



THE RISK CAUSED BY HYDROCARBON SPILLS IN THE EASTERN REGION OF THE CANARY ISLANDS WATERS: TESEO MODEL AND SIROCO SYSTEM

RIESGO DERIVADO POR VERTIDOS DE HIDROCARBUROS EN LA REGIÓN ORIENTAL DE LAS AGUAS CANARIAS: MODELO TESEO Y SISTEMA SIROCO

J.M. Calvilla*, J.R. Bergueiro, J.I. Gómez, J.A. González, E. Calvilla
Universidad de La Laguna (Grupo I+D CONSEMAR)
*jmcalvi@ull.edu.es

(recibido/received: 11-11-2017; aceptado/accepted: 01-06-2018)

ABSTRACT

In view of the increasing oil interest shown by Spain and Morocco, the aim of this project is to test the risk of hypothetical spills of hydrocarbons in the eastern region of the Canary Islands waters and their surroundings through the Simulation Model of Hydrocarbon Transport (TESEO) and the Island Response and Operations System against Ocean Pollutants, in Spanish Sistemas Insulares de Respuesta y Operaciones Ante Contaminantes Oceánicos (SIROCO).

Palabras clave: Oil Spill; SIROCO; TESEO

RESUMEN

En este trabajo se analizan a través del Modelo de Simulación de Transporte de Hidrocarburos (TESEO) y los Sistemas Insulares de Respuestas y Operaciones ante Contaminantes Oceánicos (SIROCO) el riesgo derivado de hipotéticos vertidos de hidrocarburos en la región oriental de las Islas Canarias, parte de España y Marruecos.

Keywords: Derrame de petróleo; SIROCO; TESEO

1. INTRODUCTION

The core of the oceanic operational system consists of two elements: observing services and dynamic models with data assimilation. The appliances of this system are countless and they have prompt scientific, technological and socio-economic benefits. Optimal strategies against marine pollution (LCC) are set out to trace and analyse the progression of spills through the oceanographic operational system, at both regional and local level. The developed appliances are equally useful to predict floating objects and shipwrecks. The integrated systems are also useful for the integrated management at coastal zones, maritime transport, port engineering and the management of fish resources, through physical variables predictions, both meteorological and oceanographic, that are the basis of chemical-biological models.

The ESEOO Project (Establishment of an Oceanographic Operational Spanish System) provides essential information to respond to emergency situations by accidental polluting spills and allows addressing these critical situations in the best possible way. The oceanographic operational system consists of a range of services based on numerical modelling and oceanographic data analysis, both historical and live data. The Simulation Model of Hydrocarbon Transport (TESEO) can simulate the transport and degradation of hydrocarbons. The structure of the TESEO operational system is as shown in Figure 1.

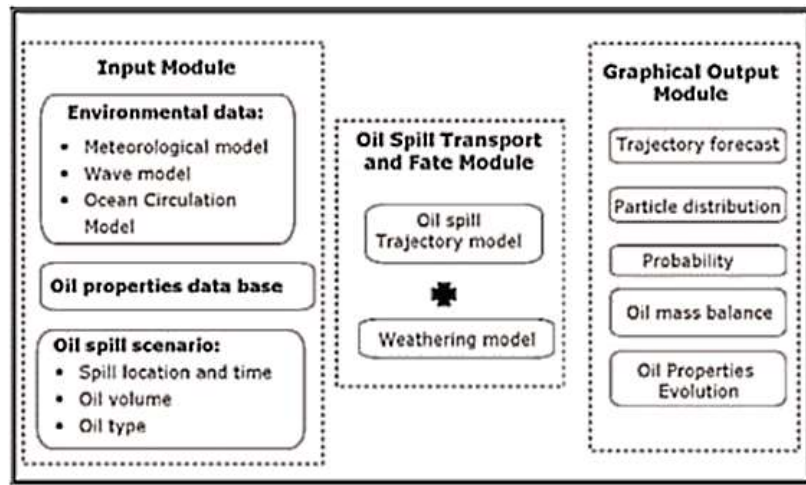


Figure 1 - Operational Structure of the TESEO Model.

Source: (ABASCAL, 2008).

The drifting model is a two-dimensional Lagrangian Model, which simulates the movement and degradation of a hydrocarbon, considering the spill as the sum of particles that move separately, due to strengths such as wind, waves, current and turbulent diffusion.

The model has been calibrated using the algorithm SCE-UA (Shuffled Complex Evolution Method – University of Arizona) and adapted for its application in Oceanography (ABASCAL, 2008).

The calibration using drifting oceanographic buoys enables to optimize the algorithm (Figure 2) and obtain ratios which reduce the differences between the real movement of the spill and the numerical prediction. The optimization method pursues the calibration of the predictive Lagrangian Transport Model. The objective of the calibration is to find the value of the coefficients that minimize the objective function.

$$J = \sum_t \sum_{i=1}^N \left[(U_{Bx}(x, t) - U_{Mx}(x, t, \theta))^2 + (U_{By}(x, t) - U_{My}(x, t, \theta))^2 \right] ; \theta(C_D, C_C) \quad (1)$$

where:

N : Buoys number

U_B : Buoys velocity

$$U_B = \frac{x_f - x_0}{\Delta t} \quad (2)$$

U_M : Velocity (wind, wave, current)

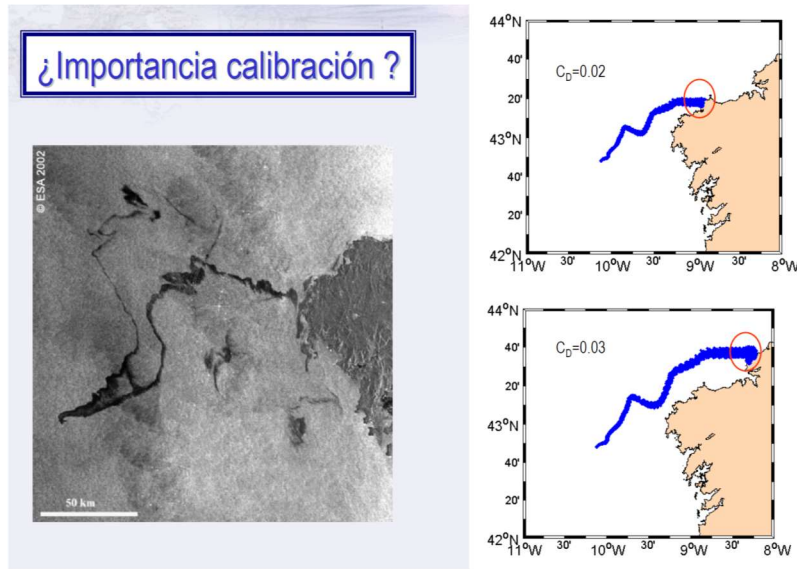
$$U_{Mx}(t) = C_H U_{olax} + C_D U_{vientox} + C_C U_{corrientex} \quad (3)$$

$$U_{My}(t) = C_H U_{olay} + C_D U_{vientoy} + C_C U_{corrientey} \quad (4)$$

C_D : wind drag coefficient

C_H : wave coefficient

C_C : current coefficient (opcional)



Source: (SANTAMARÍA, 2006).

Figure 2 - Calibration TESEO Model (Prestige).

The application has two operating modes called operational and re-test mode. The re-test mode can manage the forcing files and control the parameters of implementation of the model. The system consists of three modules: the input module, the Oil Spill Transport and Fates module and the Graphical Output module. Each module is integrated in a simple graphical user interface (GUI), which provides efficient information on the ability to manage oil spills and respond to them (ABASCAL, 2008).

The results obtained are analysed through the Island Response and Operations System against Ocean Pollutants (SIROCO) (Figure 3) as a comprehensive managing tool for the analysis, planning, mobilisation and support in decision-making of the human resource and the material resources against pollution with the aim of preventing or minimizing the pollution effects in the affected áreas (BERGUEIRO, J.R. *et al.*, 2001) (BERGUEIRO, 2004) (BERGUEIRO, 2009).

