AN INTEGRATED PROJECT TO ANALYZE AND DETERMINE THE CONSEQUENCES OF A CHEMICAL SPILL ON THE WEST COAST OF FRANCE: AN OPERATIONAL POINT OF VIEW THROUGH THE *ECE* INCIDENT

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ABSTRACT

Within a few decades, the European coasts and seas endured major environmental incidents of chemical pollution. For example, the "Ievoli Sun" incident, October 31, 2000, which was transporting 4,000 tonnes of styrene or the "Ece" incident, February 01, 2006 in the Channel, with a cargo of 10,000 tonnes of phosphoric acid.

When a disaster occurs, authorities aspire to a faster and more effective management of pollution to limit the consequences. To this end, French authorities which take response measures for health or economic protection during a marine pollution incident need efficient software tools to assess the risks related to marine pollution. This allows them to quickly set up a relevant safety area, the aim being to protect the populations and the environment, to mobilize the appropriate response tools and to anticipate the situation in the short or medium term.

It is in this particular and significant context of crisis management of marine pollution that the CLARA ("Calculation related to accidental releases in seawater") project was developed. This project, funded by the French Research Ministry, has been carried out, since November 2003, by the Ecole des Mines d'Alès, Cedre, Ifremer, Météo-France and Ineris, in order to jointly simulate evolution of hydrodynamic flow, physicochemical characteristics of pollutants and to assess chemical behaviour in the marine environment (water and/or atmosphere). Concerning hazards, they will be defined in terms of effects on the aquatic environment, bio-accumulation capacities of substances in marine organisms and toxicological thresholds (e.g. IDLH: Immediately Dangerous to Life or Health). This software is a preliminary approach to assess toxicological and ecotoxicological risks of accidental marine spills.

This paper presents the model developed and its different functionalities through a concrete case: the Ece accident. This presentation takes place within an operational context and aims to highlight the restraints and needs of experts and operational responders when using this kind of tool.

1 - CONTEXT AND CONTENT

When a chemical pollution occurs on European coasts, population and authorities aspire to a faster and more effective management of the pollution to limit its consequences. Currently, the French authorities in charge of public health and economic protection during a marine pollution need a fast, simple and reliable data-processing tool to manage crises. However, very few software programmes are able to predict the evolution of a chemical pollutant in water or the atmosphere, to give any information about bio-accumulation possibilities, or to assess hazards due to the chemical spill (Kelly-Gerreyn *et al.*, 2007). This particular context of marine pollution crisis management led to the CLARA project (Calculation related to accidental releases in seawater). This operational software will model the consequences of an accidental chemical spill in the sea.

This project has been carried out by the Ecole des Mines d'Alès, *Cedre*, Ifremer, Météo-France and the Ineris (ARC unit) within the framework of the RITMER project of the French Ministry for Youth, National Education and Research. This project is divided into four major phases. Initially, an analysis of existing knowledge made it possible to select the more typical pollutants which are involved in marine pollution. The second phase consists in working out a physicochemical, eco-toxicological and toxicological database. The third phase, relates the modelling of the hydrodynamic mechanisms, the behaviour of chemicals in seawater and the atmospheric dispersion in the case of a volatile product. The final phase consists of a Geographical Information System (G.I.S.) approach in order to summarize the various results. (Aprin *et al.*, 2006).

This article presents the tool which was developed through the CLARA project from an operational point of view, using the *Ece* spill as an example. This document demonstrates the response which could have been provided for the authorities and experts if this tool had been available at the time of the incident.

2 - *ECE* SPILL: DESCRIPTION OF THE INCIDENT

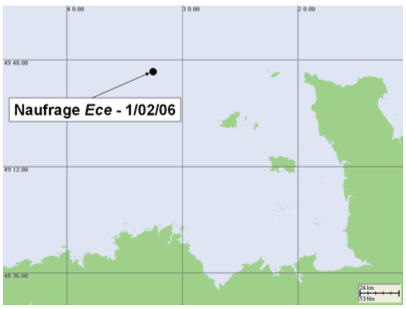

FIGURE 1: LOCATION OF THE *ECE* ACCIDENT

On the night of 30 to 31 January 2006, the Maltese bulk carrier the *General Grot Rowecki*, transporting 26,000 tonnes of phosphates from Safi in Morocco to Police in Poland, collided with the Marshall Islands chemical tanker the *Ece* en route from Casablanca in Morocco to Ghent in Belgium (Fig. 1).

The accident occurred in a zone located 50 nautical miles (90 km) west of Cherbourg, near the Casquet Traffic Separation Scheme in international waters. The *Ece*, transporting 10,000 tonnes of phosphoric acid, developed a leak and a significant list. The regional marine rescue coordination centre (CROSS-Jobourg) coordinated the crew rescue operation, in collaboration with the British Maritime and Coastguard Agency. The 22 crew members were safely evacuated to Guernsey. The tug boat the *Abeille Liberté* was sent to the scene of the accident.

