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STUDY OF THE GEOGRAPHICAL BOUNDARIES FOR THE FREE USE OF DISPERSANTS

J. Bergueiro[1,4], D. Lindo[1,3], S. Moreno[1,5], J. Calvilla[2], J. Gómez[2] and J. González[2]

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Abstract

Dispersants are chemical agents that reduce the interfacial tension between oil and water in order to enhance the natural process of oil dispersion in sea by generating larger number of tiny droplets that can be entrained permanently into the water column by wave mixing energy.

This study aims to serve as a model to follow when establishing the geographical boundaries for the use of dispersants in order to allow the response authorities to define which dispersion strategy should be take immediately after the incident. To this end, the conclusions of this paper will be based on the comparison between the results of the simulation model AREAS (Bergueiro and Domínguez, 2001), the simulation model DISPERSANTES (Bergueiro and Domínguez, 2001) and the boundaries for the free use of dispersants established by the French research centre CEDRE (Lewis and Merlin, 2006).

Key words: Oil spill, spreading, dispersant, pollutant, contingency planning, simulation model.

INTRODUCTION

When an accidental oil spill occurs, several response options are possible. These possibilities are usually studied though two different approaches; to recover the hydrocar-

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[1] Universidad de las Islas Baleares, Palma de Mallorca (Spain). [2] Universidad de La Laguna, email: (garoedi@hotmail.com), Santa Cruz de Tenerife (Spain). [3] Corresponding author. Phd Researcher. CEDRE. Centre de Documentation, de Recherche et d´Expérimentations sur les Pollutions Accidentelles des Eaux. Brest. CEDEX 2 -France. E-mail address: David.Lindo@cedre.fr; latichati@yahoo.es. [4] Profesor Titular, E-mail address: ramonbergueiro@uib.es. [5] Doctora, E-mail address: silvia.moreno@uib.es.

bon or to leave the oil in the environment. This second approach includes the spreading of dispersants and the natural elimination of the pollutant. The appropriate use of one or other option should minimize the impact of environmental pollution.

Before deciding on which response strategy to choose, it is often timely to see whether the response will mitigate the pollution and improve the situation or whether it is better to leave well alone and refrain from responding. This approach is called NEBA (Net Environmental Benefit Analysis). The impact of the dispersed oil has to be less than that of non dispersed oil. Dispersed oil is more dangerous for the aquatic fauna and flora (corals, fish farm water intakes and industrial water intakes) than oil floating on the water surface (Lewis and Merlin, 2006). Defining areas where it is possible to disperse is tantamount to doing a «net environmental benefit analysis» or an «ecological advantage analysis» of dispersant spraying for set scenarios. However, contradictory opinions exist regarding dispersant use, their effect on oil and their environmental impact.

Dispersants are chemical agents that reduce the interfacial tension between oil and water in order to enhance the natural process of dispersion by generating larger number of tiny droplets that, when small enough, can be entrained permanently into the water column by wave mixing energy.

The use of dispersants should be applied rapidly. If the oil weathers, the treatment is less effective. Based on the above considerations and from practical experience, it is evident that response actions using dispersants should be initiated as soon as possible, and every effort should be made to apply the dispersants before significant oil weathering has occurred to improve the probability of success. It should be noted that increased viscosity and water content in an emulsion also affect the ability to treat spilled oil by other response methods. Thus, it is necessary to establish a tests procedure and an intervention plan which provides for:

— The regular testing of the effectiveness of the stored products
— The storage of dispersant in precise places according to available logistics
— The definition of geographical limits beyond which use is permitted

Only certain countries have a clearly defined policy regarding the use of dispersants (Lewis and Merlin, 2006). This study aims to serve as a model to follow when establishing the boundaries for the use of dispersants in order to allow the response authorities to define which dispersion should be take immediately after the incident. To this end, the conclusions of this paper will be based on the comparison between the results of the simulation model AREAS (Bergueiro and Domínguez, 2001) the simulation model DISPERSANTES (Bergueiro and Domínguez, 2001) and the boundaries for the free use of dispersants established by the French research centre CEDRE (Lewis and Merlin, 2006).

