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ASOCIACION REGIONAL DE EMPRESAS DE PETROLEO Y GAS NATURAL EN LATINOAMERICA Y EL CARIBE

OIL SPILL TRAJECTORY MODELLING

Canadian International Development Agency

Environmental Services Association of Alberta

ARPEL REPORT

OIL SPILL
TRAJECTORY MODELLING

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Executive Summary

A report was prepared to assist ARPEL member companies in the selection and development of oil spill trajectory modelling systems. The report outlines a number of criteria which should be considered when choosing a modelling program, including the need to interface with other programs such as sensitivity mapping.

Also included is a summary matrix of commercially available software that evaluates each program based on its capabilities in supporting essential, important, and less important features.

The report outlines the various information needs that ARPEL members would require to allow oil spill modelling in their areas of interest. Three types of models are discussed as well as a seven-step process to prepare and run models.

The report shows three different types of model outputs that these programs typically can create as well as the hardware requirements to run the programs.

Finally, the benefits of oil spill trajectory modelling are discussed from a management perspective including the manpower and capital costs to implement an oil spill modelling system.

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Glossary

The following abbreviations/terms are used in this report:

Term	Definition
ARC/INFO	Geographic Information System software trademarked by ESRI
ArcView	Geographic Information System software trademarked by ESRI
ARPEL	Assistencia Reciproca Petrolera Empresarial Latinoamericana
ASA	Applied Science Associates, Inc.
bbls	barrels
deterministic model	a trajectory model estimating the path of a single spill event
GIS	geographic information system
GUI	graphical user interface
hr	hour
HPLC	High Performance Liquid Chromatography
K1	diurnal tidal constituent influenced by the sun
M2	semi-diurnal tidal constituent influenced by the moon
Mif/Mid	ASCII formatted data format for GIS defined by MapInfo
NOAA	National Oceanographic and Atmospheric Administration
receptor model	a trajectory model used to identify the probable path (source) of a spill from unknown origin
stochastic model	a trajectory model used to estimate the probability of slick trajectories based on many years of historical wind data
Windows	Windows 3.x/Windows 95 - Microsoft copyrighted personal computer operating systems/programs

1.0 Introduction

Oil spill trajectory models can be used by emergency responders, contingency planners and risk assessment personnel to predict where oil spills will go, and how the chemical and physical properties of the oil will change with time.

If there were no computer models available, a spill responder could estimate when a slick might reach a shoreline based on his observations. For example, if the prevailing winds were pushing the slick towards a shore three km away at a speed of about 0.2 m/s, the slick should reach shore in about four hours (assuming the conditions do not change substantially).

Another, more technical method often used to estimate slick speed assumes that a slick will travel at approximately 3.5% of the wind speed. For example, a 20 knot (37 km/h) wind would drive a slick at 0.7 knots (0.36 m/s) in the direction of the wind. This method should work in a lake where there are no other currents driving the oil. However, in open water, or where tidal or other currents, i.e., rivers influence surface currents, the effects of both wind and current must be combined using simple vector addition to reasonably predict slick travel.

For example, if there were a current of 0.5 knots (1 m/s) along a shoreline, and an offshore wind of 15 knots (28 km/h) blowing directly on shore, the combined effects of the two currents could be estimated as follows:

$$x^2 + y^2 = z^2$$

$$(3.5\% \text{ of the wind})^2 + (100\% \text{ of the current})^2 = (\text{slick travel})^2$$

$$(0.035 \times 15)^2 + (0.5)^2 = (\text{slick travel})^2$$

$$\text{slick travel} = 0.72 \text{ knots}$$

This would result in a combined current of about 0.72 knots (0.37 m/s) approaching shore at an angle (see Figure 1.1).

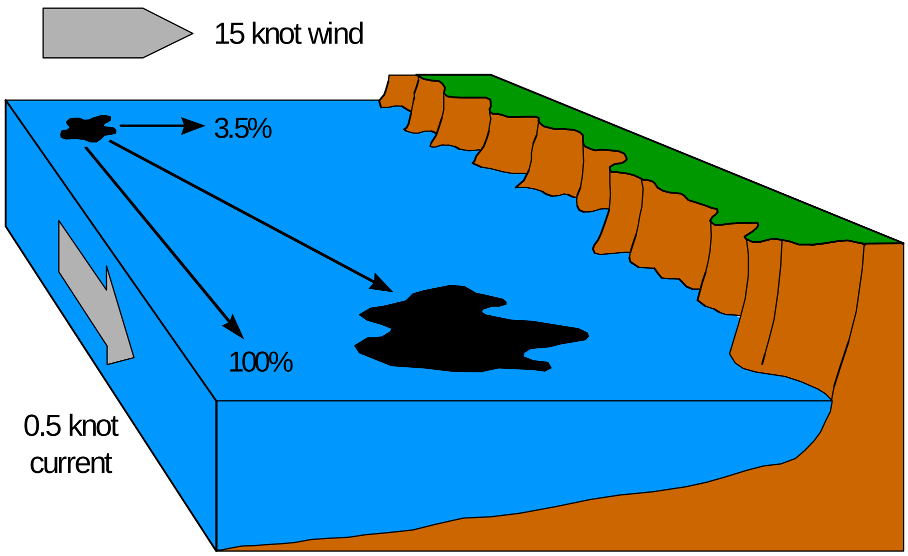


Figure 1.1 - Estimating Slick Travel

As in the example above, the area of the slick will increase until the oil has reached a minimum thickness.

Unfortunately, actual spills are normally much more complicated to predict due to changing winds, irregular current patterns, and complex tidal influences. In these cases, computer-based trajectory models are the only tool available to make reliable predictions.

1.1 Model Uses

Oil spill trajectory models can be used to perform numerous emergency response and planning functions:

Spill Response — Models can incorporate *real time* data in order to predict the trajectory and fate of spills which could threaten the coastline or other environmentally or economically sensitive areas.

Contingency Planning — Models can also be used during the preparation of contingency plans in order to develop credible scenarios and to predetermine possible response strategies and cleanup techniques.

Risk Assessment — Models can be used as risk assessment tool to project the fates and trajectories of *potential* spills in order to consider possible spill impacts and strategies to mitigate them. When used as a risk assessment tool, spill models can assist in important decisions such as the location of loading buoys, the positioning of spill response equipment, or the need for modifications to existing oil transfer facilities and procedures.

Spill Exercises	Once developed, spill models can be employed during spill exercises to assist on-scene coordinators and other decision- makers in the most expeditious deployment of countermeasures equipment.
Back Calculating	Spill models can also sometimes be used to “back calculate” spills from unknown sources that affect shorelines or other sensitive areas in order to identify possible points of origin.

In all cases, there are a number of common elements, both technical and user-oriented, that should be considered when purchasing and/or developing a modelling system. These elements are discussed in this guideline.

2.0 Choosing Modelling Software

All software, regardless of its purpose, should be easy to install, learn and use. There is no longer any valid reason for highly technical programs to be the sole domain of skilled technicians. The development of standard graphical user interfaces (GUI), i.e., Windows, has created an environment where technical applications should be available to engineers and other personnel, who may not be completely familiar with computers, but still require the power of the program's capabilities. Fortunately, there are a number of modelling program vendors who share this view.

Because the output of oil spill models is often closely linked to potential spill impacts, it may be desirable to have a link to, or even integrate with, a sensitivity mapping capability. Most programs available today provide some measure of this capability.

2.1 Vendor Philosophies

Vendor Modelling

Some modelling software vendors see the software solely as a tool to sell their consulting services. Once installed, the software becomes a mere output device which the end-user can use to *demonstrate* highly complicated models developed by the vendor. This approach may be suited to oil companies that are concerned about potential risks but that do not have the in-house manpower or capability to maintain a sophisticated system. Such a system would have a higher initial cost but would be up and running relatively quickly, capable of predicting potential spill impacts, and would require little maintenance. These systems are limited to one geographic location since setting up the hydrodynamics for other areas would require additional vendor support.

User Modelling

An alternative approach, which is somewhat more open, allows the end-user to become a more active participant in the modelling process. Although considerable modelling expertise is required, some users may want to have greater control of the hydrodynamics used in the model. This will allow both changes in the existing model as well as the modelling of new areas without assistance from the software vendor. Some programs come with tools which allow the user to *paint* tide and background (seasonal) currents. While these models may be less sophisticated, they offer the end user much greater flexibility, particularly in emergency spill situations where no model exists but an initial estimate (*best guess*) is required. It should be noted that there are a number of model vendors that offer products that combine the best of both approaches.

2.2 Data Input

Environmental Data

The software should provide the user with tools (ideally graphical) to enter environmental data such as air and water temperature, wind and possibly current data. If the input of current data is possible, it should include:

- wind-driven flows
- fresh water flows (rivers)
- periodic (tidal constituent) phase and amplitude

Essentially all commercially available models include these parameters.

Some commercially available models can import wind data directly from weather services in a standard format. The use (and interpolation) of multiple wind data sources might also be possible.