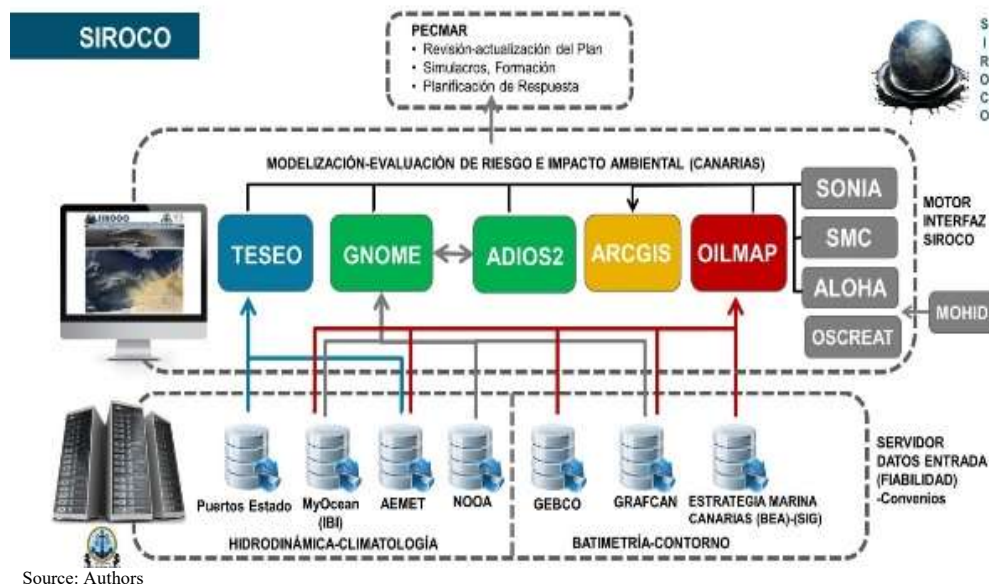
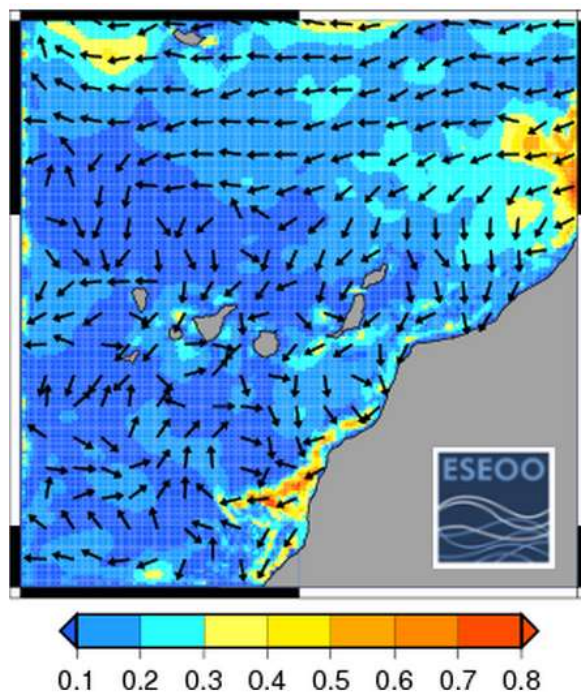


Figure 3: SIROCO Model.

2. METHODOLOGY

2.1 Input Model

The relevant event data, the forcing data and the selection of the type of spill are entered in the TESEO System input module. The interface allows remote control (FTP) to different operational predictive systems and the data can be introduced in NETCDF format (Figure 4).



Source: Puertos de Estado (State Ports). ESEOO Project.

Figure 4– Speed (m/s) and direction of surface currents (00 H GMT 02/10/2014).

2.2 Oil Spill Transport and Fate Module

The transport model takes into consideration the influence of weathering processes on the evolution of the spill. The drift processes are described by approaching to a multiparticle system, based on the PICHI model developed by the University of Cantabria after the Prestige oil spill (2002). The Table 1 shows the equations used in TESEO model [Fay (1969, 1971); Lehr et al. (1984); Stiver and MacKay (1984); MacKay (1980)].

Table 1: Equations used in TESEO model.

Magnitude	Equation
Particle position	$\frac{d\vec{x}}{dt} = \vec{u}_a(\vec{x}_i, t) + \vec{u}_d(\vec{x}_i, t)$
Advective velocity	$\vec{u}_a = \vec{u}_c + C_D \vec{u}_w + C_H \vec{u}_H$
Turbulent diffusion	$ \vec{u}_d = \sqrt{\frac{6D}{\Delta t}}$
Evaporation velocity	$\Delta F = \exp\left[6,3 - \frac{10,3}{T}(T_0 - T_G F)\right] \left(\frac{kA\Delta t}{V_0}\right)$
Emulsification	$\frac{dY}{dt} = -k(W_{10} + 1)^2 \left(1 - \frac{Y}{Y_f}\right)$
Density	$\rho = Y\rho_w + (1 - Y)\rho_0(1 - C_T(T - T_0))(1 + C_F F)$
Viscosity	$v_f = v_0 \exp\left(\frac{C_3 Y}{1 - C_4 Y}\right) \exp[C_5(T - T_0)] \exp(C_6 F)$

Where: \vec{u}_a advection velocity; \vec{u}_d diffusion velocity; \vec{u}_c current velocity; \vec{u}_w wind velocity; \vec{u}_H Stokes drift; A Spill Area; V_0 Volume; T Temperature; T_0, T_G son las constantes de destilación; W_{10} wind velocity (10 m); Y_f maximum water content in oil.

2.3 Graphical Output Module

The results of the numerical simulation are shown in this section and they are represented in five different types of graphics: the positions of the centre of gravity, distribution of particles, probability maps, mass balance and evolution of the hydrocarbon characteristics.

- The positions of the centre of gravity: It represents the position of the centre of gravity, meaning the central position of the cloud of particles in the course of time.
- Graphic of particles: These graphics represent the distribution of particles at a given time. The programme shows a map of particles every hour.
- Probability maps: These graphics show the chance of finding a spill or a floating object in an area and at a given time.
- Mass balance. TESEO generates the following graphics:
 - Evaporation (%): hydrocarbon evaporation percentage.
 - Evaporation (t): tonnes of evaporated hydrocarbon
 - Hydrocarbon in the water (%): percentage of hydrocarbon that remains in the water.
 - Hydrocarbon in the water (t): tonnes of hydrocarbon that remain in the water.
 - Hydrocarbon on land (%): percentage of hydrocarbon that has reached land.
 - Hydrocarbon on the ground (t): tonnes of hydrocarbon that have reached land.
 - Product in the water (t): tonnes of emulsifying product (hydrocarbon plus water)
 - Product on land (t): tonnes of emulsifying product (hydrocarbon plus water) that have reached land.
 - Mass balance (t): this graphic shows simultaneously the evaporated hydrocarbon, the hydrocarbon that remains in the water and the one that reaches land (in tonnes).

- Evolution of the hydrocarbon characteristics: the properties that can be represented are the density, the water volume and the viscosity.

The results obtained can be taken into consideration for the implementation of contingency plans and cleaning operations, both at sea and throughout the coast.

TESEO has been successfully tested as an operational tool at emergency actions in different oil spill simulation exercises carried out by Maritime Rescue (SASEMAR), in the Atlantic and the Mediterranean Sea. These experiences were the first attempt made in Spain to include operational systems to respond to hydrocarbon spills. The capacity of TESEO to use live data for the decision-making process was proved during the performance of the simulation. Comparing the predictions of the system with the track of the buoys, the results showed a high level of coincidence with the model behaviour (ABASCAL, 2008).

In order to get the best results from the path of the various spills, as well as to estimate the aging process of crude petroleum once it has been spilled into the water, a number of simulations have been carried out using the TESEO Model.

By comparing the results obtained from the simulations with any of the applied models, you can estimate the most likely path of a certain spill and how will its properties vary as it moves on the water surface and until it hits the coast. Besides that, you can obtain an average value of the quantity of hydrocarbon that has remained on the coast, where it hit.

3. RESULTS AND DISCUSSIONS

Several deterministic and stochastic cases have been analyzed. The following lines show the results obtained in a deterministic case from a hypothetical hydrocarbon spill in a region which has received significant interest from the oil industry. To conclude, a chart synthesizing various scenarios is attached.

