# CHAPTER 130

## OIL SLICK FATE IN A REGION OF STRONG TIDAL CURRENTS

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ABSTRACT

This study examines the drifting, spreading and aging of small slicks of crude oil in the middle St. Lawrence Estuary. This region was chosen because it is well documented with field measurements, hydraulic scale models, and mathematical models; and also because it is becoming a strategic area for the development of supertanker ports for 300,000 and possibly 500,000 ton tankers.

Two controled releases of Venezuelan crude (370 and 800 litres) were made in November 1972, as ice began to form in the St. Lawrence Estuary. The experiments were supported by the Canada Centre for Remote Sensing which carried out extensive airborne monitoring.

The results indicate that it is impossible either to recover or to disperse small spills of oil in this region of strong tidal currents. Models also predict slick motion poorly. The alternative is to construct slick-drift roses that will indicate areas of expected beaching and assist in deployment of oil-spill clean-up technology.

## INTRODUCTION

Concern with the fate of oil in the St. Lawrence Estuary was prompted by the planning of supertanker ports to accomodate 300,000 and possibly 500,000 ton vessels. The St. Lawrence Seaway is an important sea route for petroleum products (Fig. 1). Supertankers of any tonnage could reach the Saguenay area. The

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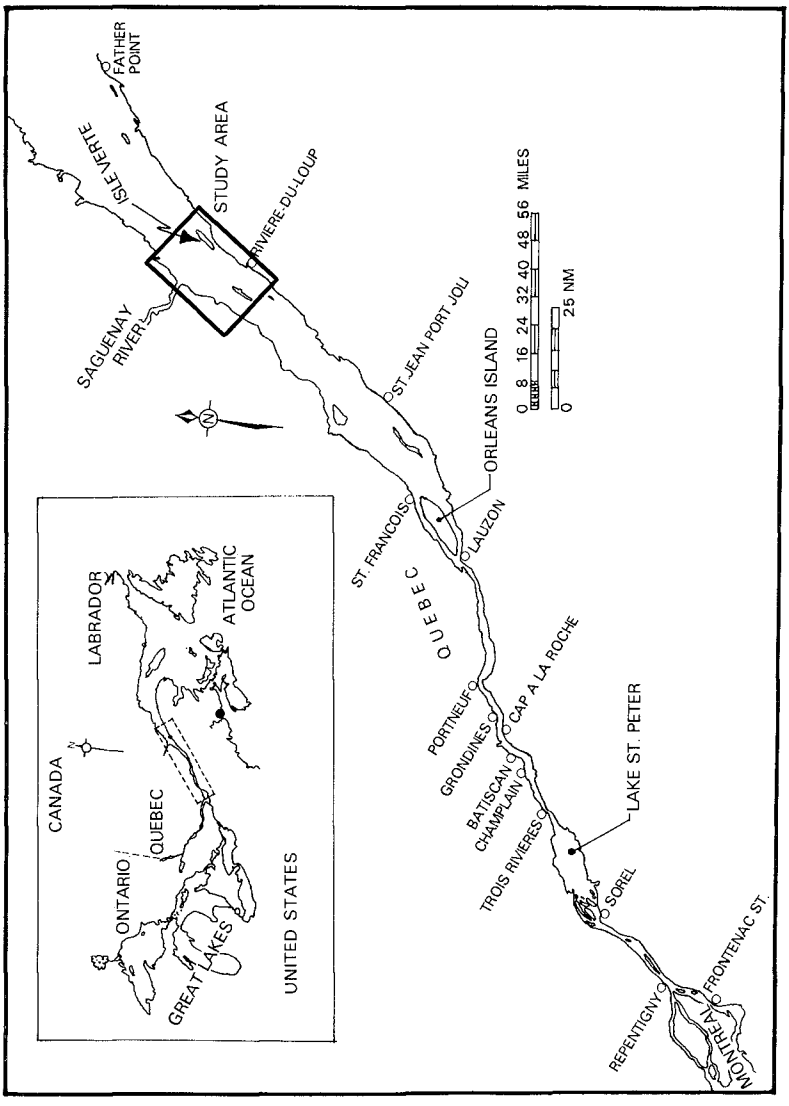


FIG. 1 Location of the study area in the Middle St. Lawrence Estuary.

promoters of a supertanker port in the study area contend that, in addition of the economic advantage, pollution risks are lesser with fewer larger vessels than with smaller tankers sailing further up the river.