Oil Database

The model should come with a wide range of crude oils and products -- ranging from gasoline to Bunker C and should allow the user to input oil characteristics for new oils.

Spill Information

The model must allow the input of various model parameters including:

- spill start time
- spill end time
- amount of release
- rate of release

Some, more sophisticated models allow the user to describe non-linear spill releases, i.e., 100 bbls/hr for 12 hours, then 10 bbls/hr for the next 24 hours.

2.3 Hydrodynamics

Spill trajectory models are designed to estimate what will happen in the real world. The modelling of a complex (always changing) hydrocarbon in an open, three dimensional environment is an extremely complicated process which the software tries to mimic using a number of mathematical equations. These equations invariably include a number of assumptions. This explains why different models get different results and why some models work better under certain circumstances.

When choosing a model, consider the track record of the model, if possible, in conditions (coastal environments, oil types) similar to your own. Models which include large numbers of complex variables are generally more prone to error. Simpler, easy-to-use models are often equally accurate, especially when the uncertainty of some of the more important variables, i.e., wind speed and direction, is high.

2.4 Modelling Modes

Most programs are capable of both *deterministic* models (the trajectory is based on a particular spill event) and *stochastic* models (years of historical wind data are used, coupled with the hydrodynamic model) to formulate probabilities of spill trajectories during certain periods.

Deterministic models (see Section 4.1 for more details) are typically used to predict the path of an actual spill. These individual models are also usually the first step in other more complex models.

Stochastic models (see Section 4.2 for details) allow the user to estimate the likelihood or probability of paths that a possible spill might take. For example, a *stochastic* model might predict that if a spill occurred at a potential spill source, i.e., a platform during the month of March, that there was a 60% chance of impact on the adjacent shoreline, a 20% chance of oil moving away from shore, and a 10% chance of transport to the north or south (see Figure 2.1).

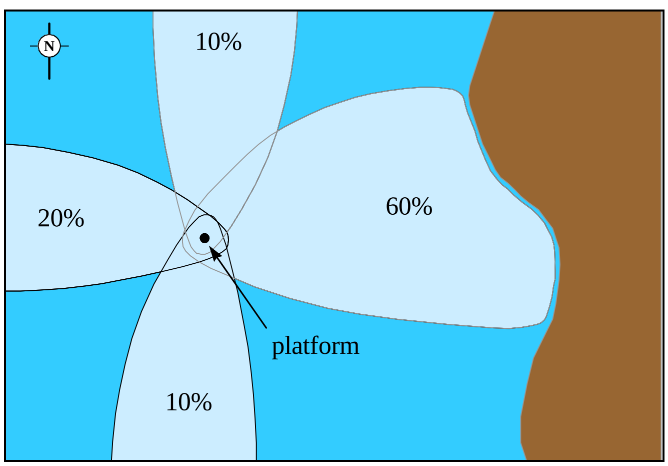


Figure 2.1 - Example Stochastic Model Output

Receptor models (see section 4.3 for details), use the same basic techniques as those used in *stochastic* models to back-calculate the probable path of spills from unknown sources.

2.5 Oil Fate and Behaviour

There are a number of processes which should be modeled including spreading, evaporation, dispersion, oxidation, emulsification and sinking.

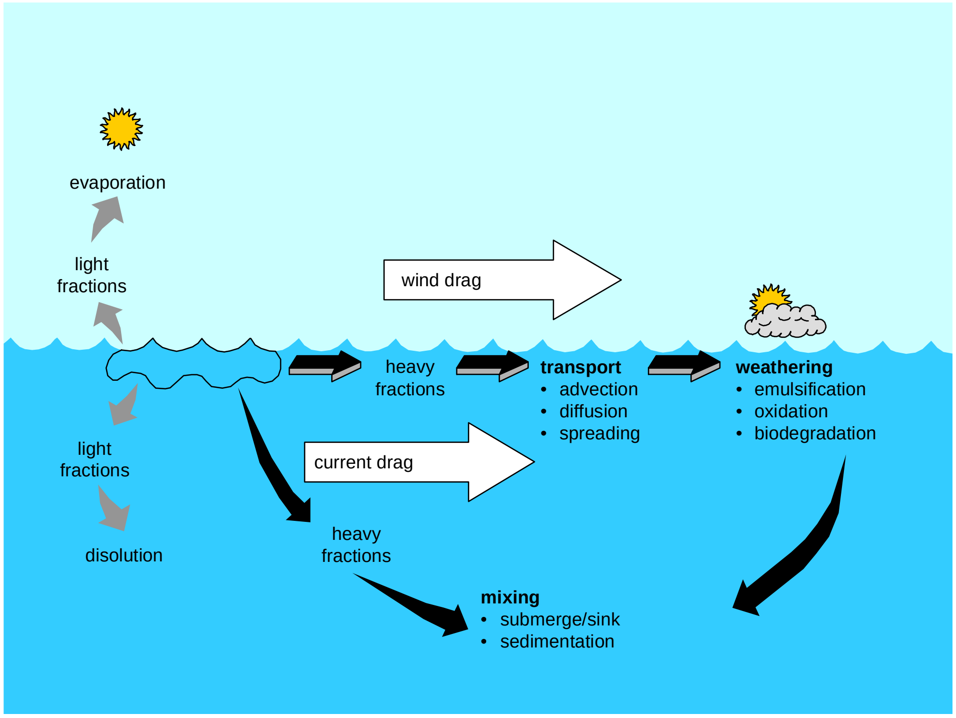


Figure 2.2 - Processes Affecting Spilled Oil

Most programs are generally two-dimensional although some consideration may be given to the sinking and re-floating of spill droplets (particles). Some, very sophisticated (and expensive) models are truly three-dimensional but are not likely necessary for most oil spill modelling applications. Also, the complex data required for 3-dimensional simulations will likely not be available during a spill. Some models are also capable of calculating and displaying the concentrations of oil below the water surface. This capability may be of interest in areas with sub-marine sensitivities such as coral.

2.6 Additional Model Parameters

Some programs offer additional capabilities such as the diversion and containment of slicks using oil spill booms. Some, more sophisticated models include failure algorithms for wave height (oil splashover) and current velocity (oil underflow). Some models are capable of predicting the effects of chemical dispersion.

Models should allow the importing of satellite images, spill tracker buoys or the on-screen depiction of observations, i.e., from an aircraft, in order to update the model with observed estimates of the spill location, thickness and volume.

2.7 Model Outputs

Typical model outputs range from a black and white depiction of a simple, two-dimensional model to a multi-coloured map, coded to identify oil concentrations or age. Mass balances (see example below) can be used to show the weathering and fate of the spilled oil.

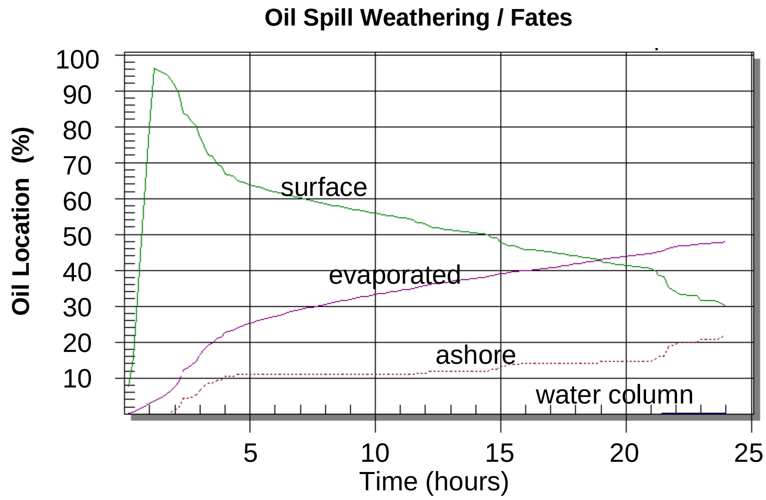


Figure 2.3 - Example Oil Fates Graph

Some programs offer additional model outputs such as the display of modelled (calculated) currents and the ability to determine which environmental resources are affected by oil (see Section 2.8).

2.8 Sensitivity Mapping (GIS)

Whether a model is used for emergency response or spill planning, it is desirable that the system provide either an integrated sensitivity mapping capability or, at least, a means of overlaying sensitivity information over spill trajectories. Ideally, the following capabilities should be available:

Map Types — The display of vector- and rastor-based maps should be possible. This would allow the use of both digitized and scanned base maps.

Layering — Information should be stored on layers for point, line and polygon objects.

Importing/Exporting The system should allow the importing and exporting of point, line, and polygon data (with attribute data) to and from ArcInfo and ArcView standard files (such as Mif/Mid) formats.

Database Attribute information should be stored in a database with a standard record format to ensure compatibility with other programs. The system should also provide a means of importing external data base records with latitude and longitude fields.

Selection Sets The system should also allow the selection of displayed point objects either by area (rectangles, circles, or polygons) or by the selection of attribute fields.