3.1 Region “Canarias-6” (TESEO)

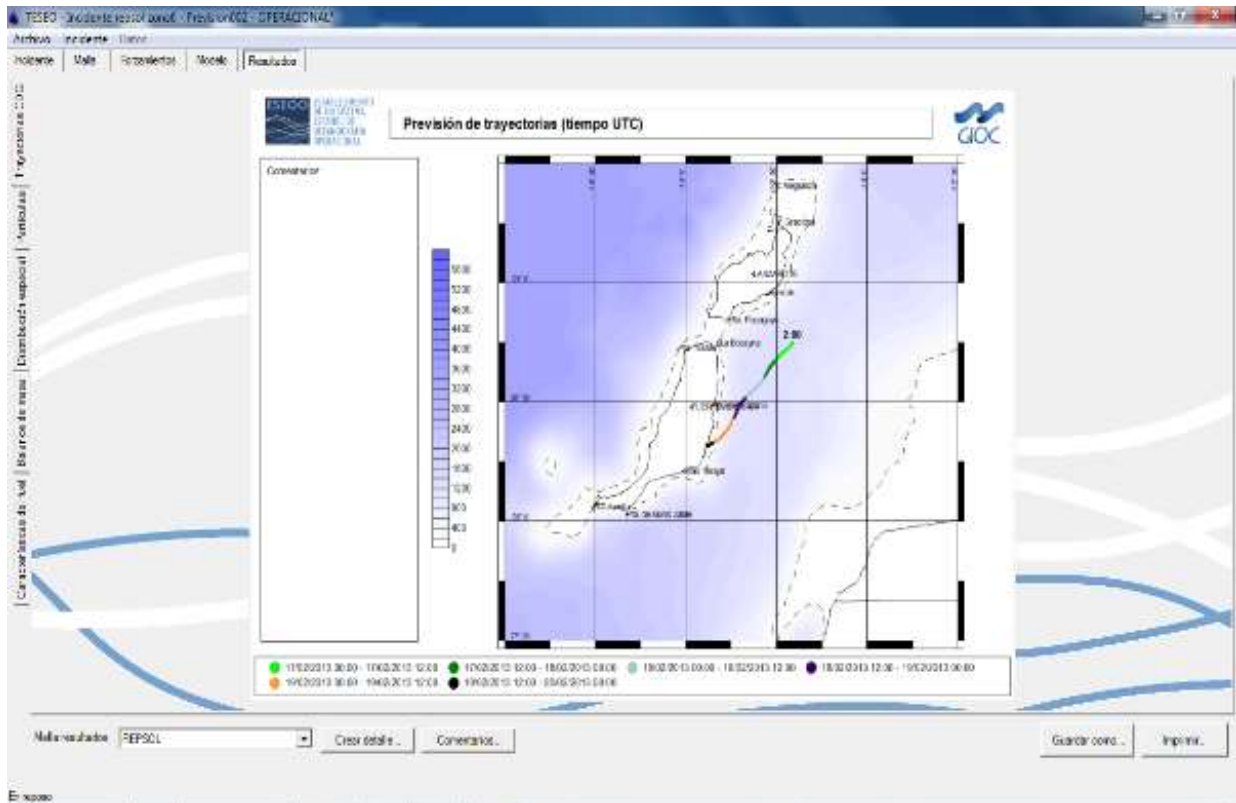
The project starts by analysing the region “Canarias-6”. The input parameters to carry out the simulation are detailed in Table 2.

Table 2- Input parameters TESEO Model. Canarias 6 Region. Source: Own elaboration

Spill location coordinates	Longitude	Latitude
	13,41 W	28,75 N
Region	Canarias 6 (West border)	
Type of oil	Arabian Ligth	
Sea currents data	State ports	
Wind data	AEMET	
Water temperature	18°C	
Volume of spill	960.000 L	
Duration of spill	Instant	
Simulation time	72 hours	
Diffusion coefficient (m ² /s)	50	

Source: Authors

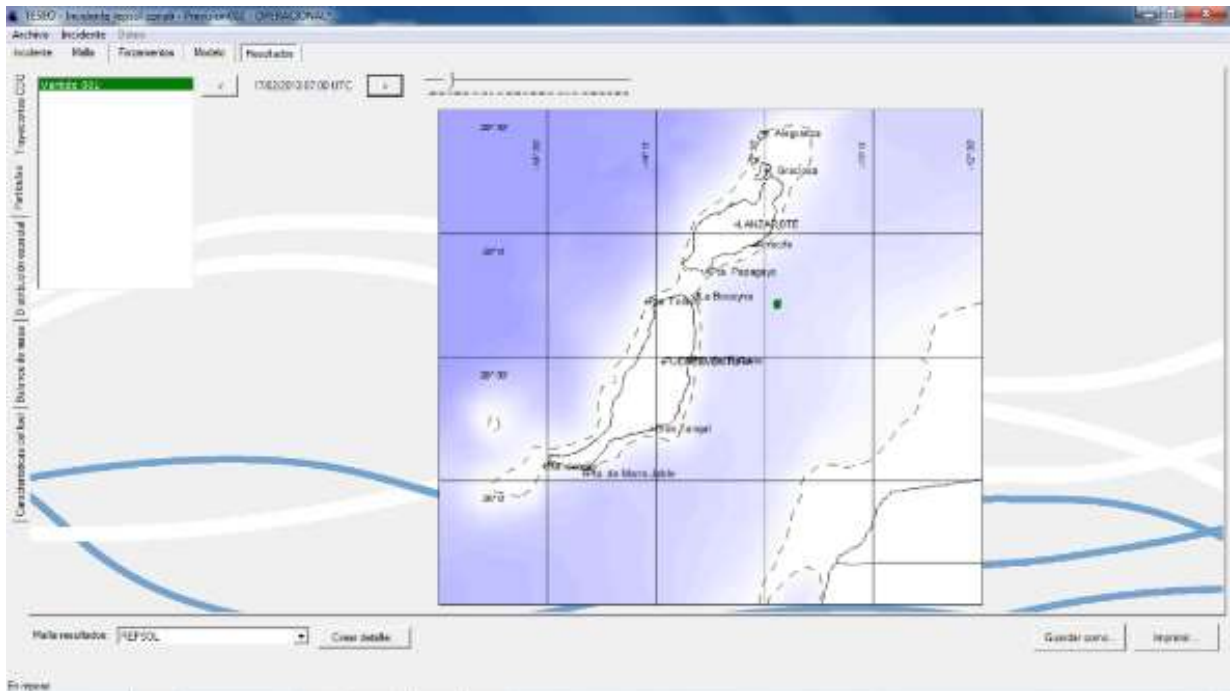
On the present simulation TESEO splits the path into three different sections. It is possible to observe date and time of the spill from each of them, as well as the moment when it hits the coast. Figure 5 shows the predicted path and the evolution this spill will take until it hits the coast of Fuerteventura.



Source: Authors.

Figure 5: Path prediction of the oil spill. Canarias 6 Region. Teseo Model.

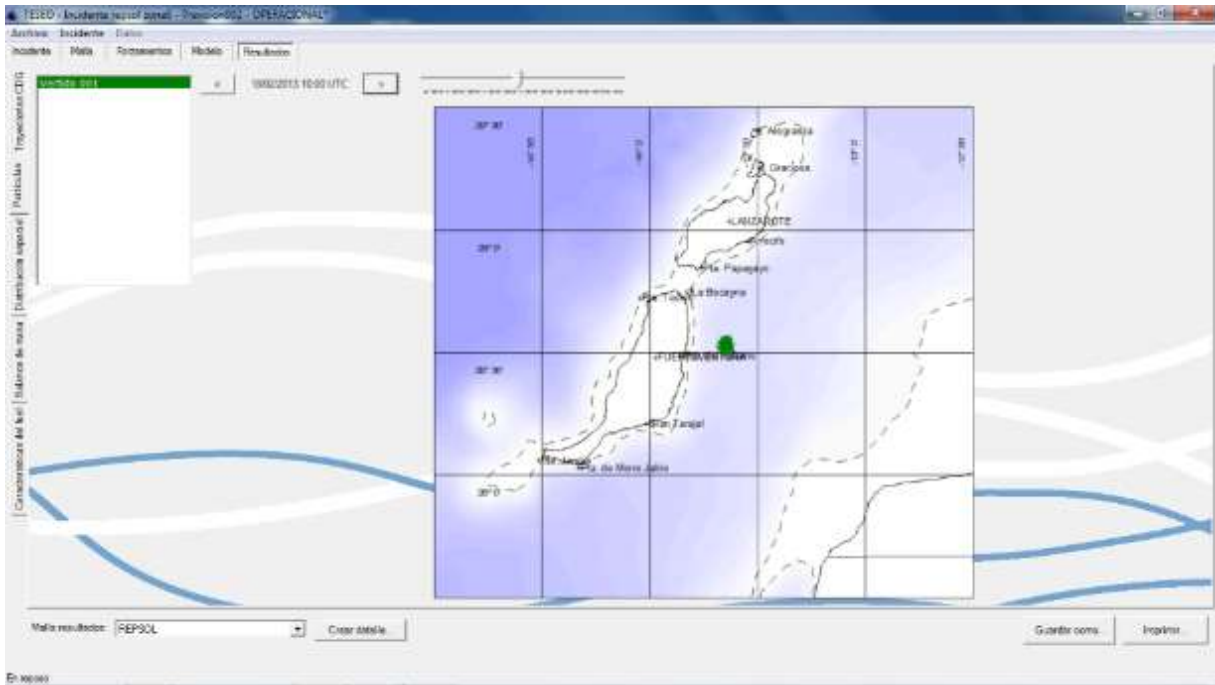
Figure 6 shows the location of the spill after 7 hours.



Source: Authors.

Figure 6: Spill location after 7 hours. Region Canarias 6. TESEO Model.