The *Préfecture Maritime* for the English Channel and the North Sea (Premar-Manche) then carried out a pollution risk analysis, with the support of the French Navy pollution response centre (CEPPOL) and *Cedre*. In addition to the cargo, according to information provided by the ship owner, there were 70 tonnes of propulsion fuel (IFO 180), 20 tonnes of marine diesel and 20 tonnes of lubricating oil onboard the *Ece*. The *General Grot Rowecki*, whose bluff bow was slightly damaged, was able to continue her journey.

The tug boat the *Abeille Liberté* arrived on site on January, 31 around 7 am. The assessment teams did not note any pollution, and boarded the two damaged ships. The *Ece* showed a 25° stabilized list to port and was no longer operating. When the assessment had been completed, the vessel was taken in tow by the tug the *Abeille Liberté* at around 3:30 pm, bound for the port of Le Havre. In the course of towing, the *Ece* sank 70 m deep 50 nautical miles west of the point of The Hague, on 1st February at 3:37 am. The wreck lies in international waters, on the continental shelf of the United Kingdom, in the French exclusive economic zone and the French pollution response zone.

The Manche Plan, a bilateral Franco-British mutual aid agreement for rescue and pollution response, was activated on 1st February.

Negotiations between French and British authorities on the one hand and the ship-owner and insurers on the other hand led to an agreement being met on June,16 2006 for the removal of the fuel remaining onboard the wreck (some forty tonnes) and for the planned controlled release of the phosphoric acid, by opening the access channels to the six tanks using a remote controlled robot. The operation was undertaken by the ship-owner from the summer period to the end of September, under the control of the authorities. Fishing was banned around the wreck until operations were completed.

Information on the pollutant and risks involved:

- wreck was not deemed to be a danger for traffic
- propulsion fuel oil was to be eliminated by pumping
- the cargo of phosphoric acid was estimated at between 25 % and 80 %, and was released at sea under control
- the sea water around the wreck was monitored every week.

The following simulation is based on phosphoric acid, which is miscible in water. When spilt in water, phosphoric acid sinks and mixes with the water to release heat which is rapidly absorbed. The mixture of the acid with seawater causes an acidification of the water, however a buffering effect by the seawater, which is slightly alkaline, rapidly occurs. Phosphoric acid is not volatile at ambient temperatures. However, it can be found in the atmosphere in the form of vapours, which can lead to irritation of mucous membranes. The greatest risk is the contact of the chemical with tissues: phosphoric acid is corrosive and causes irritation or even burns in the case of prolonged contact.

Acidification of seawater (pH of less than 5) can be fatal for the aquatic environment. However, these high acidities can only be found in the area directly surrounding the spill location and only for a limited period of time which will depend on the agitation of the water. The phosphate ions formed are not bioaccumulated (Cedre, 1990).

3 - SIMULATION OF A PHOSPHORIC ACID SPILL DURING THE *ECE* INCIDENT

3 – 1 Presentation of the CLARA software

The CLARA software is made up of two coupled entities, each with different functions:

- One component designed to create scenarios, to obtain toxicological and physicochemical information on products and to conduct hydrodynamic and physicochemical simulations. This element is referred to as the "input interface".
- A second component designed to analyse the results of simulations, the evolution of concentrations and dispersion of the product in the water or atmosphere. This element is referred to as the "display interface".

Simulations are conducted in three stages.

Stage 1: Creating a scenario
First, the weather forecast file, when available, is integrated from the secured Météo-France Internet server. Otherwise, a spatially homogeneous wind speed and direction can be entered manually in a new window.

When the weather forecast has been integrated, the user must fill in the following data fields: "Date, time and location of spill", "Number of days simulated".

Stage 2: Conducting a hydrodynamic simulation
The user can then conduct a hydrodynamic simulation by selecting the relevant hydrodynamic models for the area in question from a drop-down menu. The composition of the different models is based on a method involving several nested models of varying coverage and resolution, which together cover the whole of the French Atlantic and Channel coastline, with a horizontal resolution of 800 m and a vertical resolution on 10 levels (Pous *et al.*, 2004).

The different models run one after the other for a total duration of 50 minutes (on a standard PC computer) in the case of a 5-day simulation.