METHODS

State of the art

As a result of their different geographic locations, different maritime states of the EU have reached various agreements with their regional neighbours with the aim of dealing with the problem of oil pollution. The major agreements in Europe are:

— The Bonn Agreement (concerning the North Sea)
— The Helsinki Commission (HELCOM) (concerning the Baltic Sea)
— The Barcelona Convention (concerning the Mediterranean Sea)

The French Centre of Documentation, Research and Experimentation on Accidental Water Pollution, CEDRE, established, with the help of French scientific organizations, an old geographical boundary beyond which the use of dispersants was possible (Lewis and Merlin, 2006). Thus, the widespread use of dispersants was not accepted at sea in the following cases:

— In depths of less than 20 m in the North Sea, English Channel and Atlantic
— In depths of less than 50 m in the Mediterranean
— At a distance of less than one nautical mile from the coastline

However, the need has become apparent to modify these limits considering the distance from the coast, depth, biological resources in areas considered, currents and tides. Therefore, as an initial approach, new limits will be defined for oil spills of 10 t, 100 t and 1000 t.

Present and possible role of models

Various chemical and physical processes constrain a number of operational decisions and play a significant role in evaluating potential impacts of whole and dispersed oil on sensitive species or habitats. Models are, therefore, powerful and necessary tools to support decisionmakers during all phases of oil spill planning (Bergueiro and Domínguez, 2001; Bergueiro *et al.*, 2004) response, and assessment. Currently trajectory analysis is a key component of contingency planning (Castanedo *et al.*, 2004) real-time prediction of slick trajectory, size, and thickness, and in natural resource damage assessment. These models could used in real time to support decisionmaking for dispersant use. Thus, their ability to predict the concentrations of dispersed oil and dissolved aromatic hydrocarbons in the water column with sufficient accuracy to aid in spill decisionmaking has yet to be fully determined.

The sensitivity analysis identified that dispersant effectiveness and oil droplet size change are the most important parameters for dispersant application modelling (National Research Council of the National Accademy, 2005). Unfortunately, oil spill models currently available do not simulate physical mechanisms and chemical reactions in order to predict these parameters. Emulsification is also an important process that greatly influences dispersant effectiveness (Reed *et al.,* 1999), M. Predicting emulsification requires accurate oil properties, as well as conducting a detailed mechanistic investigation on emulsification processes and their influence on dispersant effectiveness. It is also important to evaluate turbulence in the open sea and reflect it more accurately in the transport modeling (Reed *et al.,* 1999).

Models show significant progress for supporting real-time spill-response decisions regarding dispersants use; however, models should improved, verified, and then validated in an appropriately designed experimental setting or during an actual spill. Specific steps that should be taken to improve the value of models for dispersant use decisionmaking include:

— Improve the ability to model physical components of dispersed oil behavior (e.g., distribution of horizontal velocities as a function of depth, variations in the vertical diffusivity as a function of depth, sea-surface turbulence, etc.)
— Improve the ability for models to predict concentrations of dissolved and dispersed oil, expressed as specific components or pseudocomponents, that can be used to support toxicity analysis
— Validate how advective transport of entrained oil droplets is modeled through specifically designed flume/tank studies and open-ocean (spill of opportunity) tests.
— Develop an ability to predict the formation of water-in-oil emulsions under a variety of conditions.
— Conduct a sensitivity analysis based on three-dimensional, oil-component, transport and fate models, and develop necessary databases (evaporation, dissolution, toxicity, etc.) for the oil-component based assessment approach

There have been some attempts to incorporate surface flow measurements into real-time oil transport models (Ojo and Bonner, 2002). However, these require preinstallation of data acquisition (e.g., high frequency radar) and transmission systems are currently applicable only to horizontal surface current and diffusion with relatively coarse grid resolution-not for the three-dimensional distributions needed for the three-dimensional modeling (Ojo and Bonner, 2002). The growing availability of ocean observing systems in coastal waters will likely improve the availability of real-time data useful for improved modeling of physical processes.

Method of defining geographical boundaries

Initially, the boundaries are defined based on the minimum depth and distance from the coastline. To this end, the boundaries are drawn on maps of the National Geographic Institute considering only the bathymetry of the continental shelf and the distance from the zero line of marine maps (low tide line). Emerging rocks, islets, islands and ports are also considered. The boundaries are drawn freehand for the whole national coast: Atlantic, Mediterranean and insular.