Resource Hits After spill trajectories are calculated, the model should identify those resources in the path of the spill.

2.8.1 Integration of Modelling and Mapping Systems

Ideally, modelling and mapping systems should operate seamlessly within one program. Alternatively, the use of two systems operating in the same environment (i.e., Windows) would substantially reduce potential data exchange problems.

The system should also allow the user to input polygons which describe observed/actual locations of spills. The model should be capable of incorporating these data and continuing the trajectory based on the observed data (polygons).

The GIS should support a method of representing the locations of deployed spill containment and deflection booms. Ideally the model should be capable of estimating the effectiveness of the booms based on the modeled currents and wave heights when compared with failure values entered by the user.

2.9 Commercially Available Models

Table 2.1 (below) lists each of the known commercially available spill trajectory models and provides an indication of their capabilities according to a number of different categories.

Table 2.1 - Model Capability Matrix

	Platform	Modelling Modes			User Updatability						Oil Fates Algorithms					Release Types		
		deterministic	stochastic	receptor	spill location	wind	oil types and properties	spill types and volumes	coastline	hydrodynamics	spreading	evaporation	dsipersion	emulsification	sinking	instantaneous	linear	non-linear
Applied Sciences **OILMAP**	Win 95	●	■	▲	●	●	●	●	⬓	⬓	●	●	●	●	■	●	●	□
BMT Marine **OSIS**	Win 95	●	■	▲	●	●	●	●	○	⬓	●	●	●	●		●	●	□
Meteo France **Oil Spill Model**																		
Danish Hyd. Inst. **SAW**																		
IKU **OWU**		n/a	n/a	n/a	n/a	●	●	●	n/a	n/a	●	●	●	●		●	●	
NOAA **ADIOS**	Win 95	n/a	n/a	n/a	n/a	●	●	●	n/a	n/a	●	●	●	●		●	●	
Oceanor **OSCAR**																		
Seaconsult **SPILLSIM**	Win 95	●	■	▲	●	◒	●	●	■	□	●	●	●	●	⬓	●	●	■
WINOIL **ESC**	Win 95	●	■	▲	●	●	●	●	■	⬓	●	●	●	●	■	●	●	□

essential features
● fully supported
◒ partially supported
○ not supported

important features
■ fully supported
⬓ partially supported
□ not supported

unnecessary features
▲ fully supported
◭ partially supported
△ not supported

n/a = not applicable

Where possible, the programs were either observed or tested and values were assigned. However, little first-hand information is known about some of the models and, in some cases, scored values were based solely on information provided by the program developers/vendors.

Within each category, individual criteria are coded to indicate importance, i.e., round icons indicate essential elements, square icons represent important elements, and triangular icons represent useful - but likely not necessary elements. These are provided for ***guidance only*** and it is recognized that individual requirements will vary greatly depending on the user and his/her specific application.

Table 2.1 - Model Capability Matrix (cont.)

	Hydrodynamics				Sensitivity Mapping		Spill Response			Sub-Surface		Model Outputs			Other	
	background	tidal	import data from current meters	import data from other models	mapping capability	links to GIS software	update model with observed data	oil booms	dispersants	sinking and re-floating of oil	sub-surface spreading	printed maps	graphs/charts	text files	experience with ARPEL members	costs
Applied Sciences **OILMAP**	●	●	■	▲	■	▲	■	▲	△	■	▲	●	■	■	▲	
BMT Marine **OSIS**	●	●			⬓	◭						●	■	■		
Meteo France **Oil Spill Model**																
Danish Hyd. Inst. **SAW**																
IKU **OWU**																
NOAA **ADIOS**	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	■	■	▲	free
Oceanor **OSCAR**																
Seaconsult **SPILLSIM**	●	●	□	◭	⬓	◭	□			□	△	●	■	■		
WINOIL **ESC**	●	●	■	▲	⬓	▲	□	△	△	□	△	●	■	■	△	

essential features
● fully supported
◒ partially supported
○ not supported

important features
■ fully supported
⬓ partially supported
□ not supported

unnecessary features
▲ fully supported
◭ partially supported
△ not supported

n/a = not applicable

Applied Sciences Associates reports that their models have/are been used by PDVSA, PEMEX, Bridas, BP Trinidad, the Clean Caribbean Cooperative and a number of CCC members including Esso, Chevron and Amoco.

Environmental Software Consultants reports that WinOil, which is based on Applied Sciences Associates' WOSM software, should be commercially available in 1998.

The ADIOS model, available from NOAA, provides only weathering algorithms, and is designed as a decision-making tool for chemical dispersion and in-situ burning. No calculation of the transport of the oil is carried out.

Seaconsult reports that they have 6 users worldwide although none in Latin America.

SINTEF reports that they have 10 users worldwide although none in Latin America.

3.0 Information Needs

There are a number of types of data required to run spill trajectory models. Depending on the type of modelling to be performed, these might include:

- coastline
- water depth (bathymetry)
- currents (tidal, seasonal, and fresh water influences)
- wind forecasts (deterministic modelling)
- wind histories (stochastic modelling)
- air temperature
- water temperature
- oil type and physical/chemical characteristics
- the nature of the spill (instantaneous or continuous release)
- sea state (calm, protected or open water)
- information on shoreline and shore types

Models must calculate both the fate (what will happen to the physical/chemical characteristics of the oil) and the trajectory of the spill. These calculations depend on the oil properties, i.e., viscosity, pour point, and flash point and the environmental conditions. For example, a spill of fresh light crude oil on a warm, breezy day will evaporate quickly, while a spill of heavy, viscous Bunker C into cold water will persist for a considerable time and may even sink over time.

The model should also consider the multiple effects of tidal constituents (i.e., M2, K1), seasonal patterns (see Figure 3.1) and possibly also fresh water influences, as well as wind- driven currents. Models of some more hydrodynamically complex areas may require eight or more tidal constituents although this is probably not necessary for most applications.

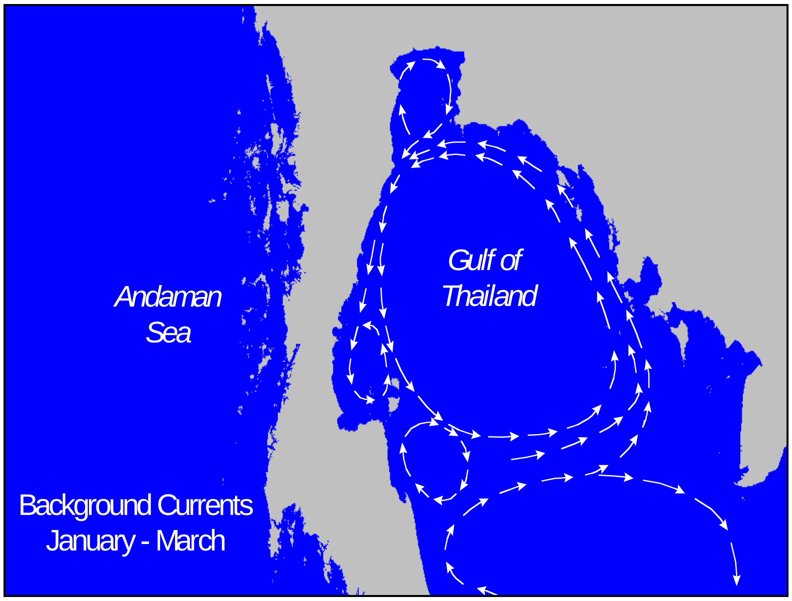


Figure 3.1 - Background Currents in the Gulf of Thailand

Some models support current data in a time series format. This capability allows data to be imported from other hydrodynamic models, current meters and sea surface radar.

It should be noted that while a number of available models allow the user to develop simple seasonal and tidal current patterns, the setup and calibration of a hydrodynamic model is an extremely complicated task and should only be attempted by trained modelling professionals.

4.0 Types of Models

As previously mentioned, there are three different types of models:

- deterministic (where will a specific spill go?)
- stochastic (what are the chances of oil coming ashore if a spill occurs?)
- receptor (where did the oil come from?)

Regardless of the model type, it is important that the modeller develop a simple, logical approach that can be applied to different models.

4.1 Deterministic Modelling

Deterministic models (see Figure 4.1) are the simplest types of models because the spill location, volume and oil type are all known. Normally, recent environmental conditions, i.e., wind and temperature, and hydrodynamics (currents) for the area are also known. The only unknowns are what will happen to the oil, i.e., how will it weather and where will it go? These models are often used on a real-time basis for spill response but are also useful for planning.