The Saguenay area of the St. Lawrence Estuary was chosen as a site for experimenting with oil slicks because tides generate strong currents in that area and also because the experiments could be carried out in late November at the time when ice begins to form in the Estuary, thus providing a good simulation for Arctic conditions. Furthermore, this area is well documented with measurements of surface currents (Canadian Hydrographic Service, 1939; Clarke, 1973) and analyses of tidal transports and streams (Forrester, 1969), with simulations based on one-dimensional (Kamphuis, 1970) and two-dimensional numerical models (Prandle and Crookshank, 1972) as well as with a hydraulic scale model built by the National Research Council of Canada. Logistics were also relatively simple and ship and aircraft surveys were easily coordinated.

## ENVIRONMENT

Salinity in the area where experiments were carried out varies at the surface between 15°/oo in May and 29°/oo in September. Cold ocean water migrates upstream at the bottom of the Laurentian Trough and contributes to keep the water mass cool even during the summer months where it average 7°C at the surface (El Sabh, 1974).

Waves in this part of the Estuary are not conspicuous because of the short fetch. For instance during one experiment waves of a period of approximately 4 seconds reached a height of one meter after the wind had been blowing at 10 to 15 m/sec for half a day.

Tides are the dominant oceanographic phenomenon in the Estuary. They are semi-diurnal and show considerable monthly variations. In the sutdy area, the spring tides reach a maximum of 4.6 metres (Canadian Hydrographic Service, 1972).

Tidal currents which are in the order of 1 m/sec (2 knots) in the lower Estuary become stronger and more intricate in the Saguenay area because of the complexity of the bottom topography, the inflow of deep "ocean" water from the Laurentian Trough, and the fresh water outflow of some 1500 $m^3$/sec from the Saguenay River. Currents of 3 m/sec are experienced locally. The currents in the study area are far from being uniform either in direction or intensity as can be seen on Fig. 2 which shows the distribution of surface currents at high tide. Tidal currents occasionally form gyres as shows the path of the oil slick offshore of Isle-Verte (Fig. 3).

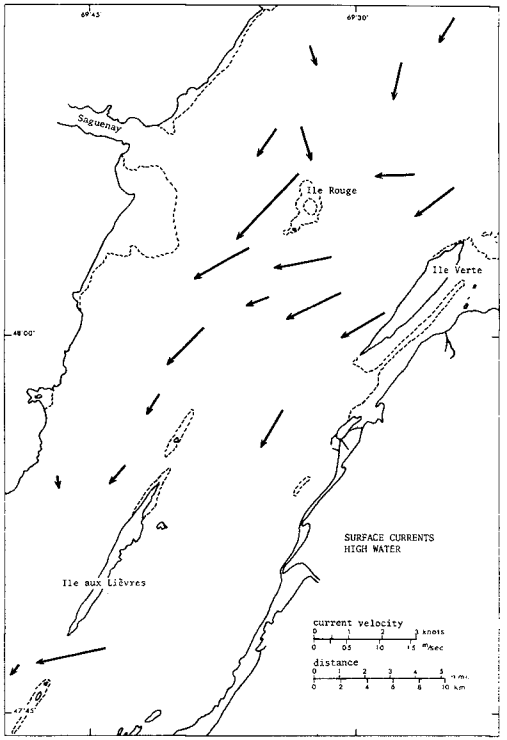


FIG. 2 Surface currents at high tide in the study area. Arrows show direction and relative intensity of currents.

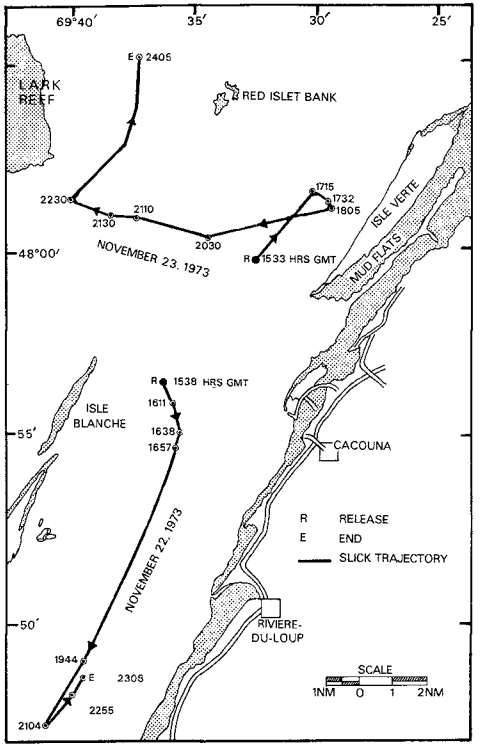


FIG. 3 Oil slick trajectories observed for the two experiments carried out in the St. Lawrence Estuary.