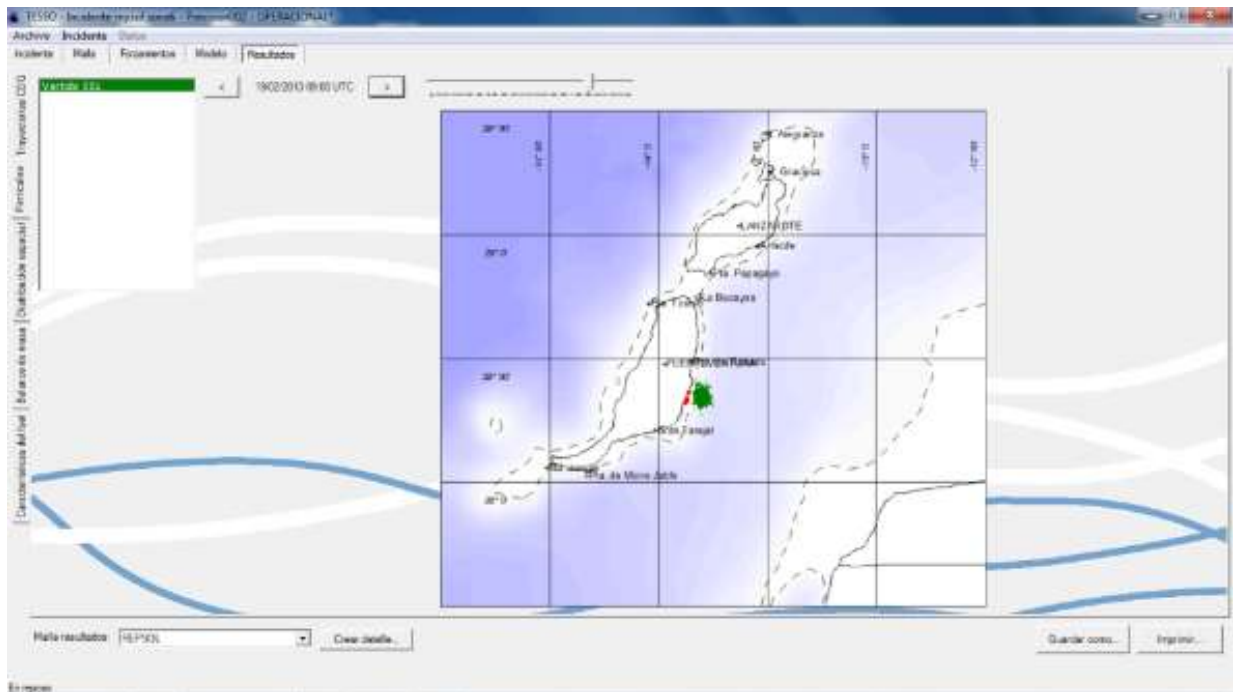
Figure 7 shows the location of the spill after 34 hours.



Source: Authors.

Figure 7: Spill location after 34 hours. Region Canarias 6. TESEO Model.

Figure 8 shows the location of the spill after 57 hours. At this point the mixture of hydrocarbons hits the coast of Lanzarote.



Source: Authors.

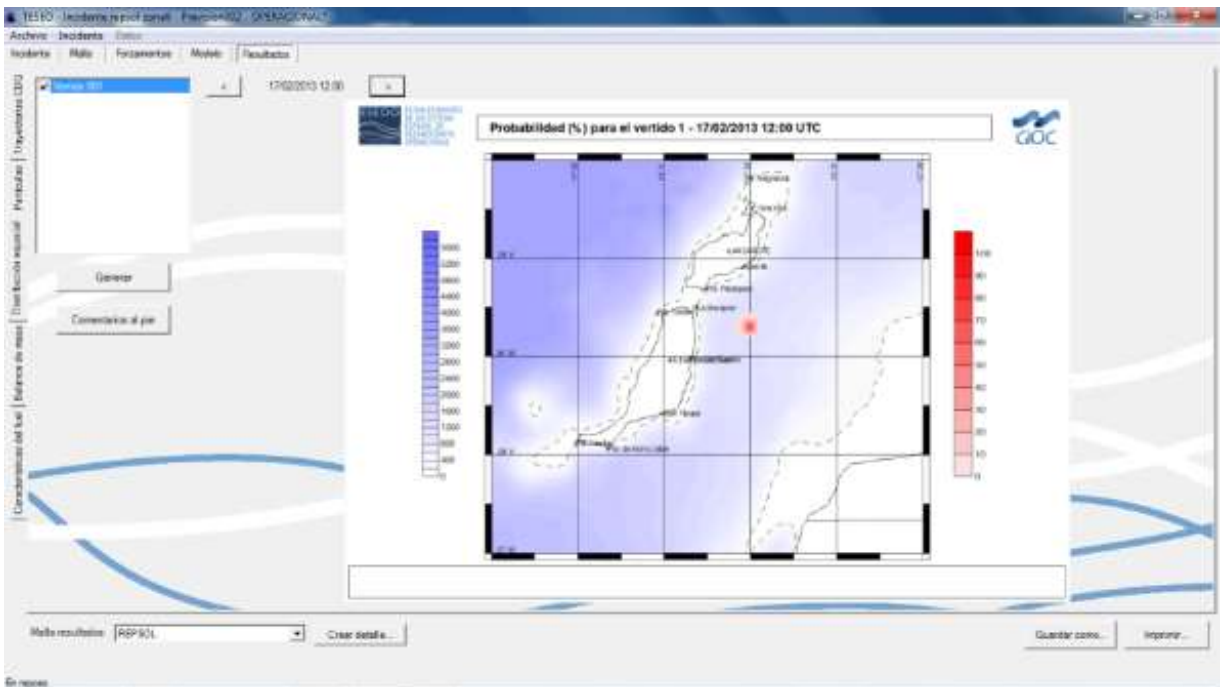
Figure 8: Spill location after 57 hours. Region Canarias 6. TESEO Model.
The location of the spill after 72 hours is shown in Figure 9.



Source: Authors.

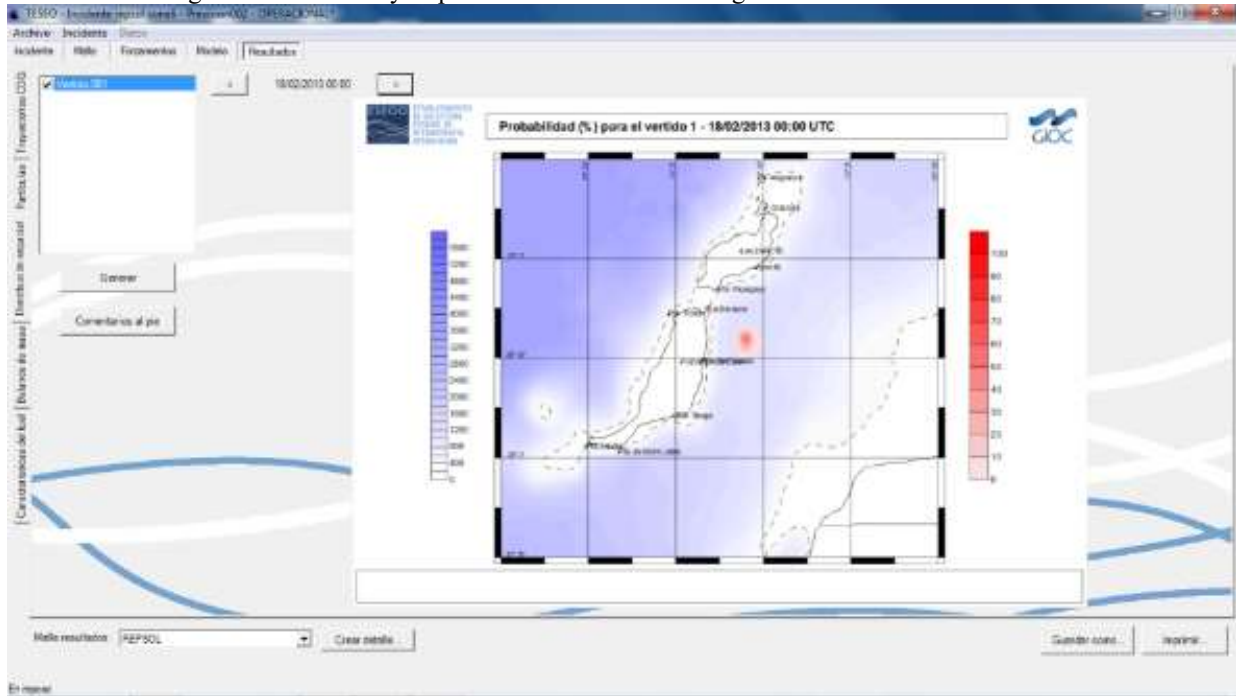
Figure 9: Spill location after 72 hours. Region Canarias 6. TESEO Model.

Figure 10 to Figure 13 show the probability (%) of a certain marine area to be affected by a hydrocarbon spill going on for 72h.