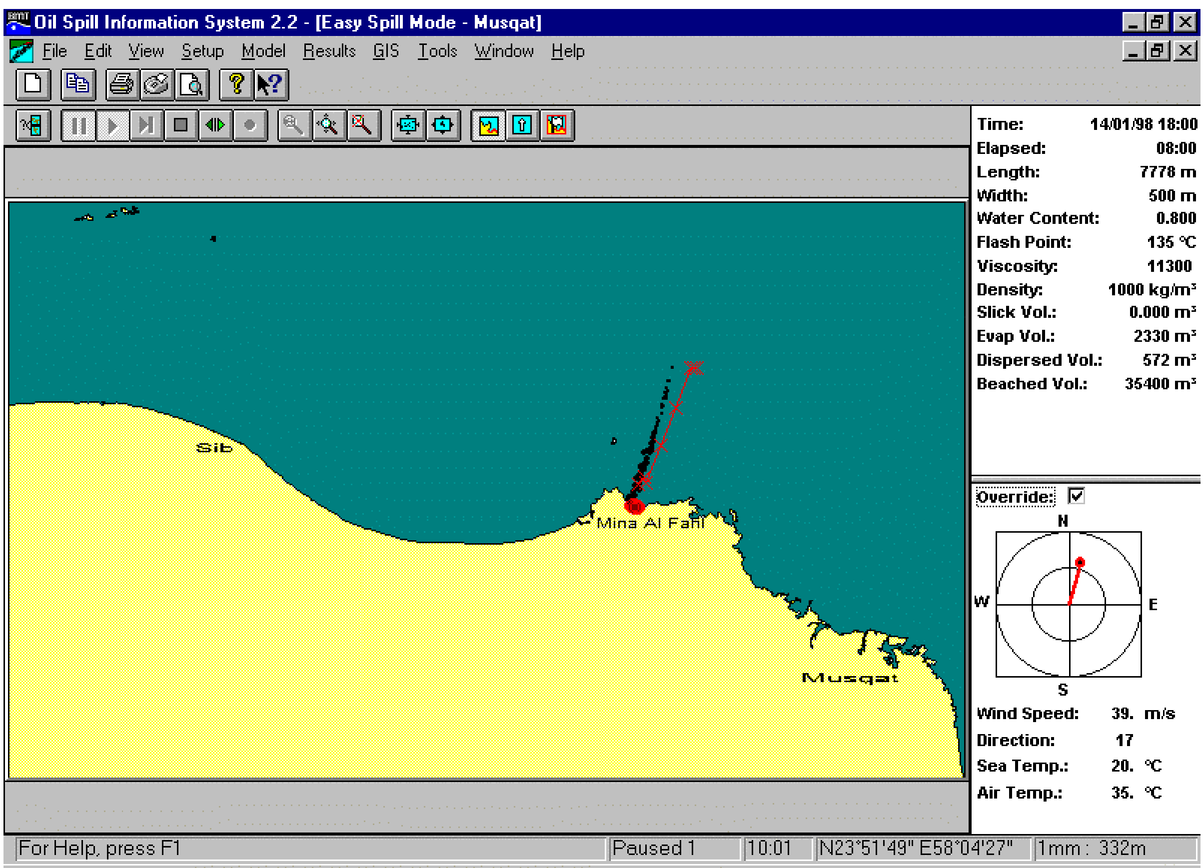


Figure 4.1 - Example Deterministic Model in the Gulf of Oman

4.2 Stochastic Modelling

Stochastic models are more oriented towards planning. They can estimate the range of distances and directions that spills from a particular location might travel, based on historical wind speed and direction information. These models run multiple (sometimes hundreds) of scenarios using various historical wind data. As a result, considerable historical wind data are required (up to 10 years). The output of a stochastic model (see Figure 4.2) can be used to identify areas where oil impact is likely to occur.

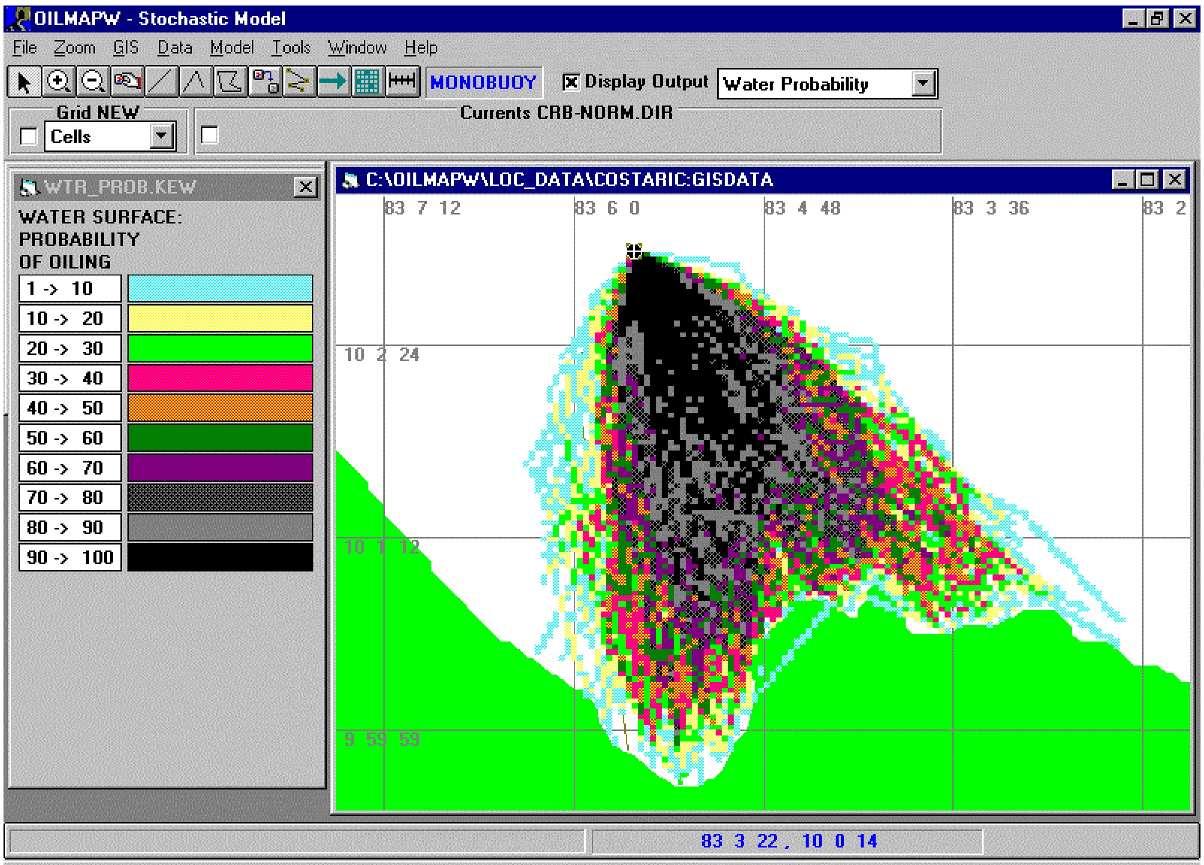


Figure 4.2 - Example Stochastic Model, Port Limon, Costa Rica

4.3 Receptor Modelling

These models are similar to stochastic models except that the model is run in reverse. They can be used in conjunction with chemical analysis methods, i.e., gas chromatography, pattern analysis, HPLC, etc., to identify possible unknown spill sources.

5.0 Running Models

The specific approach to running models depends on the software used and the types of models being developed. However, the following seven-step process can generally be followed when setting up a model.