EXPERIMENTS

The experiments were carried out as follows. Field work was conducted aboard the research vessel LE QUEBECOIS, a 28 metre stern trawler. Two releases of Venezuelan crude oil were performed using a domestic fuel tank to produce a uniform splashless spill by tilting the tank at the water surface. Slick imagery was accomplished by airborne sensors provided by the Canada Centre for Remote Sensing. Serial sampling of slicks for physico-chemical analysis was accomplished from a small inflated boat in order not to interfere with the displacement and spreading of the slick.

Some 370 litres (80 gal.) of crude oil (Fig. 3) were spilled for the first experiment, on November 22, 1972, under moderate and steady wind conditions (8 m/sec) in an area offshore of Rivière-du-Loup where tidal streams reach a speed of 1.5 m/sec and follow a simple reversing pattern of flood and ebb currents. The resulting oil slick was followed for 7 hr. 24 min. over a distance of 27.2 km and reached during that time a maximum drifiting speed of 1.2 m/sec. Twice as much oil was spilled, (800 litres) for the second experiment, on November 23rd, under more severe wind conditions (15 m/sec) in an area where tidal streams follow complex rotational patterns and reach speeds of 3 m/sec. The second slick was followed for 9 hr. 12 min. over a distance of 37 km. The rate of drifting varied considerably during that experiment and reached a maximum speed of 2.85 m/sec. The path of the spilled oil was tracked by following the slicks and obtaining fixes of the ship position by radar. At the same time, surface drifters of different configurations were released, and some were found to follow the slicks very closely. One type of surface drifter was made of crossed pieces of plywood. The drifters that followed the slick most closely were simply made of floating pieces of plywood loosely tied together. These are very stable as they adjust to the shape of waves.

The Canada Centre for Remote Sensing participated actively in the experiments by flying two aircraft at one hour intervals during all the time that lasted the two experiments. Primary and secondary sensor platforms were a C-47 Dakota transport aircraft and a Falcon executive jet transport, respectively. Operational altitude of the aircraft ranged from 275 to 610 metres above sea level. The flight lines coincided with the longest slick axis and attempted to include as a photographic reference point the study vessel LE QUEBECOIS.

The C-47 aircraft was equiped with four vertical Vinten 70 mm cameras, one Zeiss RMK 8.5/23 camera (9" x 9" format), and one Deadalus infrared line scanner. The Dakota was also used at night to test laser induced fluorescence using a Helium-Cadmium laser operating at 441.6 nanometres (O'Neil et al., 1973). The laser