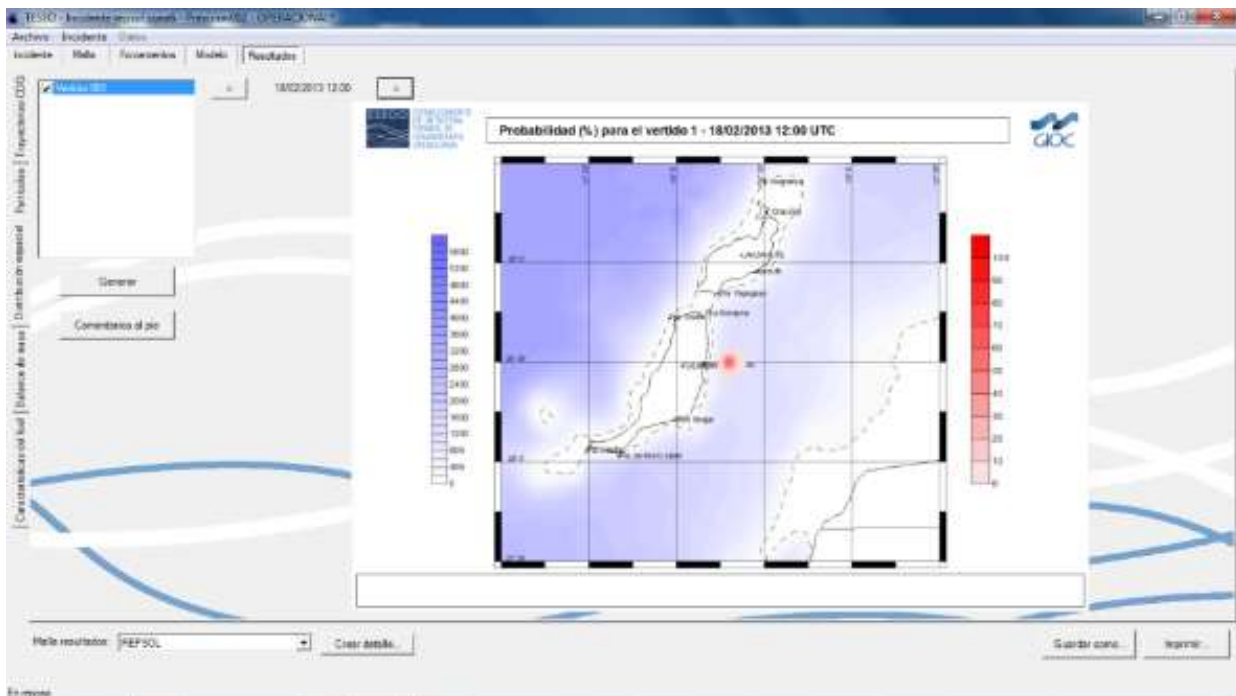
Source: Authors.

Figure 10- Probability of pollution after 12 hours. Region Canarias 6. TESEO Model.



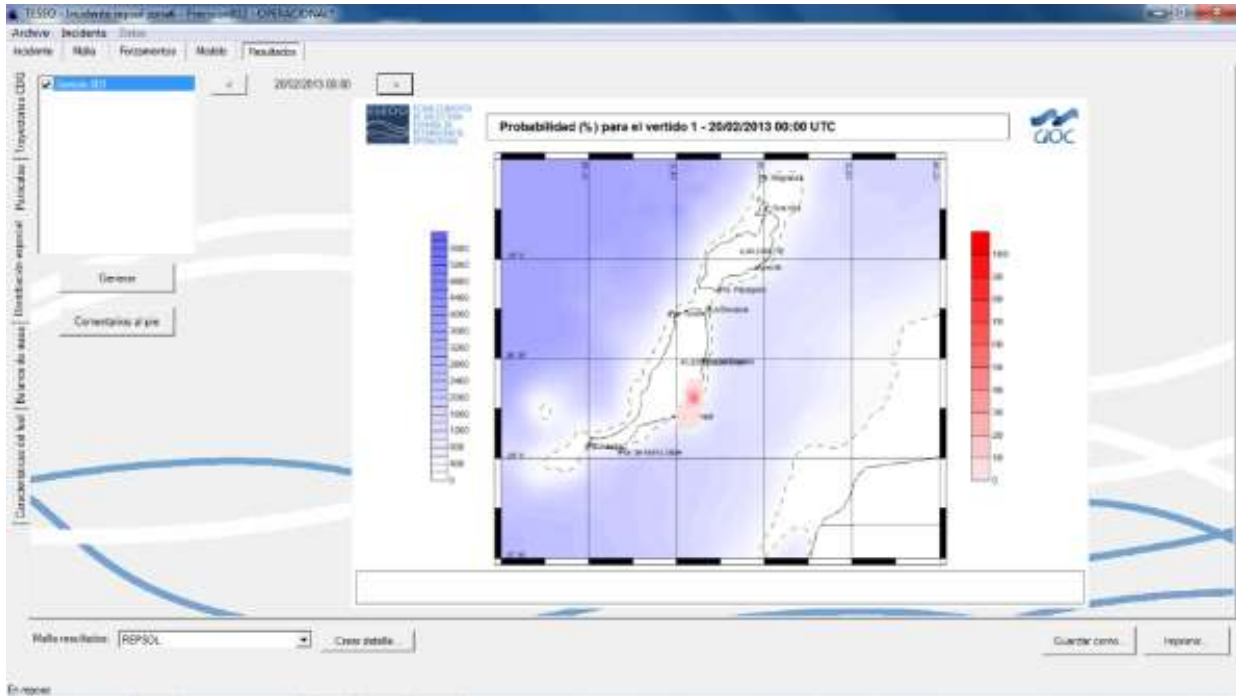
Source: Authors.

Figure 11- Probability of pollution after 36 hours. Region Canarias 6. TESEO Model.



Source: Authors.

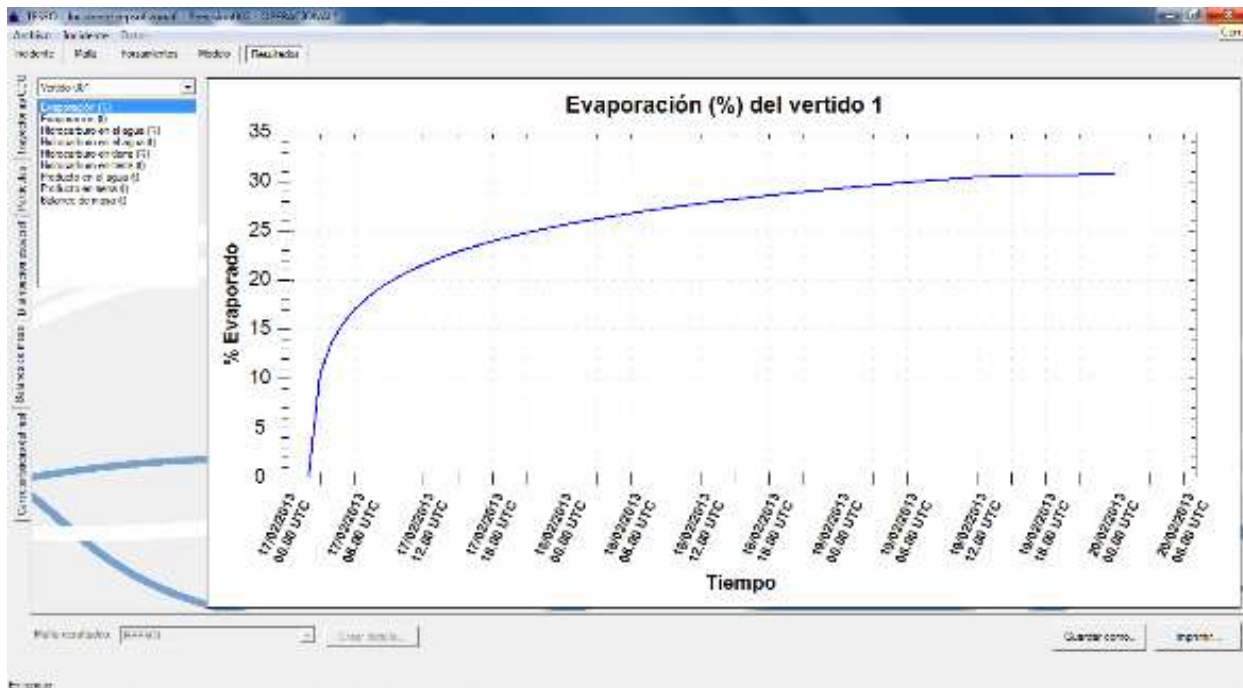
Figure 12- Probability of pollution after 60 hours. Region Canarias 6. TESEO Model.



Source: Authors.

Figure 13- Probability of pollution after 72 hours. Region Canarias 6. TESEO Model.