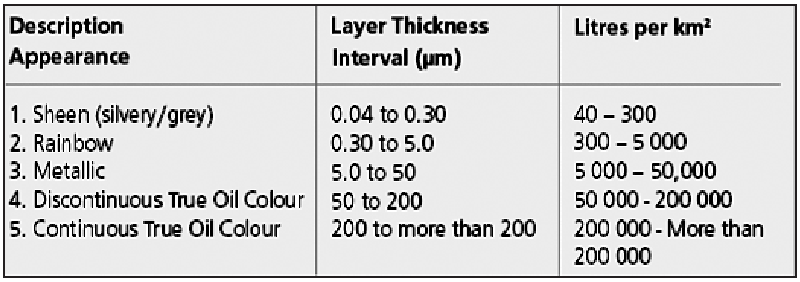
It is recommended that a standard area with the following characteristics be chosen:

— A high morphological diversity
— Presence of islands or islets around it
— Wealth of fisheries and aquaculture
— Location likely to encounter oil spills because of nearby oil routes (eg. Spanish Finisterre)

RESULTS

Determination of the approximate minimum depth

The thickness of the oil slick will not be uniform and it is difficult to determine it with precision. Research conducted by the Bonn Agreement has led to the adoption of an oil appearance code as shown in table 1 and image 1.



Description Appearance	Layer Thickness Interval (µm)	Litres per km²
1. Sheen (silvery/grey)	0.04 to 0.30	40 – 300
2. Rainbow	0.30 to 5.0	300 – 5 000
3. Metallic	5.0 to 50	5 000 – 50,000
4. Discontinuous True Oil Colour	50 to 200	50 000 - 200 000
5. Continuous True Oil Colour	200 to more than 200	200 000 - More than 200 000

Table 1. Appearance code.

A thickness of 0.1 mm is chosen.

For a layer of oil with a thickness of $0.1 \cdot 10^{-3}$ m and surface $S(m^2)$, the volume of oil V will be $0.1 \cdot 10^{-3} \times S(m^3)$

This volume corresponds to a level of 100 ppm of hydrocarbon in the case of total dispersion in the first few meters of the water column.

For the definition of the new limits, it is considered that ecological systems can withstand a temporary toxic effect due to the toxic mixture of oil and dispersant.

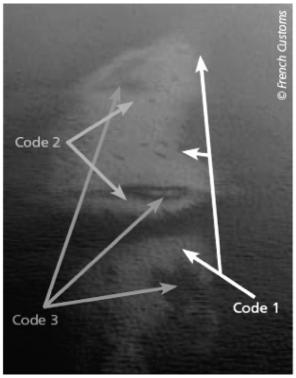
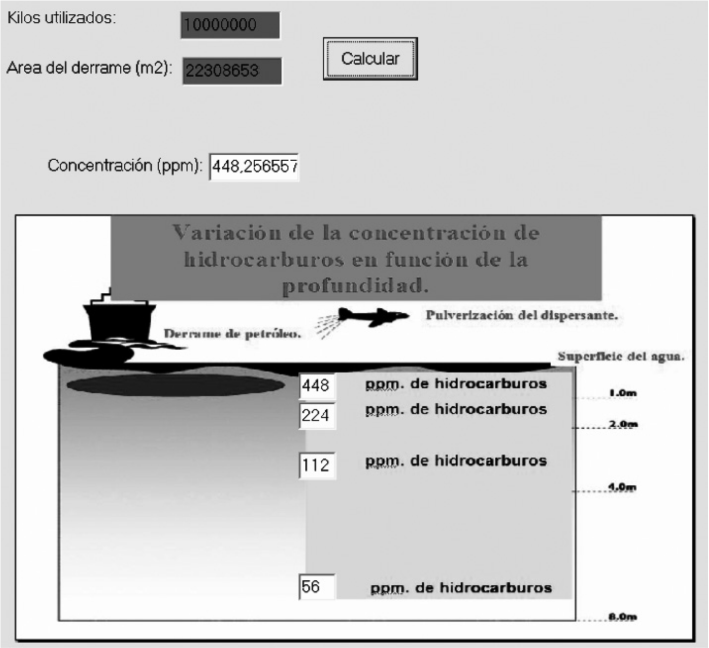


Image 1.