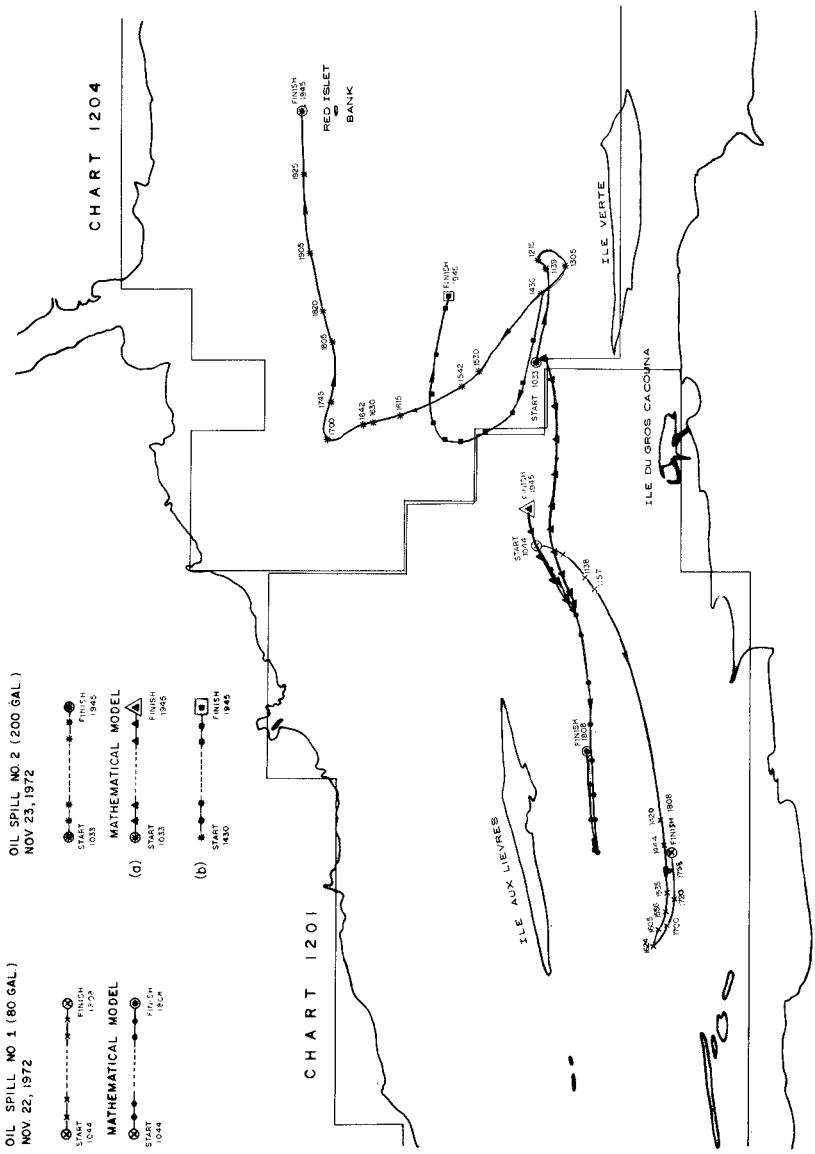


FIG. 4 Simulation of oil slick trajectories obtained from a two-dimensional mathematical model developed by the National Research Council of Canada.

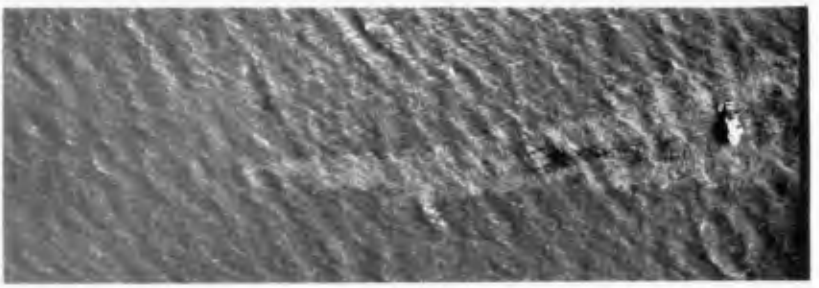

FIG. 5 Oil slick (800 litres) 24 minutes after its release. Wind speed was 10 m/sec and current speed was 1 m/sec. Photograph taken with a Wild RC-10 88-mm camera, fitted with a PAN 500 filter at f/5.6, t: 1/150, on Double-X Aerographic film at an altitute of 305 metres. The ship on the right side of the photograph is 28 metres long.

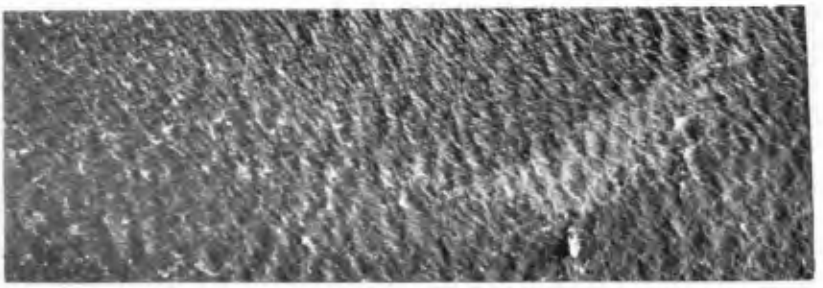

FIG. 6 Part of same oil slick as above 1 hr. 21 min. after its release; same photographic settings at an altitude of 455 metres. The dark yolk visible on the first photograph has disappeared.