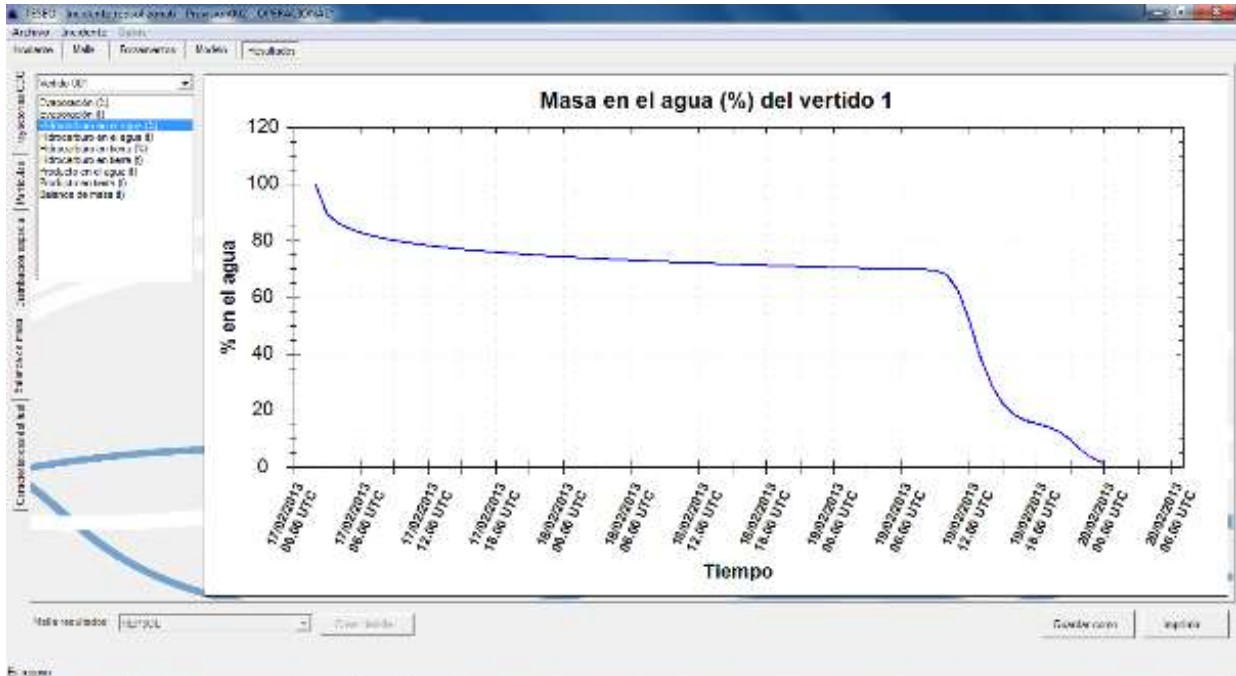
Figure 14 shows the variation over time of the evaporated percentage.



Source: Authors.

Figure 14: Variation over time of the evaporated percentage. Region Canarias 6. TESEO Model.

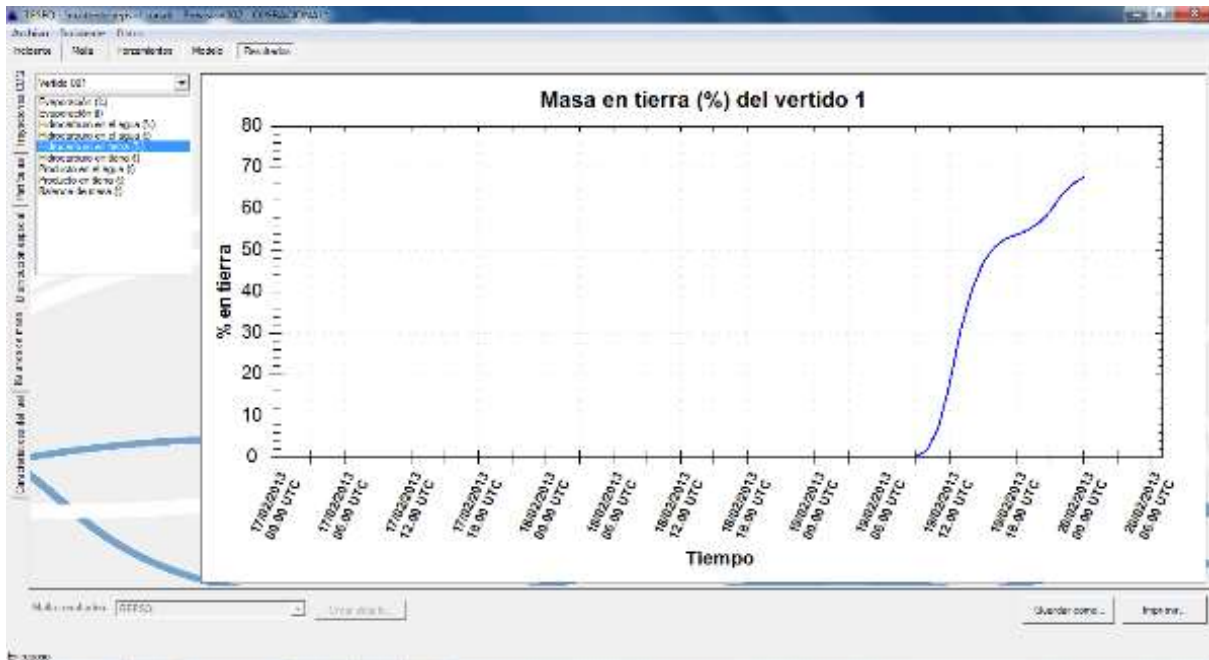
Figure 15 shows the variation over time of the hydrocarbon percentage in water.



Source: Authors.

Figure 15 - Variation over time of the hydrocarbon percentage in water. Region Canarias 6. TESEO Model.

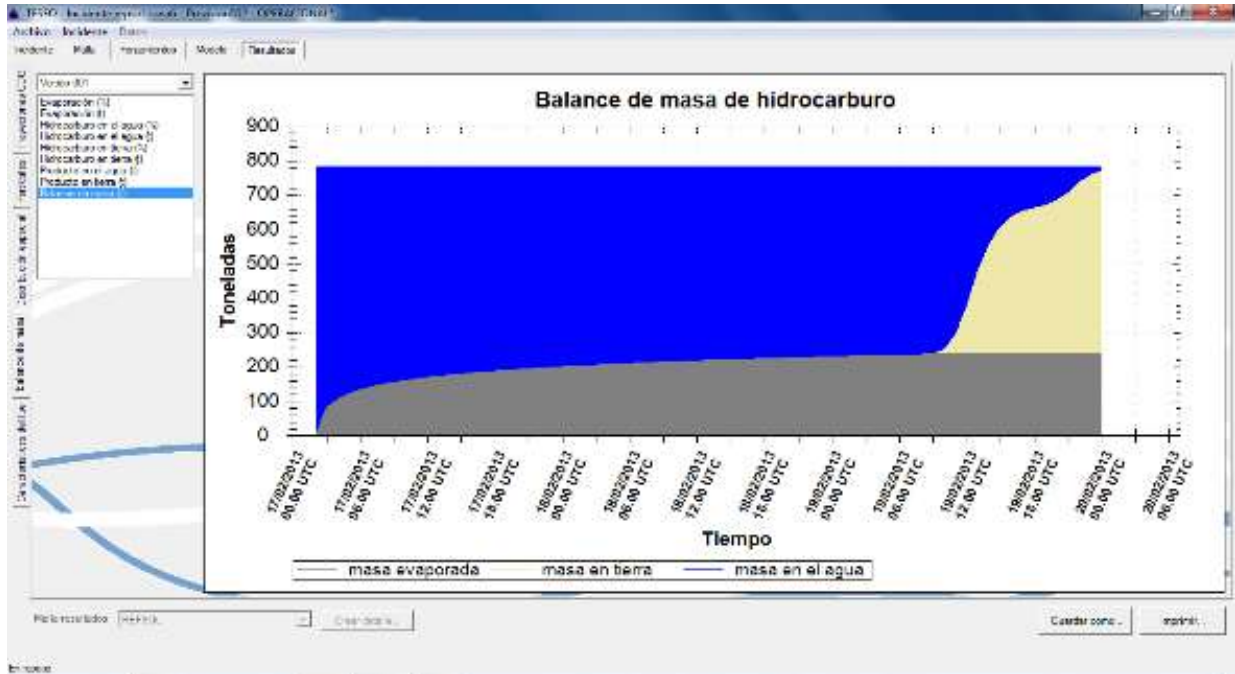
Figure 16 shows the variation over time of the percentage of the mass of hydrocarbons settled on the coast.



Source: Authors.

Figure 16: variation over time of the percentage of the mass of hydrocarbons settled on the coast. Region Canarias 6. TESEO Model.