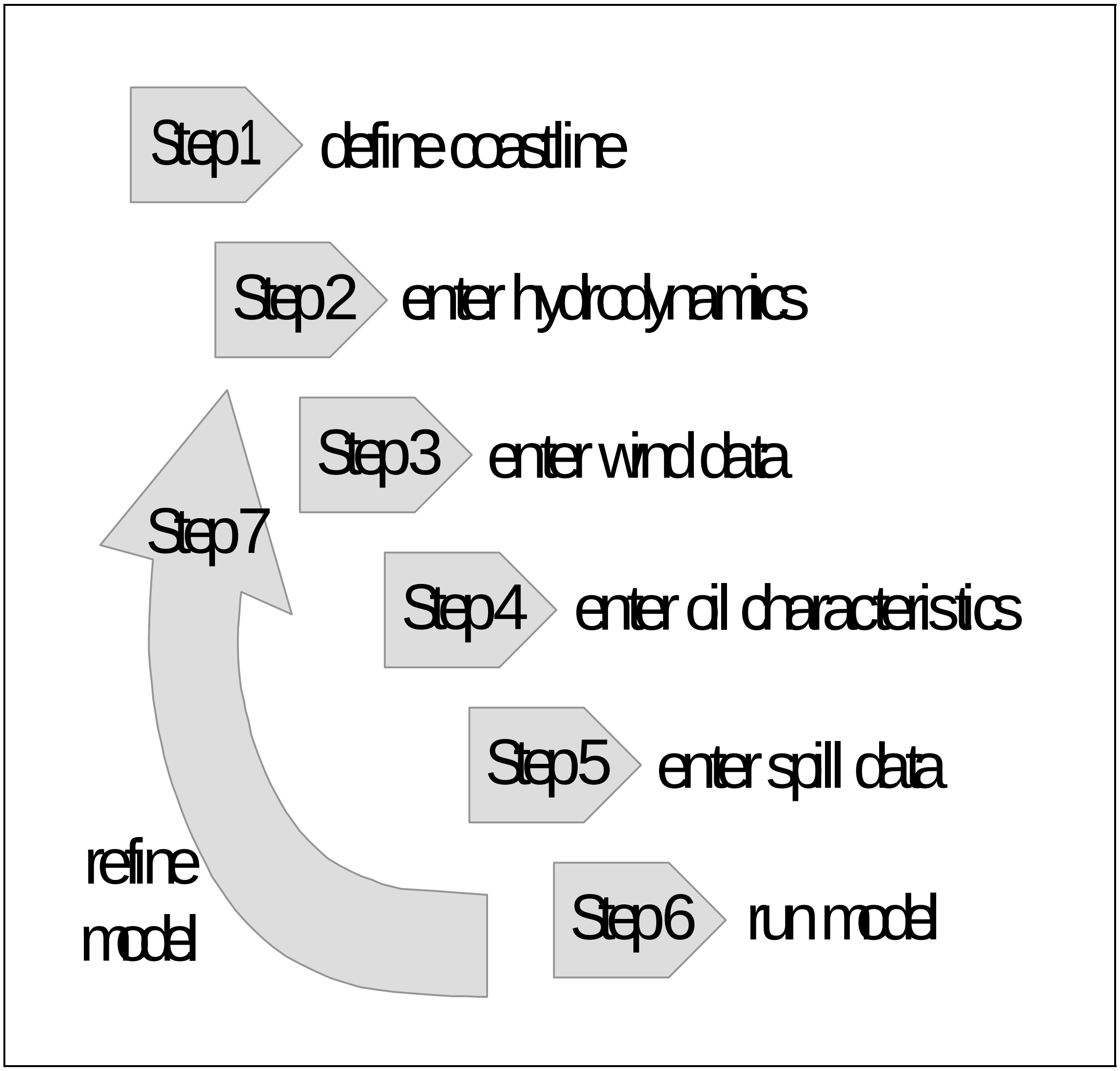


Figure 5.1 - Seven-Step Modelling Process

5.1 Step 1 - Define Coastline

The first step of the modelling process is to define the coastline for the area. Coastline data files can normally be purchased from a software vendor, or digitized from charts. There are a number of CD-ROMs available which have digital files of the world's coastline at 1:100,000. This should be sufficient for most model applications. If greater detail is required, then the coastline will have to be either scanned or digitized manually.

Most models require the user to define both land and water areas. Usually, land can be easily differentiated from water on the computer screen since it is normally *painted* in different colours.

The computer, however, requires a grid, with two types of cells, one each for land and water (see Figure 5.2).

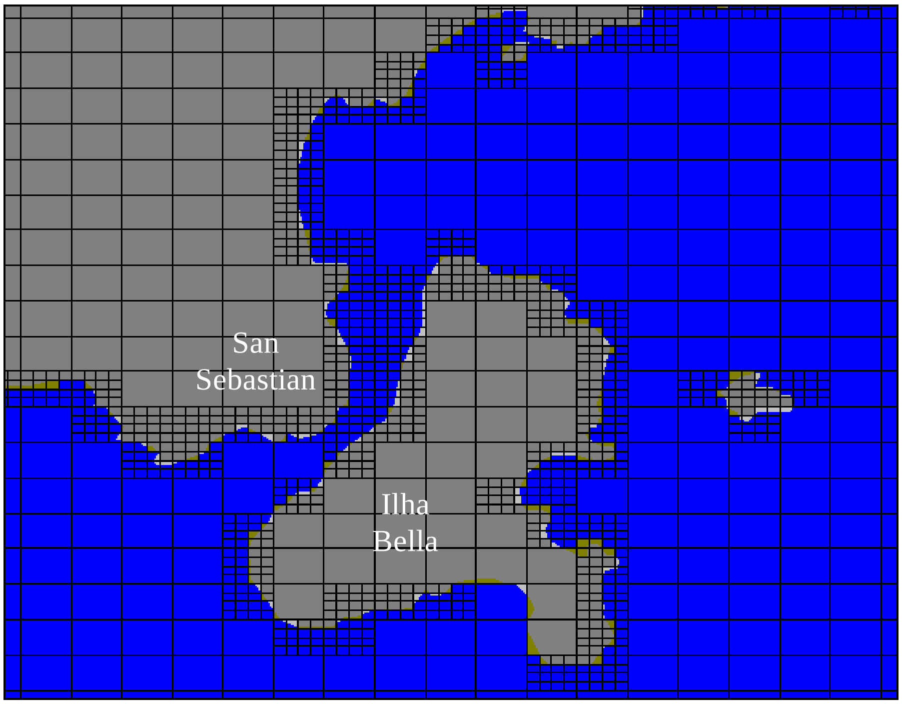


Figure 5.2 - Example Coastline Grid, San Sebastian, Brazil

Some programs allow the creation of subdivided grid cells to further define the coastline (as shown above).

Some, more sophisticated programs also allow the user to define the shoreline types. This serves two purposes. First, it provides a quick and easy method of graphically depicting different shore types, i.e., with different colours. Also, the model may consider the shoreline type to determine the length of time that oil might be stranded on the shore. For example, oil will not usually be stranded on an exposed rocky headland for a long time while oil could persist on a marsh or mudflat for several months or more.

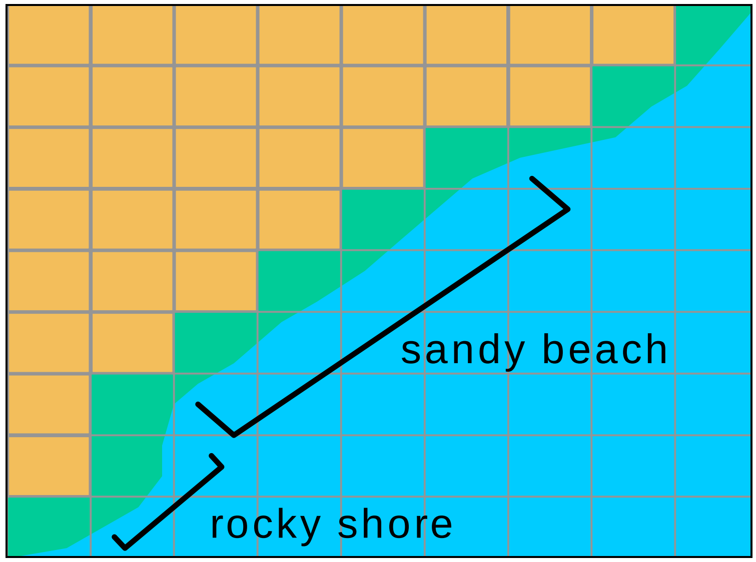


Figure 5.3 - Defining Shoreline Types

5.2 Step 2 - Develop a Current (Hydrodynamic) Field

The development of a current field is the most important step in the modelling process since the hydrodynamics are the building block on which the model is based. It is advised that modelling experts (trajectory software providers usually have this capability) develop the hydrodynamic model. Some models provide the user with simple current *painting* tools to develop their own models and, with some practice, users can sometimes quickly develop simple models which closely describe real current patterns. Their use is limited to cases (typically offshore) where the currents are driven by one principal tidal constituent and where there may not be time to develop a sophisticated model.

Note The development of complex mathematical models is beyond the scope of this Guideline. Those interested in in-depth modelling methods should consult Appendix B - Additional Reading/Modelling Resources.

All hydrodynamic models utilize a grid of some sort or other. There are a number of different types of grids, i.e., rectangular, triangular, and irregular. Also, some models calculate currents at the centre of each grid cell while others calculate current values at the intersection of the grid lines. A typical current grid (depicting background current vectors) is shown in Figure 5.4.