First simulation

The hypothetical scenario consists of a spill of 10,000 t of Arabian Light oil, with a viscosity of 14 mPa.s and showing 25% weathering. It is assumed that the oil is dispersible, and that it is logistically feasible to apply dispersants. The simulation model DISPERSANTES gives the following results:



Kilos utilizados: 10000000

Area del derrame (m2): 22308653

Concentración (ppm): 448,256557

Image 2. Dispersed oil distribution in the water column after treatment

As shown in Image 2, the oil concentration decreases from 400 ppm to 100 ppm in the first four metres deep, just before dropping to 50 ppm at 8 metres.

Measurements taken during sea trials by CEDRE show that in the early stages, the oil is concentrated in the immediate vicinity of the surface: a maximum concentration of oil from 50 to 60 ppm was measured 1 m below the surface for 2-3 hours. For depths of between 1 m and 2.5 m, it was estimated that low concentrations will fall suddenly because of dilution. Therefore, the calculated values and tests at sea are remarkably similar.

Determining the distance from the coast

In order to determine the distance from the coast, a thickness of 0.1 mm was chosen. It is assumed that after spreading dispersant, the slick drops from 0.1 mm thick (ie. 100 μm) to 20 μm thick. Based on the average density of the products normally transported, it is known that a thickness of 20 μm corresponds to 20g/m^2 of oil, i.e. $2 \cdot 10^{-5}\ t / m^2$). Based on this data, the minimum distance from the coastline is calculated for oil spills of 10 t, 100 t and 1000 t.

— Spill of 10 tonnes of crude oil:

The area affected by the dispersed slick (*S*):

$$S = \frac{10t}{2 \cdot 10^{-5} t/m^2} = 5 \cdot 10^5 \, m^2$$

If we consider the layer as circular,

$$S = \pi \cdot R^2$$

Thus,

$$R \cong 400 \, m$$

Using a safety factor of 2.25.

$$R = 2.25 \cdot 400$$

$$R = 900 \, m \quad \Rightarrow \quad R = 0.5 \, MN$$

— Spill of 100 tonnes of crude oil:

Similarly:

$$S = \frac{100t}{2 \cdot 10^{-5} t/m^2} = 5 \cdot 10^6 \, m^2$$

$$R \cong 1300 \, m$$

Using a safety factor of 1.45.

$$R = 1.45 \cdot 1300$$

$$R = 1850 \, m \quad \Rightarrow \quad R = 1 \, MN$$

— Spill of 1000 tonnes of crude oil:

Similarly:

$$S = \frac{1000t}{2 \cdot 10^{-5} t/m^2} = 5 \cdot 10^7 \, m^2$$

$$R \cong 4000 \, m$$

Using a safety factor of 1.15.