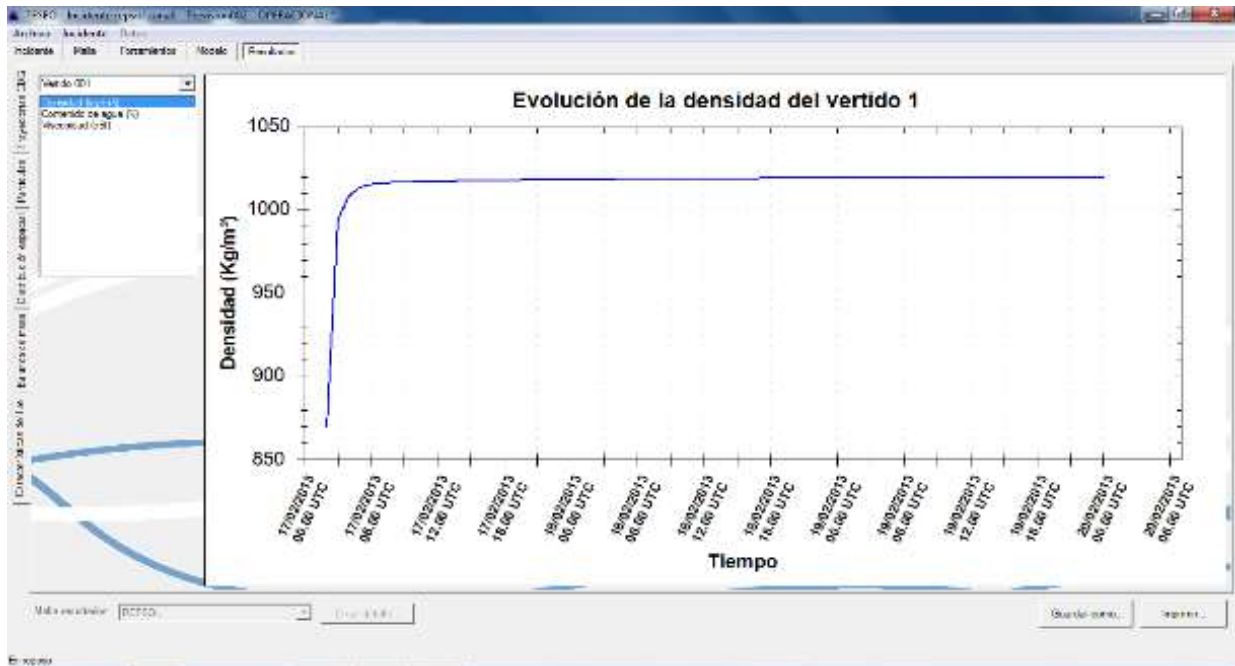
Figure 17 shows the variation over time of the balance of spilled oil material.



Source: Authors.

Figure 17: variation over time of the balance of spilled oil. Region Canarias 6. TESEO Model.

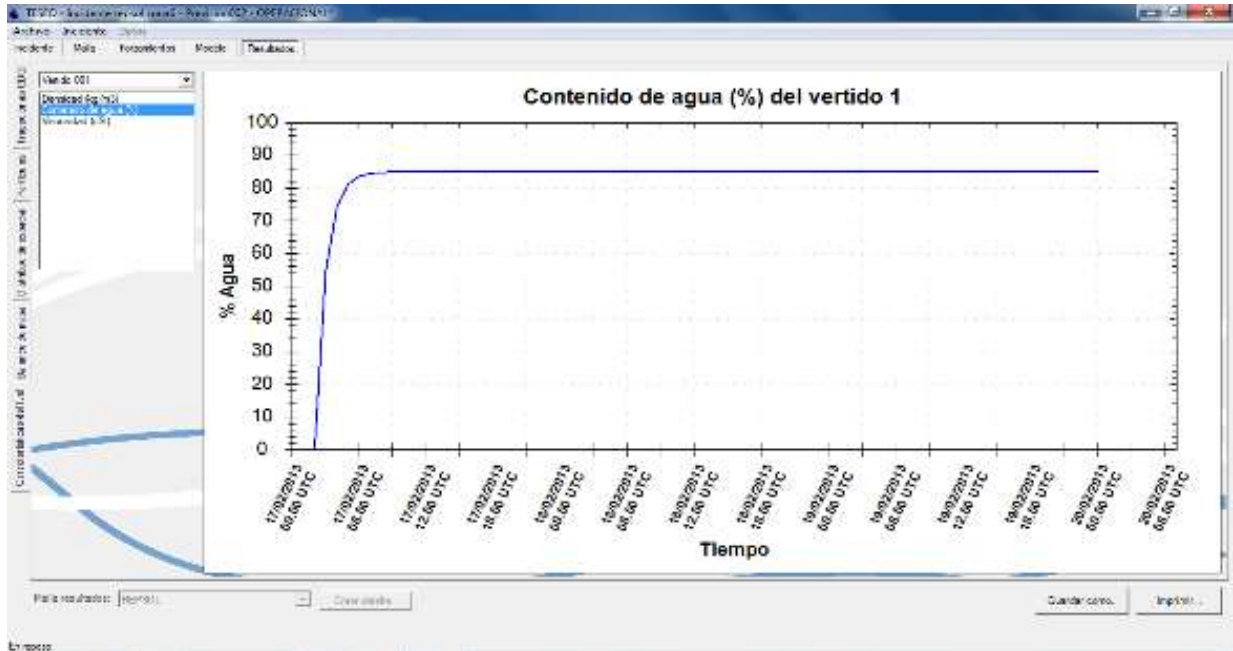
Figure 18 shows the variation over time of the density of the remaining hydrocarbon mixture.



Source: Authors.

Figure 18: Variation over time of the density of the remaining hydrocarbon mixture. Region Canarias 6. TESEO Model.

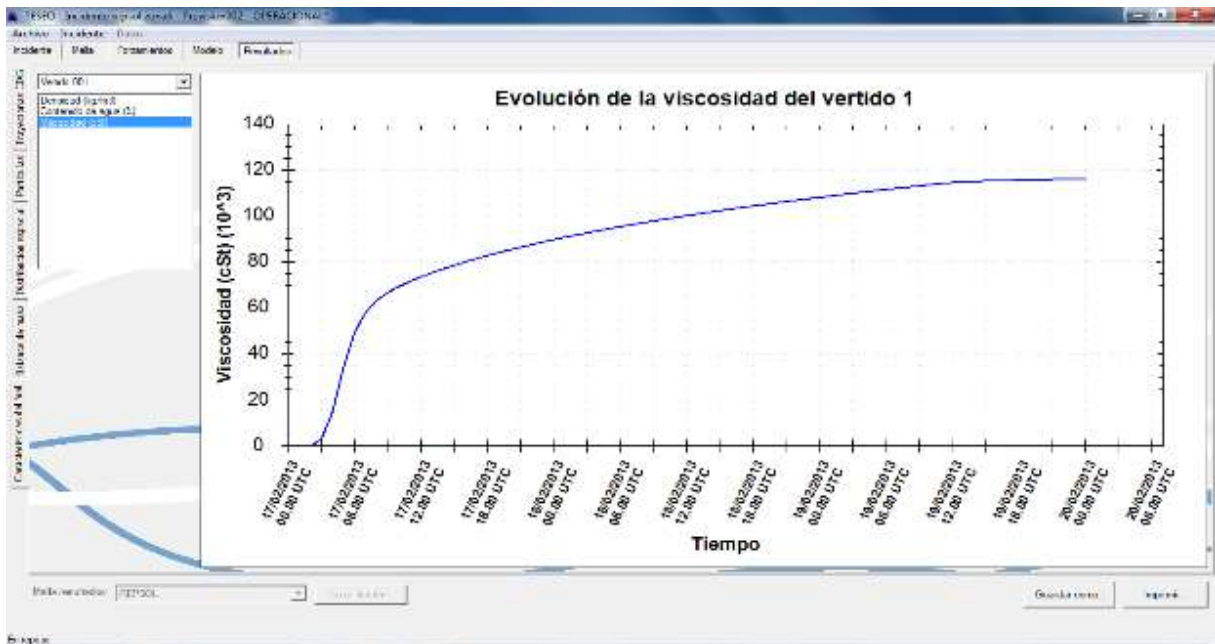
Figure 19 shows the variation over time of the water content on the remaining oil.



Source: Authors.

Figure 19: variation over time of the water content on the remaining oil. Region Canarias 6. TESEO Model.

Figure 20 shows the variation over time of the viscosity of the remaining hydrocarbons.



Source: Authors.

Figure 20: variation over time of the viscosity of the remaining hydrocarbons. Region Canarias 6. TESEO Model.

Figure 21 shows the path of the spill until it hits the coast of Fuerteventura. The impact point coordinates on the coast are the following: 28° 18,6'N ; 13° 53'W.