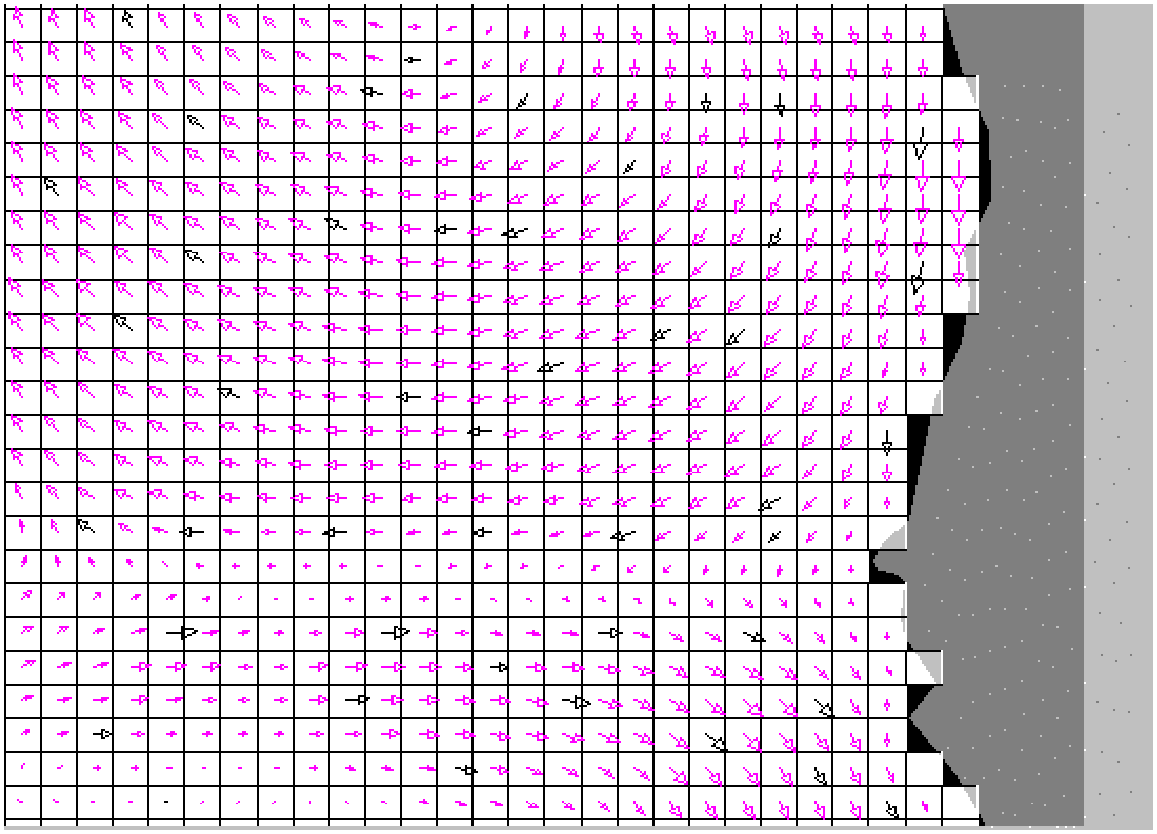


Figure 5.4 - Example Rectangular Current Grid, Gulf of Tarouba, Trinidad

Hydrodynamic models usually include various tidal components, i.e., M2, K1, etc. Normally, only a few of these constituents have a dominant influence on the tide, depending on the latitude and other factors such as bathymetry. While it is possible to include many of the lesser influential tidal constituents, including them may not be necessary, especially given the low tolerance (high uncertainty) of the more important variables. Their inclusion will likely merely complicate the model and not improve its accuracy.

Some programs allow the user to *paint* both tidal and background current patterns on the screen. Flood tides for various tidal constituents can be entered by the user and the software will automatically calculate the values (the model assumes that the currents are rectilinear and equal in magnitude in both directions) for the remainder of the tidal cycle. Other features, including spreading, smoothing and scaling algorithms are provided to facilitate the depiction of the currents across the current field.

Note Such programs merely provide rough estimates and are not intended to be mathematically perfect. It is possible to develop current patterns that are inherently impossible, i.e., there is no assurance that the conservation of mass or momentum laws are satisfied. Also, these *paint* programs are not capable of depicting complex current patterns where reverse eddies or other anomalies are present. In these cases, in-depth hydrodynamic studies should be performed by experts and then incorporated into the model.

Programs with *current painting* capabilities are particularly useful in cases where a spill has occurred in a region where no hydrodynamic model exists, and a quick, rough estimate of slick trajectories is necessary.

5.3 Step 3 - Enter Wind Data

Wind can play an important role in the model, both in terms of wind-driven current and in the amount of wave energy, which can greatly enhance the dispersion of oil into the water column. Incorporating wind data might involve entering data into tables, importing real-time data directly from meters, or by simply picking points on a wind rose (see Figure 5.5).

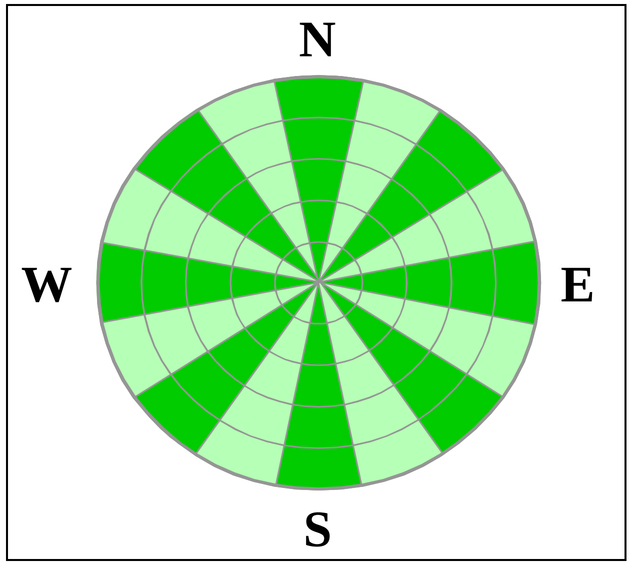


Figure 5.5 - Wind Rose

5.4 Step 4 - Enter Oil Characteristics

The oil type (and its characteristics) might also play a key role in the model. For example, gasoline or light crude oils evaporate much more quickly than diesel or heavier crude oils. Oil viscosity might change significantly over the spill period and can be estimated. Most (if not all) models have a number of pre-loaded oil types from which the user can choose. Some programs also allow the user to define new oil types by delineating their properties, including:

- density
- viscosity
- interfacial tension
- maximum water content
- initial boiling point
- chemical composition
  - % saturates
  - % aromatics
- minimum slick thickness
- toxicity (if impacts to biological resources are to be modelled)

5.5 Step 5 - Enter Spill Data

Finally, before running the model, the user must define a number of variables specific to the spill including:

- volume
- location
- (release) start time
- (release) end time
- (model) start time
- (model) end time
- type of release, i.e., instantaneous (batch) or continuous
- water/air temperature

5.6 Step 6 - Run the Model

Once the model is prepared, it is important that the user implement the model in stages. For example, if a model were intended to ultimately include tidal (i.e., M2), background, and wind-driven current, the user should run the model with each current component individually to ensure that the output is appropriate. Much like using a calculator, the modeller should have some idea of what the outcome will be before starting the model. Once each component is observed to provide reasonable results, they can be combined.

Before the model is run, it will be necessary to set a number of model parameters which the software will consider during the calculations. These include:

- model step time interval
- model output interval
- number of oil particles (most models divide the slick into small oil fragments)
- wind factor, i.e., 3% or 3.5%
- spreading coefficient
- horizontal diffusion
- minimum oil layer thickness

5.7 Step 7 - Refine the Model

It is extremely rare that a model perfectly depicts the desired trajectory on the first attempt. Instead, the modeller should refine the model using whatever information is available, including:

- satellite data
- observed data
- aerial photographs
- anecdotal information from fishermen or others familiar with local current patterns
- current meters

6.0 Model Outputs

Generally, there are three types of output from spill trajectory models. The most common (see Figure 6.1) is a map showing the trajectory of the spill.

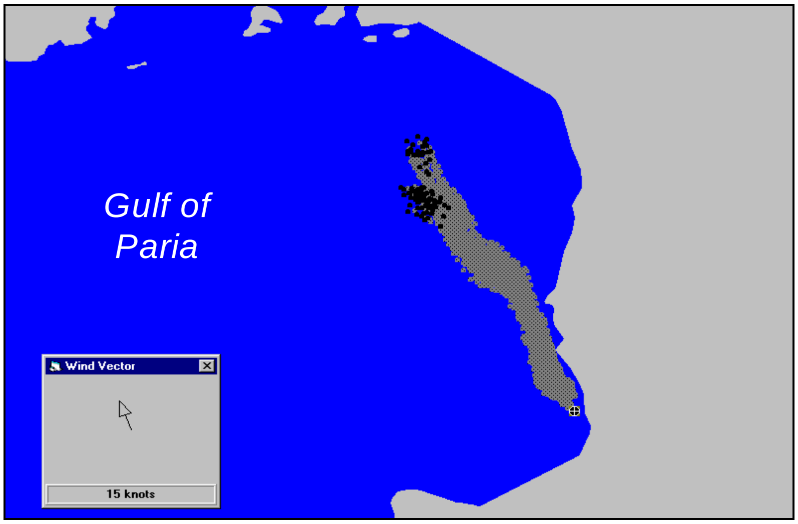


Figure 6.1 - Example Output, Point a Pierre, Trinidad

Other model outputs include text files (see Figure 6.2), which are often very large, indicating amounts of oil (values are in barrels in the example) on the surface, in the water column, stranded on shore, and evaporated, for each time step in the model.