FIG. 7 Part of the same oil slick 3 hr. 17 min. after its release; same photographic setting at an altitude of 335 metres. The slick is shredded due to wind action and had by that time spreaded over an area of some 80,000 square metres.

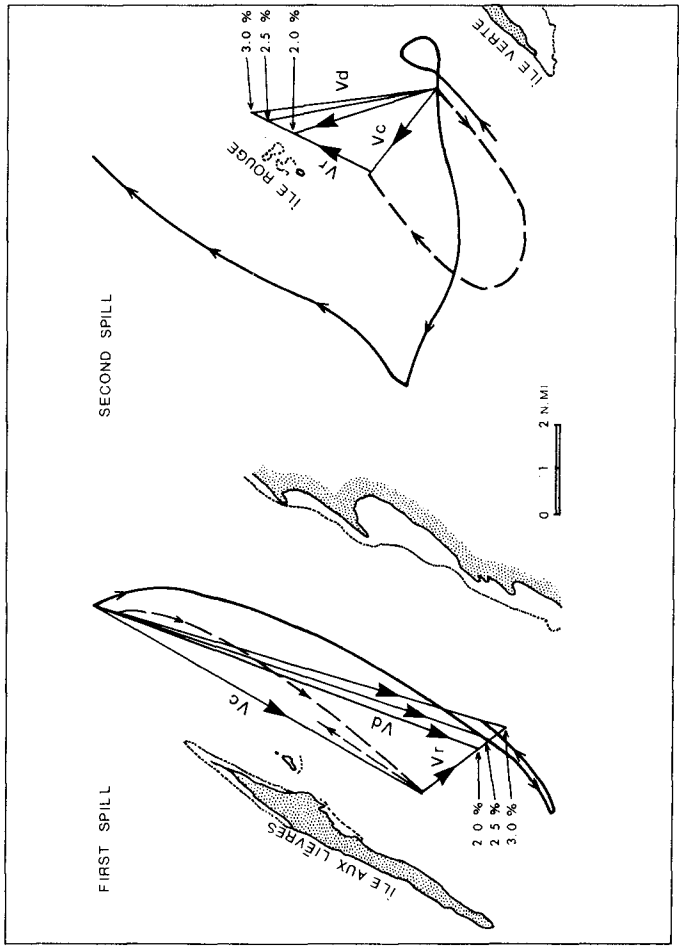


FIG. 8 Drift simulation based on vectorial addition of wind and current components of oil slick drift. The observed drifts are outlined by solid lines and the dotted lines show the computed tidal drift based on a two-dimensional mathematical model. The surface current component is then represented by the vector Vc and the wind effect on the oil slick by the vector Vr. The simulated displacement is outlined by vector Vd which is the resultant vector of Vc + Vr. The length of vector Vr varies according to the wind factor used. Lengths of vector Vr are shown for wind factor of 2.0, 2.5 and 3.0%. For the first spill, the simulation is good particularly if allowance were made for a drift angle towards the right. For the second spill, the drift simulation is unrealistic because a two-dimensional mathematical model is inadequate for surface current simulations in that area.

detector was at the development stage at the time of the experiments. The Falcon aircraft was equiped with a RS14 infrared line scanner system (fitted with a UV detector) and a Wild RC-10, 88-mm camera.

Film/filter combinations on the Vinten cameras were as follows: 1) Aerochrome Infrared (2443) with filter W12{f/2.8 at 1/1000 sec}, 2) Ektachrome M.S. Aerochrome (2448) with no filter {f/2.8 at 1/1000 sec}, 3) Double-X Aerographic (2405) film with filter 58{f/2.8 at 1/1000 sec}, and 4) 2405 film with a Wratten 47 filter {f/4 at 1/1000 sec}. Aerocolour negative (2445) film was used in the Zeiss camera at f/4, 1/100 sec, and Double-X Aerographic film was used in the Wild RC-10 at f/5.6, 1/150 sec. (Fig. 5, 6, and 7).

The Deadalus infrared line scanner used cooled mercury-cadmium telluride and indium-antinomide detectors having spectral resolutions ranging between 8-14 um and 3-5 um, respectively. After about 20-30 minutes oil and water had come to nearly identical temperatures and the infrared line scans lost their usefulness for imagining the oil slicks.