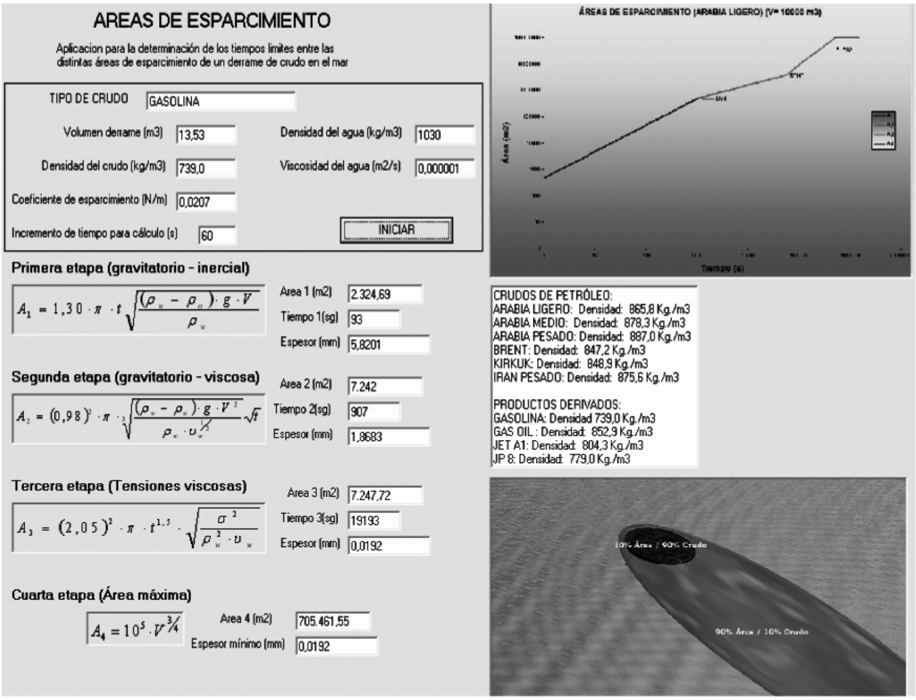
$$R = 1.15 \cdot 4000$$

$$R = 4600 \, m \quad \Rightarrow \quad R = 2.5 \, MN$$

Note that safety factors decrease as we move away from the coast and are set arbitrarily on the basis of experience gained by CEDRE in such operations.

Second simulation

The hypothetical scenario consists of a spill of 10 t of gasoline, equivalent to 13.5 m^3. Although gasoline has a very high evaporation rate, which normally would discourage its dispersion treatment, this oil is chosen here because it has a very high spreading rate and, consequently, it will reach a larger area and it will be the most unfavourable dispersion scenario. It is assumed that the product is dispersible, and that it is logistically feasible to apply dispersants. The simulation model AREAS gives the following results:



AREAS DE ESPARCIMIENTO

Aplicacion para la determinación de los tiempos limites entre las distintas áreas de esparcimiento de un derrame de crudo en el mar

TIPO DE CRUDO: GASOLINA

Volumen derrame (m3): 13,53

Densidad del agua (kg/m3): 1030

Densidad del crudo (kg/m3): 739,0

Viscosidad del agua (m2/s): 0,000001

Coeficiente de esparcimiento (N/m): 0,0207

Incremento de tiempo para cálculo (s): 60

Primera etapa (gravitatorio - inercial)

$$A_1 = 1{,}30 \cdot \pi \cdot t \sqrt{\frac{(\rho_w - \rho_o) \cdot g \cdot V}{\rho_w}}$$

Area 1 (m2): 2.324,69

Tiempo 1(sg): 93

Espesor (mm): 5,8201

Segunda etapa (gravitatorio - viscosa)

$$A_2 = (0{,}98)^2 \cdot \pi \cdot \sqrt[3]{\frac{(\rho_w - \rho_o) \cdot g \cdot V^2}{\rho_w \cdot \upsilon_w^{1/2}}} \sqrt{t}$$

Area 2 (m2): 7.242

Tiempo 2(sg): 907

Espesor (mm): 1,8683

Tercera etapa (Tensiones viscosas)

$$A_3 = (2{,}05)^2 \cdot \pi \cdot t^{1,5} \cdot \sqrt{\frac{\sigma^2}{\rho_w^2 \cdot \upsilon_w}}$$

Area 3 (m2): 7.247,72

Tiempo 3(sg): 19193

Espesor (mm): 0,0192

Cuarta etapa (Área máxima)

$$A_4 = 10^5 \cdot V^{3/4}$$

Area 4 (m2): 705.461,55

Espesor mínimo (mm): 0,0192

CRUDOS DE PETRÓLEO:
ARABIA LIGERO: Densidad: 865,8 Kg./m3
ARABIA MEDIO: Densidad: 878,3 Kg./m3
ARABIA PESADO: Densidad: 887,0 Kg./m3
BRENT: Densidad: 847,2 Kg./m3
KIRKUK: Densidad: 848,9 Kg./m3
IRAN PESADO: Densidad: 875,6 Kg./m3

PRODUCTOS DERIVADOS:
GASOLINA: Densidad 739,0 Kg./m3
GAS OIL : Densidad: 852,9 Kg./m3
JET A1: Densidad: 804,3 Kg./m3
JP 8: Densidad: 779,0 Kg./m3

Image 3. Spreading areas.