Time	Surface	Water Column	Ashore	Evaporated
0.0	10000	0	0	0
1.0	9373.047	0	0	627.0743
2.0	9079.59	0	0	920.8975
3.0	8882.324	0	0	1118.498
4.0	8731.934	0	0	1268.583
5.0	7345.771	0	828.0655	1826.445
6.0	6659.486	0	1224.172	2116.476
7.0	6334.435	0	1394.476	2271.224
8.0	5110.62	0	2182.099	2707.425
9.0	5062.425	0	2184.404	2753.385
10.0	5019.46	0	2185.936	2794.751
11.0	4978.103	0	2188.764	2833.211

Figure 6.2 - Example Text File Output

An oil fates graph (see Figure 2.2) can depict the same information in a graphic format which is considerably easier to interpret and determine patterns.

Some programs with Sensitivity Mapping functionality also include a *Resources Hit* report (see Figure 6.3) which indicates those sensitive resources in the projected path of the spill.

Resources Hit Report

Layer : SALT MARSH
Object Type : Polygon
Name : SALTMARSH
Description : SALT MARSH

Layer : DUNE
Object Type : Polygon
Name : SAND DUNE
Description : SAND DUNE

Layer : SEALS and/or CETACEANS
Object Type : Point
Text1 : Seal and/or Cetacean Site
Text2 : North Lincolnshire Coast
Source : Nature Conservancy Council

Layer : WADERS & WILDFOWL
Object Type : Point
Text1 : Waders and Wildfowl Site
Text2 : North Lincolnshire Coast
Text3 : Birds present 12 months of the year
Source : Nature Conservancy Council

Layer : OTHER SEABIRDS
Object Type : Point
Text1 : Seabird Site
Text2 : North Lincolnshire Coast
Text3 : Birds present April Through July
Source : Nature Conservancy Council

Layer : REGIONAL FISHING ZONES
Object Type : Polygon
Name : North Lincolnshire
Text1 : North Lincolnshire Coast Fleet

Layer : REGIONAL FISHING ZONES
Object Type : Polygon
Description : River Boat Fish Zone

Layer : OFFSHORE LEASE SITES
Object Type : Polygon
Text1 : Proposed site of continental shelf
Text2 : offshore licensing award

Figure 6.3 - Example Resources Hit Report

7.0 Hardware Requirements

Computer hardware requirements, whether IBM- or Mac-based, will depend on the type and nature of the software used. It should be noted that most commercially available trajectory models are IBM (Windows-based).

IBM Computers

Generally, 486 or Pentium machines with at least 16 Mbytes of RAM are essential. In most cases, high resolution colour monitors and colour printers will also be needed.

Macintosh Computers

The same strategy applies to Mac users with a minimum requirement of an 040 based machine to run simple models and 601 or 604 PowerMacs with at least 16 Mbytes of RAM to run more complex models. As with the IBM computers, high resolution colour monitors and printers are needed.

8.0 Conclusions & Recommendations

Computerized oil spill trajectory models, when applied effectively, can provide invaluable assistance to contingency planners, risk assessors, trainers, and emergency responders.

There are a number of commercially available oil spill models which have been designed and tested sufficiently to provide ARPEL member companies with the capability of confidently predicting the paths and chemical characteristics of oil spills which could threaten shorelines or other significant resources. Models which also allow the creation of oil spill sensitivity maps or provide links with GISs are preferred.

There are also a number of locally available (often from a nearby university) programs which, although technically sound, usually offer little in the way of user features or graphics. These models are likely significantly less expensive to purchase. However, hidden costs related to the lack of technical support, upgrades, ease of use, and documentation generally make these models undesirable for industry.

The capital cost of implementing a commercial oil spill modelling program ranges from US$15,000 - US$50,000 depending on the software chosen and the complexity of the currents in the area of concern. Internal costs of implementation would include the training of personnel (normally less than one week) and the time (likely one to six person-weeks per year) to maintain the system. Hardware costs should me minimal as most programs should operate on existing computers.

These costs of implementation are relatively small when compared with the potential savings if the software were applied to any of a number of possible issues such as:

1 the positioning of a single point mooring system in a location least likely to result in environmental impact of an adjacent shoreline
2 the decision whether to apply chemical dispersants to a spill (at a cost of US$500,000 per day) which might drift offshore or might disperse naturally if left untreated
3 the location of oil spill response equipment
4 the development of spill response strategies
5 the training of emergency response teams
6 the creation of computerized oil spill sensitivity maps and an associated GIS

The procurement and development of an oil spill model should involve a team of interested individuals within the organization to ensure that all team members needs are met when the project is complete.

Finally, when considering an oil spill model, consult other ARPEL member companies who have experience with many of these models and their developers.

Appendix A Modelling System Vendors

Company/Address	Product(s)	Contact Information
Applied Sciences Associates, Inc. 70 Dean Knaus Dr. Narragansett, RI 02882-1143 USA	Oilmap for Windows WOSM	Phone (401) 789-6224 Fax (401) 789-1932 e-mail ela@appsci.com web site www.appsci.com
BMT Marine Information Systems Limited Grove House, Meridian Cross 7 Ocean Way, Ocean Village Southampton, Hampshire UK SO14 3TJ	OSIS SOCRATES	Phone 01 (703) 232222 Fax 01 (703) 232891 e-mail web site www.bmtmis.com
Danish Hydraulic Institute Agern Alle 5 Horsgolm DK-2970 Denmark	SAW	Phone (45) 45-769-555 Fax (45) 45-762-567 e-mail web site
Environmental Software Consultants 65 Ferris Rd. Toronto, ON Canada	WINOIL	Phone (416) 285-9305 Fax (416) 285-9305 e-mail dmcgesc@aol.com web site
IKU	Oil Weathering Model	Phone Fax e-mail web site
METEO - France		Phone Fax e-mail web site
NOAA HAZMAT Division 7600 Sand Point Way NE Seattle, WA 98115 USA	ADIOS	Phone (206) 526-6317 Fax (206) 526-6329 e-mail web site
OCEANOR Pir-Senteret 7005 Trondheim Norway	OSCAR	Phone (477) 52-5050 Fax (477) 52-5033 e-mail web site
Seaconsult Marine Research Inc. 8805 Osler St. Vancouver, BC V6P 4G1 Canada	SPILLSIM	Phone (604) 266-9135 Fax (604) 266-8855 e-mail web site

Appendix B Additional Reading/Modelling Resources

Publications

Bennett, A. F., *Inverse Methods in Oceanography*, Cambridge Press, UK, 1993.

Copeland, G. J. M., *"An Inverse Method of Kinematic Flow Modeling Based on Measured Currents"*, Proceeding of Civil Engineering Water, Maritime, and Energy, Vol. 106, pp. 249-258, 1994.

Muin M. and M. L. Spaulding. *"Three Dimensional Boundary Fitted Circulation Model"*. Journal of Hydraulic Engineering, Vol. 123, No. 1, pp. 2-12, 1997.

NOAA. *"Digital Distribution Standard for NOAA Trajectory Analysis"*. Prepared by Hazardous Materials Response and Assessment Division, National Oceanic and Atmospheric Administration and Florida Marine Research Institute and Florida Department of Environmental Protection, HAZMAT, 43p, 1996.

Spill Trajectory Analysis - Questions and Answers, NOAA HAZMAT Report 96-6, April, 1996

Modelling Resources

Materials Management Service (MMS)
USA
Contact Mr.Walter Johnson
(703) 787-1642

National Oceanographic & Atmospheric Administration (NOAA)
USA
Contact Hazmat Division
(206) 526-6400

US Geological Survey
USA
Contact Dr. Roy Walters
(303) 236-5024

Appendix C Cartographic Agencies of Mexico, Central America, South America and the Caribbean