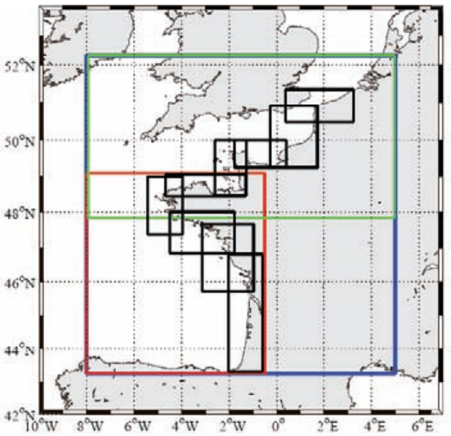

FIGURE 2: DOWNSCALING FROM LARGE MODEL (THREE MODELS DOMAINS: GREEN, BLUE AND RED FRAMES) TO LOCAL MODEL (NINE MODELS DOMAINS: BLACK FRAMES) WITH INCREASING RESOLUTION.

At the moment, CLARA model is available for the Atlantic Ocean and the English Channel. In the future, CLARA could be adapted with minor constraints to other part of the world; the model would need operational model results available with suitable time step and domain. The necessary inputs are:

- Conservative 3D velocity field
- Sea level (only for tidal areas)
- Temperature and salinity fields
- Turbulence parameters : eddy diffusivity
- Wind stress (to calculate evaporation rate if necessary)
- Wind field (10, 50 and 100 meters) (for atmospheric simulation if necessary)
- Chemical variables (from chemical database)

Stage 3: Conducting a physicochemical simulation
As soon as the hydrodynamic simulations are completed, the user can execute a physicochemical simulation, in association with a hydrodynamic simulation and assess the environmental and human health risks. A product must be chosen from the drop-down menu. If the product is not available, the user can search in the existing database for a product with similar physical properties (density, saturation vapour pressure and water solubility). The spill may be instantaneous or continuous (if the spill is continuous, the percentage of immediate release and the date and time of the end of release must be entered). The spill may occur on the surface, on the seabed or at a given depth. The quantity of chemical, the surface area of the slick (default value: 1 m^2) and the time interval of release (default value: every hour) must be specified. The user can stipulate that the product has already dissolved in the vessel. The number of "spillets" is set by default at 500, but can be modified: this function determines the spatial and temporal evolution of the slick. In the case of a floating product, the user can specify a different value for the drift speed (default value: 3% of the wind speed), in order to give the wind greater or less importance for the slick drift. Finally, the user can employ a different evaporation model (Mackay & Matsugu, 1973 or Kawamura & Mackay, 1986); this option has not yet been approved due to a lack of experimental data.

In the case of an evaporating product, when the physicochemical simulation is complete, the atmospheric dispersion module automatically runs and generates a log file providing all the concentrations in the atmosphere at four different levels (10, 20, 50 and 100 metres).

The software also gives the information on ecotoxicity and toxicity of the substance spilled by providing three thresholds: the predicted no effect concentration (PNEC), for short term and long term exposure, and the IDLH (Immediately Dangerous to Life or Health).

A 5-day simulation currently requires around 20 minutes on a computer with a 2 GHz processor and 1 Gigabyte of RAM.

Finally, all the simulations (hydrodynamic and physicochemical) are carried out on average in the space of 1 hour.

Displaying the results
The interface allowing the analysis of the results presents all the functions needed to interpret the consequences of a spill at sea. This interface:

- displays the spill location on a map, as well as the geographical and bathymetric coordinates
- displays the evolution of isoconcentrations (e.g. more than one sample point exhibiting the same isolate concentration) according to the time and the depth in the case of a product which dissolves or the altitude (less than 100 m) in the case of a product which evaporates
- displays concentration graphs according to the depth for a given point and at each time step
- displays summary graphs (quantity of product evaporated, dissolved and remaining)
- displays a spatial and temporal representation of the slick on the surface and location of spillets at each time step
- displays PNEC (James *et al.*, 2006) and IDLH iso concentrations.

The colour scales, concentration rankings and detection levels can be altered. The results can be printed out and exported in the form of an image (.jpg) or of an animation.

3-2 Case study: the *Ece* spill

Given the circumstances in which the *Ece* spill occurred three different scenarios are presented here: a scenario involving a surface release due to a collision and two scenarios involving a leak from a crack in the wreck.

3-2-1 Scenario 1: spill of 5,000 tonnes of phosphoric acid in the depths
This worst case scenario in terms of the risk involved consists of a release of 5,000 tonnes due to the opening of a breach in the wreck, of which 1000 tonnes (20%) are released instantaneously. The release takes place over a period of 2 days, from 02/01/2006 at 4 am, just after the shipwrecking, until 02/03/2006 at 4 am; the simulation continues until 02/05/2006.

FIGURE 3: DISPLAY INTERFACE SHOWING ISO CONCENTRATIONS ACCORDING TO THE TIME AND DEPTH

This interface (Fig. 3) shows the evolution of iso concentrations from the spill location according to the time (cursor along the upper edge is used to navigate throughout the 5 days of simulation) and the depth (left-hand cursor). In this example, the map displays the result at 07:57 am the 01/31/2006, depth: 90 meters.