Based on the Areas model of Fay (1971) concerning the three phases of oil spreading, it the maximum area will be used. The choice of one area or the other depends on the time after which the dispersant application begins. Considering the most unfavourable case, after 5.3 hours the maximum area corresponds to 705,000 m^2 and the thickness of the layer is 19.2 μm. Therefore, considering the slick as circular and applying a safety factor of 2.25 we obtain $R = 1066\ m \Rightarrow R = 0.58\ MN$

Third simulation

The hypothetical scenario consists of a spill of 100 t of gasoline, equivalent to 135.3 m^3. Similarly to second simulation, gasoline is chosen because it entails the most unfavourable dispersion scenario. Under these conditions the maximum area corresponds to 3,967,100 m^2 and the thickness of the layer is 34.1 µm. Therefore, considering the slick as circular and applying a safety factor of 1.45 we obtain $R = 1630\ m \Rightarrow R = 0.9\ MN$

Fourth simulation

The hypothetical scenario consists of a spill of 1000 t of gasoline, equivalent to 1353 m^3. Similarly to third simulation, gasoline is chosen because it entails the most unfavourable dispersion scenario. Under these conditions the maximum area corresponds to 22,308,652 m^2 and the thickness of the layer is 60.6 µm. Therefore, considering the slick as circular and applying a safety factor of 1.15 we obtain $R = 3.065\ m \Rightarrow R = 1.8\ MN$

Setting limits based on an analysis of the environmental impact

As a second stage, it is necessary to seek the support of Maritime Affairs to take stock of the sensitive areas of the coastline in the following domains:

- Aquaculture areas
- Deposits of benthic species
- Spawn areas
- Limitations and reserves

The available data will be reported to the National Geographic Institute maps and the limits defined will be adjusted in terms of the protection of sensitive sites. The limits of such places will be considered as the “zero line.” From here, the limits were defined considering the minimum distance and depth calculated in the first stage.

CONCLUSIONS

1) If 10 tonnes of crude oil are spilt in a 5 m deep water column, it is estimated that the expected oil concentration will be 20 ppm after treatment. As the slick of 10 t oil is relatively small, the area affected is not very large and 20 ppm is rapidly diluted.
2) If 100 tonnes of crude oil are spilt in a 10 m deep water column, it is estimated that the expected oil concentration will be 10 ppm in the water column after treatment. This weak concentration will not significantly affect the environment during the time necessary for effective dilution by currents.

3) If 1000 tonnes of crude oil are spilt in a 15 m deep water column, it is estimated that the expected oil concentration will be 6.5 ppm in the water column after treatment. If there is no bathymetric data for a depth of 15 m, limits will be outlined considering the bathymetry of 10 m and 20 m.
4) By means of the model AREAS, it has been estimated that in order to disperse a 10 t oil spill without affecting the coast, the slick must be located further than 0.6 NM from the low tide line of marine maps.
5) By means of the model AREAS, it has been estimated that in order to disperse a 100 t oil spill without affecting the coast, the slick must be located further than 1 NM from the low tide line of marine maps.
6) By means of the model AREAS, it has been estimated that in order to disperse a 1000 t oil spill without affecting the coast, the slick must be located further than 2 NM from the low tide line of marine maps.
7) If the currents may cause the oil spill to contaminate a sensitive area, it will be necessary to extend the limits against the current.
8) If the place has stationary sensitivity, it will be necessary to identify and determine the boundaries depending on the season.

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ESTUDIO DE LOS LIMITES GEOGRÁFICOS PARA LA LIBRE UTILIZACIÓN DE DISPERSANTES

Resumen

Los dispersantes son agentes químicos que reducen la tensión superficial entre el hidrocarburo y el agua con el fin de favorecer el proceso natural de dispersión del crudo en el mar a través de una generación de pequeñas gotas que pueden ser incorporadas permanentemente en la columna de agua con la ayuda de la energía de mezcla de las olas.

Este estudio pretende servir como un modelo a seguir para establecer los límites geográficos para la libre utilización de dispersantes y así ayudar a que las autoridades competentes de la lucha contra la contaminación por hidrocarburos definan qué estrategia de dispersión debe tomarse inmediatamente después del incidente. Siguiendo este fin, las conclusiones de este artículo se basarán en la comparación de los resultados del modelo de simulación AREAS (Bergueiro y Domínguez, 2001), el modelo de simulación DISPERSANTES (Bergueiro y Domínguez, 2001) y los límites geográficos para la libre utilización de dispersantes establecidos por el centro de investigación francés CEDRE (Lewis y Merlin, 2006).