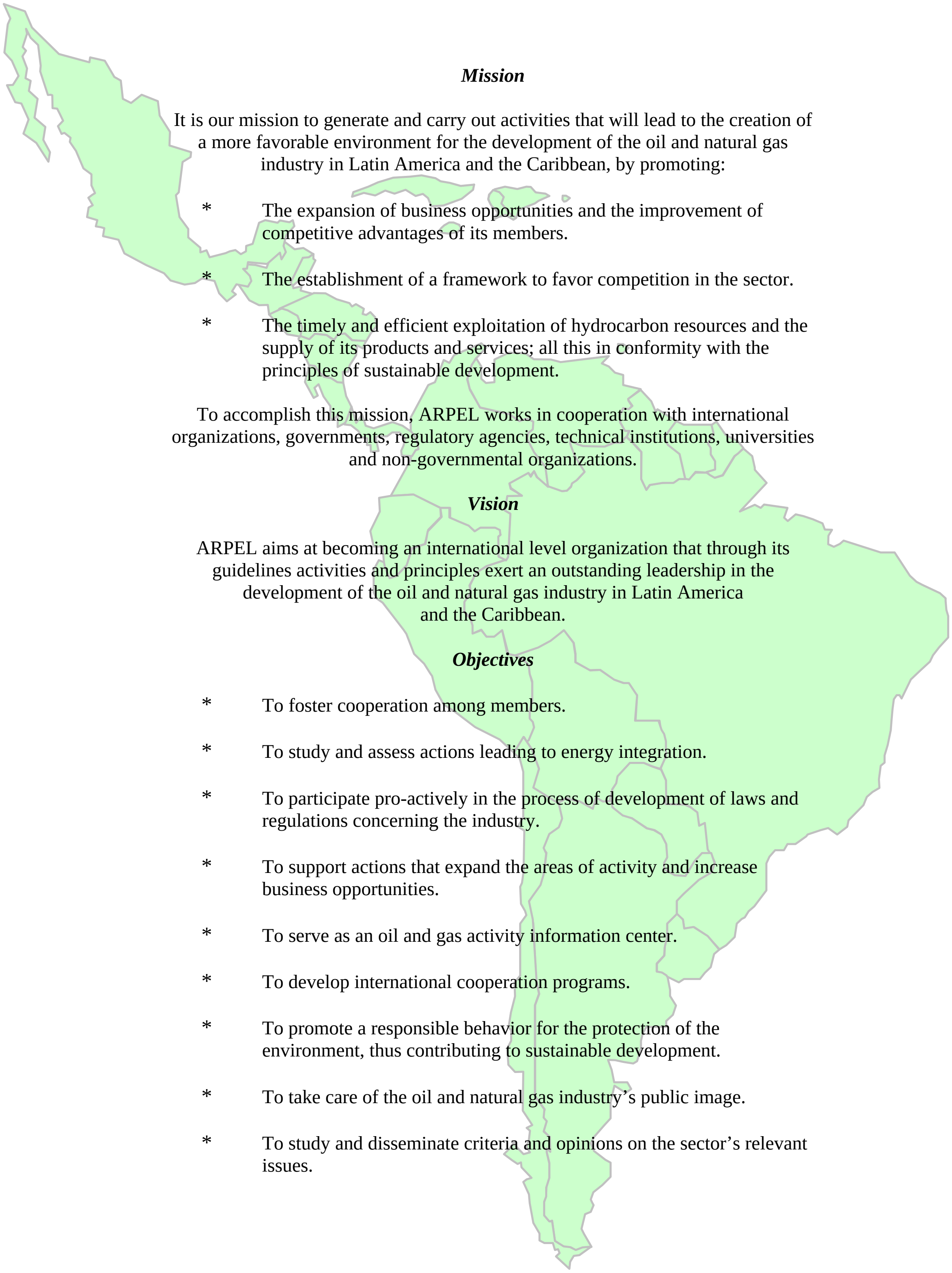
Country	Agencies
ARGENTINA	Instituto Geográfico Militar Avenida Cabildo 381 1246 Buenos Aires Telephone 771-3031
BAHAMAS	Director of Lands and Surveys P.O. Box N-592 Nassau
BELIZE	Belize Meteorologist/Hydrologist Ladyville Telephone 501-025-2012 Telex 251 BTL BUREAU DZ
BOLIVIA	Servicio Geológico de Bolivia Federico Zuazo, Esq. Reyes Ortiz Casilla de Correos 2729 La Paz Telephone 326278
BRAZIL	Instituto de Pesquisas Espaciais Caixa Postal 515 12201 Sao Jose dos Campos Sao Paulo, SP Telephone (0123) 22-9509 Telex (123) 3530 INPE BR Directoria do Servico Geografico do Exercito SMU-QG Ex., Bloco F. 20 Pav. 70630 Brasilia, D.F. Telephone (061) 223-8529 Telex (061) 1094 Directoria de Geodesia e Cartografia Instituto Brasileiro de Geografia e Estatistica Av. Franklin Roosevelt, 166 100 Andar 20021 Rio de Janeiro, RJ Telephone (021) 220-6671/6821 Telex (021) 30939 Projeto RADAM CRS 509, Bloco A, Loja 1 a 5 70360 Brasilia, D.F. Telephone (061) 244-9432 Telex (061) 2243

Country	Agencies
COLOMBIA	Instituto Geográfico Militar Subdirección Cartográfica Carrera 30 No. 48-51 Bogotá Telephone (571) 3681215 Facsimile (571) 3680991 Email codazzi.igac.gov.com
COSTA RICA	Servicio Geod sico Interamericano Instituto Geográfico Nacional Telephone (506) 222-6413 Comisión Nacional de Emergencias Telephone (506) 220-2020
CUBA	División Comercial TECNOTEX - GEOCUBA Calle No. 303, Miramar, Playa La Havana 11300, Cuba Telephone 22 28 91, 237474, 234101 Facsimile 22 28 91, 332869, 331682 Email: codazzi.igac.gov.com
EL SALVADOR	Ministry of Public Works La. Av. Sur No. 630 San Salvador Telephone 71-6026 Center for Geotechnical Research Avenida Peralta, final. contiguo a Talleres El Coro San Salvador Telephone 22-9011 National Geographic Institute “Ingeniero Pablo Arnoldo Guzman” Avenida Juan Bertis No. 79 San Salvador Telephone 25-5060 Weather Forecast and Hydrology Service Renewable Natural Resources Center Canton El Matazano, Soyapango San Salvador Telephone 27-0484/27-0622

Country	Agencies
	Ministry of Agriculture Alameda Roosevelt 2823 San Salvador Telephone 23-24434/24-2944 General Directorate of Irrigation and Drainage Canton El Matazano, Soyapango General Directorate of Irrigation and Drainage Canton El Matazano, Soyapango San Salvador Telephone 77-0490
GUATEMALA	Military Geographic Institute Avenida de las Américas 5-76, Zona 13 Guatemala Telephone 363281 to 83
GUYANA	Lands and Surveys Department 22 Upper Hadfield Street D'urban Backlands Greater Georgetown Telephone (02) 72582/60524-9
JAMAICA	Survey Department P. O. Box 493 231/2 Charles Street Kingston Telephone 809-922-6630/5
MEXICO	Departamento Geográfico Militar Servicio Cartográfico Secretaría de la Defensa Nacional Lomas de Sotelo Mexico 10, D.F.

Country	Agencies
PANAMA	Instituto Geográfico Nacional "Tommy Guardia" Apartado Postal 5267, Zona 5 Panama Telephone 64-0444
PARAGUAY	Military Geodetic Service Avenida Artigas y Via Ferrea Asuncion Telephone 208858 Ciudad Universitaria Km 10, San Lorenzo Institute of Basic Sciences Telephone 501517
PERU	Geological Mining and Metallurgical Institute Pablo Bermudez 211 Apartado 889 Lima Telephone 316233 National Office for Evaluation of Natural Resources Calle 17 # 355, Urb. El Palomar San Isidro, Lima Telephone 410425 General Bureau of Aerophotography Base Aerea "Las Palmas" Barranco, Lima Telephone 670538 Telex 21501 PE Military Geographic Institute Av. Andres Aramburu 1198 Apartado 2038 Lima Naval Bureau of Hydrography and Navigation Calle Saenz Pena No. 590, La Punta Callao, Lima Telephone 652995

Country	Agencies
SURINAME	Central Bureau Luchtkaartering P. O. Box 971 Dr. Sophie Redmondstraat 131 Paramaribo Telephone 74421
TRINIDAD and TOBAGO	Ministry of Planning and Mobilisation Lands and Surveys Div. Red House, St. Vincent St. Port-of-Spain Seismic Research Unit c/o University of the West Indies St. Augustine Telephone (809) 662-4659
URUGUAY	Dirección de Hidrografia Ministerio de Transporte y Obras Públicas Rincón 561, Piso 2 Montevideo Telephone 95 94 34 Servicio de Oceanografía, Hidrografía y Meteorología de la Armada Capurro 980 Montevideo Telephone 39 92 20
VENEZUELA	Servicio Autónomo de Geografia y Cartografia Nacional Avenida Este 6, Esquina de Camejo Edificio Camejo, Piso 2, Oficina 231 Caracas Telephone 408 1710-4081711



Mission

It is our mission to generate and carry out activities that will lead to the creation of a more favorable environment for the development of the oil and natural gas industry in Latin America and the Caribbean, by promoting:

* The expansion of business opportunities and the improvement of competitive advantages of its members.

* The establishment of a framework to favor competition in the sector.

* The timely and efficient exploitation of hydrocarbon resources and the supply of its products and services; all this in conformity with the principles of sustainable development.

To accomplish this mission, ARPEL works in cooperation with international organizations, governments, regulatory agencies, technical institutions, universities and non-governmental organizations.

Vision

ARPEL aims at becoming an international level organization that through its guidelines activities and principles exert an outstanding leadership in the development of the oil and natural gas industry in Latin America and the Caribbean.

Objectives

* To foster cooperation among members.

* To study and assess actions leading to energy integration.

* To participate pro-actively in the process of development of laws and regulations concerning the industry.

* To support actions that expand the areas of activity and increase business opportunities.

* To serve as an oil and gas activity information center.

* To develop international cooperation programs.

* To promote a responsible behavior for the protection of the environment, thus contributing to sustainable development.

* To take care of the oil and natural gas industry's public image.

* To study and disseminate criteria and opinions on the sector's relevant issues.

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