## RESULTS

### a) Drifiting of oil:

Drifting of oil on the surface of water results from the combined action of wind and surface currents. The interesting point is to establish to what extent these two parameters can be evaluated and combined to predict the path of an oil slick in a specific area. Wind direction and intensity over the spill were measured from the research ship at 15-minute intervals. As for data on surface currents along the drift path of the slicks, it was possible to have water surface movements calculated by the National Research Council on the basis of the two-dimensional numerical model (Fig. 4). The simulation from the mathematical model and the actual drift were not expected to coincide for many reasons. Firstly the mathematical model is two-dimensional and assumes vertical homogeneity in terms of density and velocity, an assumption which is not correct for the study area. Assuming vertical homogeneity results, in most cases, in under-estimating the velocity of surface currents. The numerical model does not integrate the effect of the wind on the slick drift. When compensation is made for the effect of the wind it is possible to evaluate the capability of the two-dimensional model to simulate oil drifting. It can be seen on Figure 8 that in the case of the first spill, which took place in an area where tidal currents are simply reversing, a two dimensional model is realistic in predicting the displacement of an oil slick, particularly if one allows for a drift angle towards the right. Obviously drift simulation with a

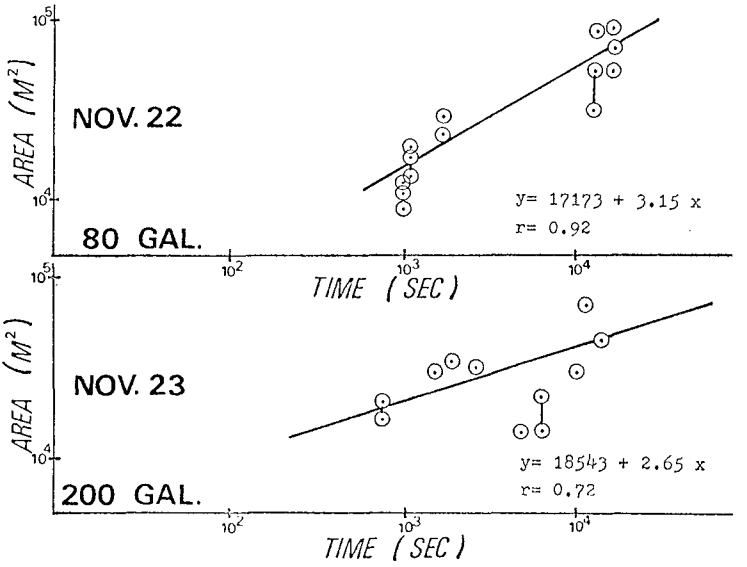


FIG. 9 Oil slick area versus time plotted on a log-log scale.

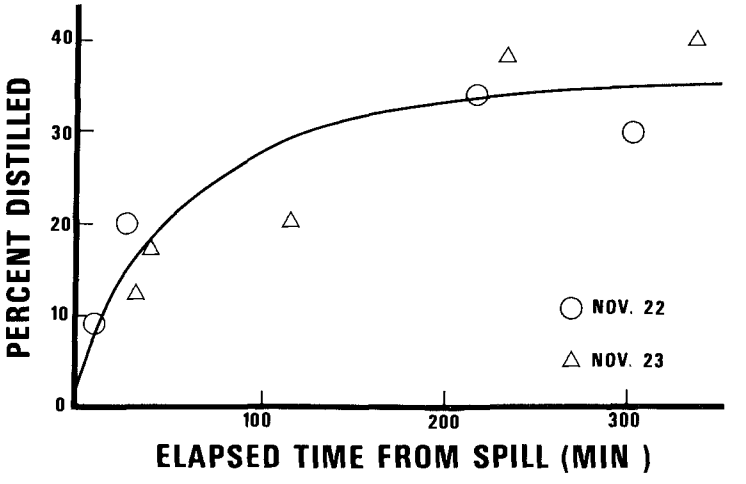


FIG. 10 Percent distilled fraction of crude oil versus elapsed time from spill.

two-dimensional model is not as succesful where tidal currents are rotational and asymetric as it was the case for the second experiment. In the latter case addition of the wind effect does not improve the solution substantially.

b) Spreading:

The aerial photographs taken by the Canada Centre for Remote Sensing permitted accurate measurements of oil slick spreading. Image of M/V LE QUEBECOIS (27.4 metres long) served as a length reference. The error in planimetering amounted to approximately one per cent of a given determination of slick area. In some cases however it was difficult to delineate exactly the edge of a slick (Bien, 1973). The figures 5, 6, and 7 show different stage of slick spreading of an initial spill of 800 litres. Areas of each slick were plotted on a log-log scale in Figure 9. In the case of the first experiment, the slick was estimated to cover an area of some 20,000 $m^2$ 15 minutes after the release, and to have spread over an area of 49,000 $m^2$ two and one half hours later. The rate of spreading was slightly less during the second experiment.

c) Aging:

The Venezuelan crude oil spilled during the experiments underwent major physico-chemical alterations during the few hours following the spilling. The physical appearance of the spilled oil rapidly changed to form a viscous spongy type of "crocodile skin" as shown on Figure 12. It resembles what is described as "chocolate mousse" in the literature. Two hours after the spill, emulsions of water in oil as shown in Figure 11, already contained 71 percent water and had reached a viscosity of 2040 centipoises (Paquin and Lebel, 1975).

Oil slicks samples were collected every hour during the experiment, stored, and later analyzed with a gas chromatograph. The chromatograms from oil slick samples were compared to a series of chromatograms obtained from laboratory distilled samples of the same crude oil. The "percent distilled" values of the spill samples are plotted as a function of time from the spill on Figure 10. The results indicate that under the prevailing environmental conditions, approximately 60 percent of the 6 hour evaporation, that is 25% of the total sample, occurs within the first hours after the spill. This is very important because the more soluble and toxic components such a benzene, are included in this first fraction.

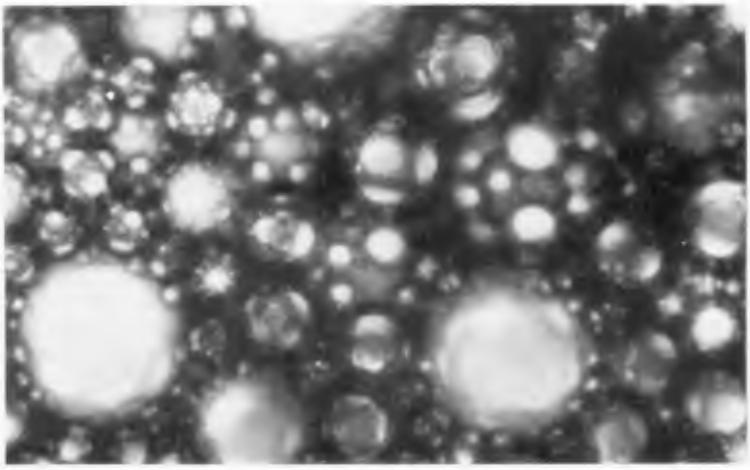

FIG. 11 Microphotograph of emulsion of water in oil.
The largest droplets are 500 microns in diameter.

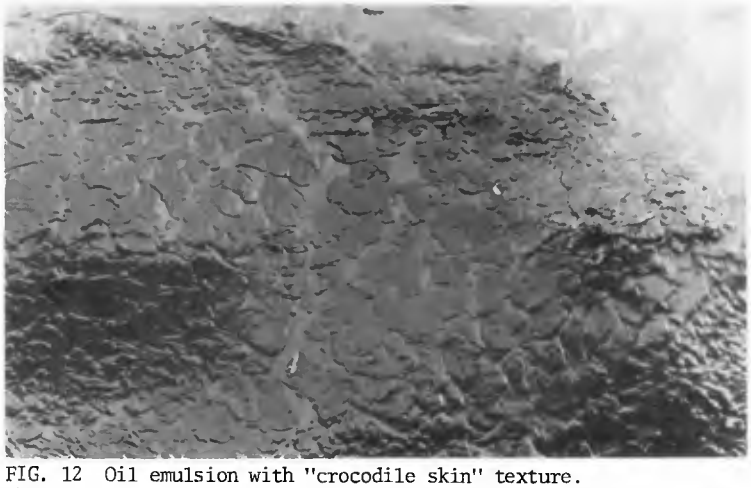

FIG. 12 Oil emulsion with "crocodile skin" texture.
Photograph taken three hours after the spilling of crude oil.
The area photographed is approximately 3 x 2 metres.