METODOLOGÍA

Estado del arte

A raíz de sus diferentes localizaciones geográficas, los diferentes estados marítimos de la UE se han volcado a acordar diversos acuerdos regionales con sus vecinos con la finalidad de abordar los problemas de la contaminación marina por hidrocarburos. Los mayores acuerdos en Europa son:

— El acuerdo de Bonn (concerniente al Mar del Norte)
— La comisión de Helsinki (Helcom) (concerniente al Mar Báltico)
— La convención de Barcelona (concerniente al Mar Maditerráneo)

El centro francés de documentación, investigación y experimentación sobre la contaminación accidental de las aguas, CEDRE había establecido con la ayuda de organismos científicos franceses un límite geográfico más allá del cual era posible la utilización de dispersantes sin riesgos para el medio marino. Así, la utilización masiva de dispersantes no estaba aceptada en mar para los siguientes casos:

— En fondos inferiores a 20 m en Mar del Norte, Mancha y Atlántico
— En fondos inferiores a 50 m en el Mediterráneo
— A menos de una milla náutica de las costas

Sin embargo, surge la necesidad de modificar estor límites considerando la distancia a la costa, la profundidad, los recursos biológicos de las zonas consideradas, las corrientes y las mareas. De esta manera se definirán nuevos límites para vertidos de 10 t, 100 t y 1000 t.

Método de definición de los límites geográficos

Inicialmente, se definen los límites a partir de la profundidad mínima y de la distancia a la costa. Para ello, se trazan los límites sobre los mapas del Intituto Geográfico Nacional considerando exclusivamente la batimetría de la plataforma continental y la distancia a la línea cero de los mapas marinos (línea de bajamar). Se consideran también las rocas emergentes, los islotes, las islas y los puertos. Los límites se trazan a mano alzada sobre toda la costa nacional; atlántica, mediterránea e insular.

Es recomendable escoger una zona como estándar que presente las siguientes características:

— Una elevada diversidad mofológica
— Presencias de islas u islotes a su alrededor
— Riqueza en actividades de pesca y acuicultura
— Situación geográfica susceptible a vertidos debido a la proximidad de rutas petroleras (ie, el finisterre español)

CONCLUSIONES

1) Si se vierten 10 toneladas de petróleo en una columna de agua de 5 m de profundidad, se estima que la concentración de hidrocarburo esperada después del tratamiento será de 20 ppm. Como el vertido de 10 t de petróleo es relativamente pequeño, el área afectada no es muy extensa y los 20 ppm se diluyen rápidamente.
2) Si se vierten 100 toneladas de petróleo en una columna de agua de 10 m de profundidad, se estima que la concentración de hidrocarburo esperada después del tratamiento será de 10 ppm. Esta débil concentración no afectará al medio ambiente durante el tiempo necesario para una dilución efectiva llevada a término por las corrientes.
3) Si se vierten 1000 toneladas de petróleo en una columna de agua de 15 m de profundidad, se estima que la concentración de hidrocarburo esperada después del tratamiento será de 6,5 ppm. Si no existen datos de batimetría para una profundidad de 15 m, los límites se establecerán considerando la batimetría de 10 m y 20 m.
4) Mediante el modelo AREAS, se ha estimado que para dispersar 10 t de petróleo sin que se afecte a la costa, el vertido debe estar situado a más de 0.6 MN de la línea de bajamar de la carta náutica

5) Mediante el modelo AREAS, se ha estimado que para dispersar 100 t de petróleo sin que se afecte a la costa, el vertido debe estar situado a más de 1 MN de la línea de bajamar de la carta náutica.
6) Mediante el modelo AREAS, se ha estimado que para dispersar 1000 t de petróleo sin que se afecte a la costa, el vertido debe estar situado a más de 2 MN de la línea de bajamar de la carta náutica.
7) Si las corrientes pueden ocasionar que el vertido de hidrocarburo contamine una zona sensible, será necesario extender los límites contra el sentido del que procede contra la corriente
8) Si el lugar tiene una sensibilidad estacionaria, será necesario identidicar y determinar los límites en función de la estación del año.