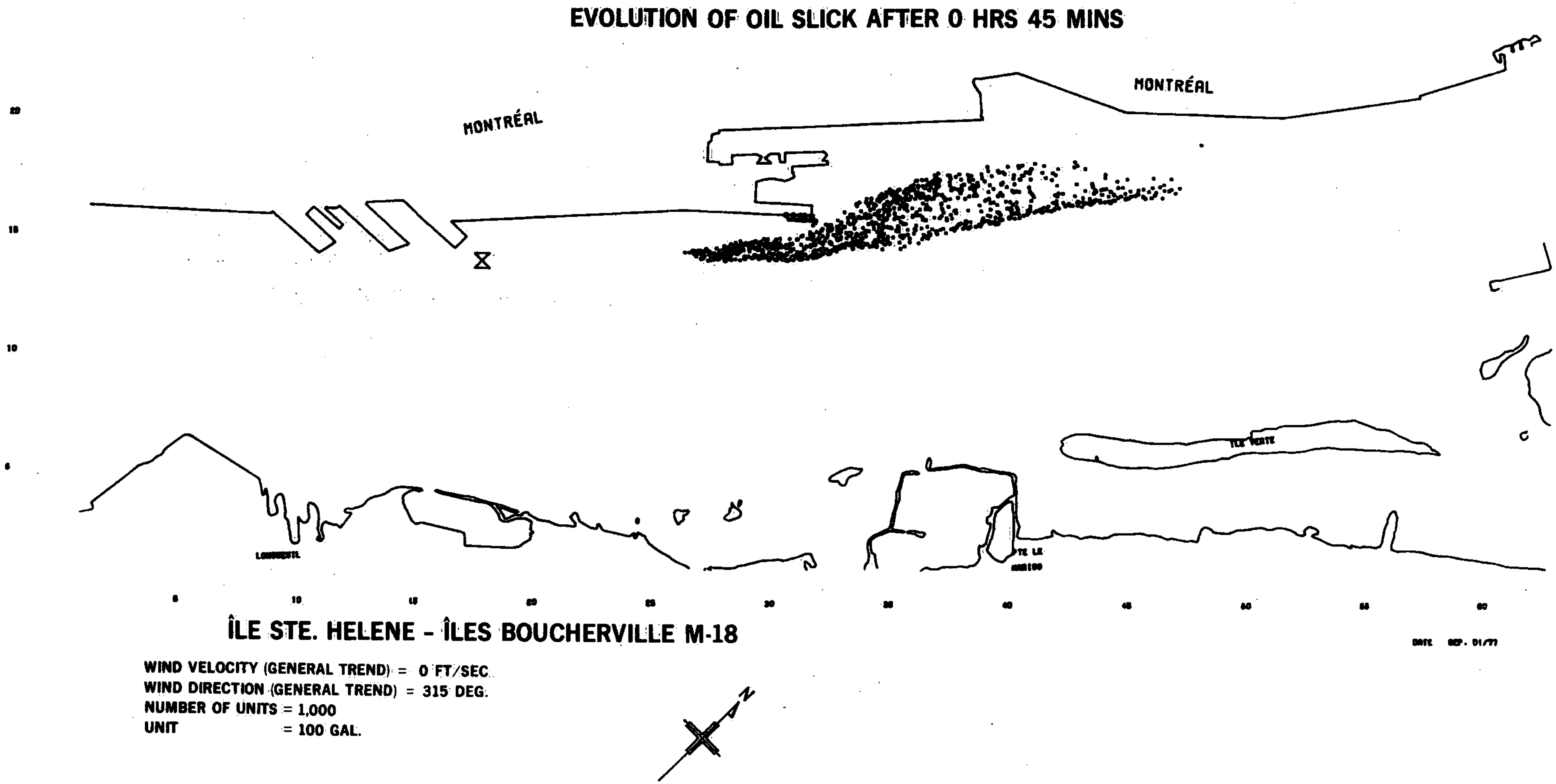


Figure 8. Port of Montreal oil spill, showing movement after 45 minutes.