FIG. 13 Slick drift roses for the months of April and October, covering the conditions of spillage occuring during high-water (flood) and low-water (ebb) slack.

## CONCLUSIONS

In a region of strong tidal currents, it is virtually impossible to recover oil after it has been lost. During the first experiment for instance, 370 litres of crude oil have spread over an area of 20,000 $m^2$ only 15 minutes after it has been spilled. This 20,000 $m^2$ slick doubled in area in less than two hours and became shredded in long streaks, which makes dispersants physically impossible to use. The rapid formation of emulsions is also a major handicap because it makes either burning or absorption impossible. As it is unfeasible to either recover the oil or disperse it the other alternative is to attempt to minimize the damages by predicting where the oil will eventually end. In an area of strong tidal currents it is difficult to predict every details of the path of a slick, but it is possible to take into consideration the combined effect of drifting, spreading and aging to predict the "reach" of spilled oil. For that purpose slick-drift roses are constructed for different phases of the tide and different wind conditions (Harrison, 1975). Construction of monthly slick-drift roses involves summation of estuarine-current and wind-transport vectors. In the present study the wind vectors used in monthly rose constructions were those corresponding to extreme wind persistence values found in a compilation of two consecutive year's worth of information for Rivière-du-Loup, the meteorological station closest to Isle-Verte (Fig. 3). The tidal-current values used for the current vectors were those associated with spring tides. Thus, the wind and tidal data used represented extreme conditions. Environmental impact analysis should in general be based upon the worst possible conditions. Monthly vectors for extreme wind persistence and for strongest tidal currents were determined, added, and the net vectors plotted for each of 12 points of the compass. The ends of the vectors were then connected by straight lines. The final result is a "rose" that shows the extreme limits of potential slick motion that can be expected from small spills originating at a given point during a given month. A series of 24 monthly slick-drift roses was prepared for a potential offshore bunker site for a super-tanker port at Isle-Verte. Twelve roses cover the condition of oil spillage at high-water slack and the other 12 cover the condition of spillage at low-water slack (that is, "slack current before flood"). Figure 13, for the months of April and October, shows unfavorable slick-drift roses for the condition of spillage at high- and low-water slack.

## REFERENCES

BIEN, W., 1973; Modeling Petroleum Spills at Supertanker Ports: Master of Arts Thesis, University of Toronto, 122 p.

CANADIAN HYDROGRAPHIC SERVICE, 1939; Tidal Current Charts, St. Lawrence Estuary, Orleans Island to Father's Point.

CANADIAN HUDROGRAPHIC SERVICE, 1972; Canadian Tide and Current Tables, Vol. 3. St. Lawrence and Saguenay Rivers. 55 p.

CLARKE, J.R., 1973; Comparison of model and ptorotype velocities - St. Lawrence Estuary; Hydraulics Lab. Rept. LTR-HY-37, National Research Council of Canada, 17 p.

EL-SABH, M.I., 1974; Water Masses and Circulation in the Maritime Estuary of the St. Lawrence (in preparation) Am. Geophy. Un. Fall Meeting, San Francisco, December 1974.

FORRESTER, W.D., 1969; Tidal Transports and Streams in the St. Lawrence River and Estuary, Rept. BI 69-2 Bedford Institute of Oceanography, 14 p.

HARRISON, W., 1975: Environmental Analysis for Bahamas Supertanker Port: Proceedings of the 14th International Conference on Coastal Engineering, Copenhagen, June 24-28, 1974 (in press).

KAMPHUIS, J.W., 1970; Mathematical tidal study of St. Lawrence River: Journal of Hydraulics Div., ASCE, Vol. 96, No NY3, Proc. Paper 7141, March 70, pp. 643-664.

O'NEIL, R.A., A.R. Davis, H.G. Gross, J. Kruus, 1973; A remote sensing laser fluorometer: Manuscript, Inland Water Directorate.

PAQUIN, Y., and J. Lebel, 1975; Some aspects of formation of oil emulsions in the St. Lawrence Estuary (in preparation).

PRANDLE, D. and N. Crookshank, 1972; Numerical Model Studies of the St. Lawrence River, Hydraulics Lab. Rept. MH-109, National Research Council of Canada, 104 p.