FIGURE 4: DISPLAY INTERFACE SHOWING MAXIMUM ISO CONCENTRATIONS FOR THE ENTIRE DEPTH ACCORDING TO THE TIME

This interface (Fig. 4) shows the evolution of maximum iso concentrations for the entire water column according to the time (cursor along upper edge). This rapidly provides responders with the maximum concentrations of the product through the simulation. In the case of phosphoric acid, the concentrations are at their highest a few hours after the beginning of the spill and do not exceed 4.10^{-03} kg/m^3.

FIGURE 5: PARTICLE DISPLAY INTERFACE

The movement of the slick on the water surface can be monitored using this information, which can help to guide in situ observations or measurements (Fig. 5).

In the case of an evaporating product, IDLH maps can be displayed, which can be used to determine exclusion zones to protect responders and local inhabitants.

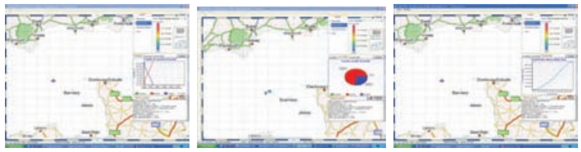

FIGURE 6: EVOLUTION OF THE BEHAVIOUR OF THE PRODUCT AND ITS CONCENTRATION IN THE WATER

A series of diagrams can also be accessed by clicking on the relevant tabs (Fig. 6). The first tab presents a diagram showing the evolution of quantities dissolved (red) and remaining (blue). In case of evaporation, the diagram displays the evolution of quantities evaporated (green). In this example, in less than one day, the product will have totally dissolved.

The second features a pie chart also showing the evolution of the product, which will continually change throughout the simulation.

The third displays a line chart showing the evolution of the concentration of the product in the water column. This can be calculated at a given point or for the whole of the affected area. In the latter case, this allows responders to very rapidly determine the predicted maximum concentration in the water column. In the chosen example, the concentration will not exceed

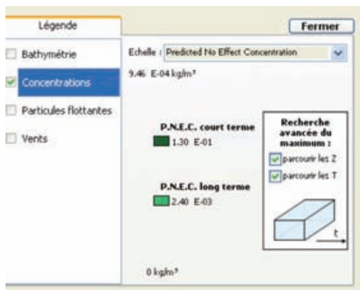

FIGURE 7: REPRESENTATION OF PNEC

If the concentration exceeds PNEC long term and short term values, it becomes visible on the map with dark green (short term) and light green (long term) colours, so as to alert responders to the environmental risk. In this scenario, the concentration (4.10^{-03} kg/m^3/ cf. Fig. 5) is less than the PNEC concentration values (long term: $1.30.10^{-01}$ kg/m^3 and short term : $2.40.10^{-03}$ kg/m^3), so there is no map representation.

FIGURE 8: ENVIRONMENTAL DATA – BATHYMETRY AND WEATHER FORECAST

Clara interface also displays bathymetry and weather forecast (wind intensity and direction).

3-2-2 Scenario 2: spill of 500 tonnes of phosphoric acid in the depths

This scenario is more likely to occur than the previous one and involves an instantaneous release of 500 tonnes due to the opening of a breach in the wreck. The spill occurs on 02/01/2006 at 4 am just after the shipwrecking, and the simulation continues until 02/05/2006.

The results of the simulation show that the 500 tonnes dissolve very rapidly and do not present a major danger for humans or for the environment.

The concentrations are at their highest a few hours after the beginning of the spill and do not exceed 4.10^{-11} kg/m^3.

3-2-3 Scenario 3: spill of 2,000 tonnes of phosphoric acid in the surface

This scenario consists of a release of 2,000 tonnes (approximate capacity of one tank), due to a collision, of which 400 tonnes (20%) are released instantaneously. The spill occurs on 01/31/06 at 4 am just after the collision, and the simulation continues until 02/04/06.

FIGURE 9: MAXIMUM CONCENTRATION IN THE WATER COLUMN

The results of the simulation show that the 2,000 tonnes dissolve very rapidly in the water column and do not present a major danger for humans or for the environment. The concentrations are at their highest a few hours after the beginning of the spill and do not exceed 2.10^{-03} kg/m^3 (Fig. 9).

CONCLUSIONS

The aim of this tool is to be able to rapidly (maximum duration of 1 hour for a simulation) provide a visual response which can be easily understood by responders and is accurate and reliable. This instrument provides responders with first line general information such as the maximum concentration in the water column. However, it also allows advanced users to obtain detailed results from the simulation, such as the concentration in a given location.

If the CLARA system had been available during the *Ece* incident, the results obtained would have allowed specialists and responders to reject the hypothesis of a peak concentration of phosphates which could have led to an algal bloom. The results show that whatever the scenario, dilution is very rapid and there is not a very large increase in concentration. This information would have influenced and reassured responders in their choice of response strategy.

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