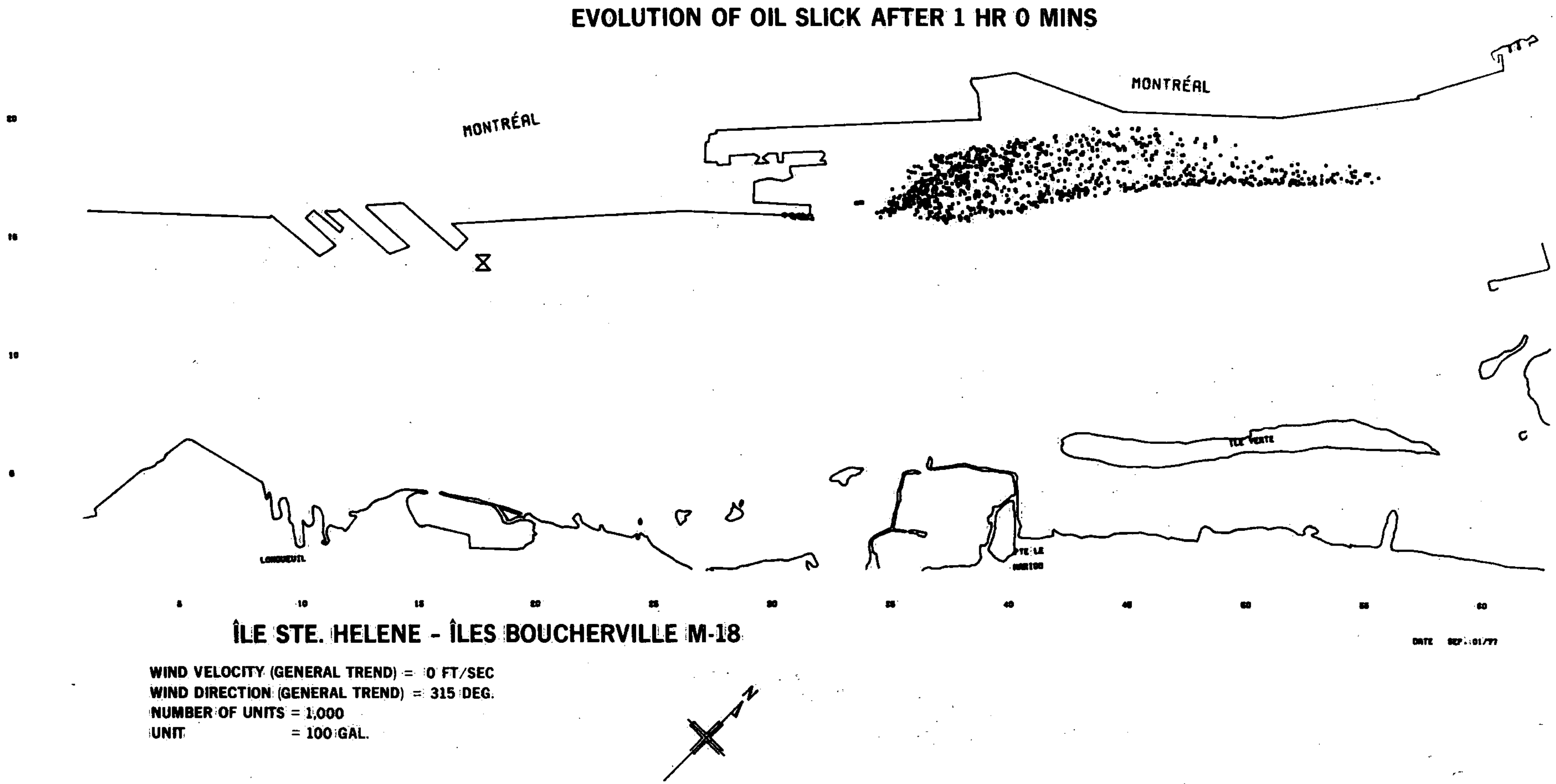


Figure 9. Port of Montreal oil spill, showing movement after 1 hour.

5.8 Results and Conclusions

In its present form, this model represents an important step in the search for a sophisticated approach to simulated oil spills and oil spill cleanup exercises. The model was programmed in a flexible manner which allows evaporation and dissolution factors to be introduced. It can be further modified to provide detailed knowledge of the direction and rate of movement of an oil slick when such information is essential to an on-site commander, especially when field observations cannot be carried out. In such a case, communication with the computer could be via direct telephone hook-up.

The model presently requires on-site meteorological data, either real time or forecasted. Official lines of communication are required with local Atmospheric Environment Service officers to obtain current weather data for river sites during a crisis situation. These data are vital for any real time simulation and should be adjusted to shoreline conditions that could influence the direction or magnitude of winds over the open water surface.

So far, the simulation results are highly promising, but further development of the system is required and should be pursued during ongoing field investigations. Only through continued development will the user ultimately obtain a model which can be used with confidence. It is the ultimate goal of modellers to strive for the development of such a practical model and to promote its use in all practical applications.

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