Source: Authors.

Figure 21: Path of the spill until it hits the coast of Fuerteventura. Region Canarias 6. TESEO Model.

Source: Authors.

3.2 RESULTS: TESEO Scenarios

Table 3 shows as an overview the results of the evolution of the spill by each of the scenarios tested with the TESEO Model.

TESEO MODEL								
Region	INPUT MODEL				RESULTS			
	Crude type	amount spilled	meteorological conditions	Oceanographic conditions	Impact time(h)	% Evaporated - Dispersed	Mass on coast (tn)	Coast Impact (km)
CANARIAS 6	Arabian Ligth	960 m ³	AEMET	Puertos Estado	57	31	530	27
	<i>Sensitive Regions Affected:</i> -Fuerteventura *Municipios: Tuineje, Antigua *LIC: Monumento Natural Cuchillos de Vigán *IBAS: Cuchilletes de Buenavista—arranco de la Torre- Los Alar, Macizo de Pozo Negro-Vigán *ZEPA: Llanos y Cuchillos de Antigua, Pozo Negro * Espacio Natural Protegido: : Monumento Natural: Cuchillos de Vigán							
Drilling Naranja (Stochastic) (D.H.)	Arabian Ligth	222 m ³	AEMET	Puertos Estado	-	34	-	-
	<i>Sensitive Regions Affected:</i> Possibly African Coast							
Drilling Naranja (Stochastic) (D.H.)	Arabian Ligth	960 m ³	AEMET	Puertos Estado	-	35	-	-
	<i>Sensitive Regions Affected:</i> -----							
Drilling Sandía (Stochastic) (D.H.)	Arabian Ligth	222 m ³	AEMET	Puertos Estado	-	34	-	-
	<i>Sensitive Regions Affected:</i> -----							
Drilling Sandía	Arabian Ligth	960 m ³	AEMET	Puertos Estado	-	35	-	-

(Stochastic)	<i>Sensitive Regions Affected:</i> -----							
Drilling Forum Draa (Stochastic) (D.H.)	Arabian Lighth	222 m ³	AEMET	Puertos Estado	221	35	86	55
	<i>Sensitive Regions Affected:</i> African Coast							
Drilling Forum Draa (Stochastic) (D.H.)	Arabian Lighth	960 m ³	AEMET	Puertos Estado	147	35	540	24
	<i>Sensitive Regions Affected:</i> African Coast							
Drilling Cabo Juby (Stochastic) (D.H.)	Arabian Lighth	222 m ³	AEMET	Puertos Estado	137	35	18	-
	<i>Sensitive Regions Affected:</i> African Coast							
Drilling Cabo Juby (Stochastic) (D.H.)	Arabian Lighth	960 m ³	AEMET	Puertos Estado	222	35	5	-
	<i>Sensitive Regions Affected:</i> African Coast							
Drilling Essaouira (Stochastic) (D.H.)	Arabian Lighth	222 m ³	AEMET	Puertos Estado	250	35	-	-
	<i>Sensitive Regions Affected:</i> African Coast							
Drilling Essaouira (Stochastic) (D.H.)	Arabian Lighth	960 m ³	AEMET	Puertos Estado	214	35	440	32
	<i>Sensitive Regions Affected:</i> African Coast							
Drilling Sandía Temporal Sur (Deterministic)	Arabian Lighth	960 m ³	AEMET	Puertos Estado	125	33	560	50
	<i>Sensitive Regions Affected:</i> Lanzarote *Municipios: Arrecife, San Bartolomé, Tías, Yaiza *LIC: Cagafrecho, Seadales de Guasimeta *ZEPa: Los Ajaches * Espacio Natural Protegido: Monumento Natural Los Ajaches							
Drilling Chirimoya Temporal Sur (Deterministic)	Arabian Lighth	960 m ³	AEMET	Puertos Estado	98	35	290	62
	<i>Sensitive Regions Affected:</i> Lanzarote *Municipios: Tías, Yaiza *LIC: Cagafrecho *ZEPa: Los Ajaches * Espacio Natural Protegido: Monumento Natural Los Ajaches Fuerteventura *Municipios: La Oliva *LIC: Islote de Lobos, Seadales de Corralejo, Corralejo *IBAS: Isla de Lobos, Jable de Corralejo *ZEPa: Dunas de Corralejo e Isla de Lobos *Espacio Natural Protegido: Parque Natural Islote de Lobos, Parque Natural de Corralejo							
Drilling Cebolla Temporal Sur (Deterministic)	Arabian Lighth	960 m ³	AEMET	Puertos Estado	85	35	86	22
	<i>Sensitive Regions Affected:</i> Lanzarote *Municipios: Haría, Archipiélago Chinijo. *Reserva Marina de Lanzarote *LIC: Los Jameos, La Corona, Archipiélago Chinijo, Los Islotes, Seadales de La Graciosa IBAS: Los Islotes de Lanzarote, Riscos de Famara *ZEPa: Islotes del Norte de Lanzarote y Famara *Espacio Natural Protegido: Monumento Natural La Corona, Parque Natural Archipiélago Chinijo							
Drilling Cabo Juby Temporal Sur (Deterministic)	Arabian Lighth	960 m ³	AEMET	Puertos Estado	138	34	560	39
	<i>Sensitive Regions Affected:</i> Lanzarote *Municipios: Arrecife, San Bartolomé, Tías, Yaiza *LIC: Seadales de Guasimeta, Cagafrecho *ZEPa: Los Ajaches * Espacio Natural Protegido: Monumento Natural Los Ajaches							
Nota: D.H.: Deepwater Horizon Conditions (Gulf of Mexico)								

Source: Authors.

Table 3: Summary of the evolution of the spill by each of the scenarios tested with the TESEO Model.

4. CONCLUSIONS

We have analyzed the results of deterministic and stochastic simulations for a possible accidental oil spill during underwater oil exploration in the eastern region of the Canary Islands waters.

The potential spill trajectories have been analyzed using TESEO model to evaluate the impact on the coast. Real data from National Meteorological Agency and Puertos del Estado was used to accomplish the description of wind, water flows and waves in the area.

From the results of these cases, it can be concluded that a large amount of oil spill stays in the water column. Likewise, exploratory research in Morocco waters does not exempt the Canary Islands of being affected by oil spill. The weathering process intervenes remarkably. From the viewpoint of impact and drift length probability we observe a moderate-high impact on the coast and sensitivity regions (Fuerteventura and Lanzarote). As an important consequence, the cleaning and coast restoration becomes more difficult and compromising the complex marine ecosystem and local economies based on tourism.

BIBLIOGRAPHY

ABASCAL, e. (2008). Description and Application of the Operational Oil Spill Forecast System TESEO. International Oil Spill Conference.

BERGUEIRO, J.R. et al. (2001). La Gestión de los Derrames de Hidrocarburos en el Mar. Palma de Mallorca: Ref. I.S.B.N.: 84-699-60571.

BERGUEIRO (2004). BERGUEIRO LÓPEZ, J. R., SERRA SOCÍAS, F., et al. Gestión Integrada de Zonas Costeras Ante Vertidos de Hidrocarburos en el Mar Balear. Palma de Mallorca: I.S.B.N.: 84 – 688 -8919 – 9. Depósito Legal: PM 2349 – 2004. Área de Ingeniería Química. Facultad de Ciencias. Universidad de las Islas Baleares.

BERGUEIRO (2009). BERGUEIRO LÓPEZ, J.R. El Modelo S.O.N.I.A: Su Aplicación a la Gestión de Derrames de Hidrocarburos en el Mar. I Jornadas Nacionales de Seguridad y Contaminación Marina. Escuela Técnica Superior de Náutica, Máquinas y Radioelectrónica Naval .ULL.

ESEOO Project. Establecimiento de un Sistema Español de Oceanografía Operacional (ESEOO). Ministerio de Ciencia y Tecnología (2004-2007).

FAY, J., (1969). The Spread of Oil Slicks on calm sea. Oil on the sea. Ed. Hoults, Plenum Press.

FAY, J., (1971). Physical processes in the spread of oil on a water surface. Proc. of the Joint Conf. on Prevention and Control of Oil Spill. American Petroleum Institute, Washington, DC, 463-467.

LEHR ET AL. (1984). Lehr, W.J., Fraga, R., Belen, M., Cekirge, H., 1984. A new technique to estimate initial spill size using a modified Fay-type spreading formula. Marine Pollution Bulletin 15 (9), 326 –329.

MACKAY (1980). Mackay, D., Paterson, S., Trudel, K., 1980. A Mathematical Model of Oil Spill Behaviour. Environmental Protection Service, Fisheries and Environment Canada, EE-7, 39 p.39 pp.

SANTAMARÍA, R. M. (2006). Los Modelos de Deriva en la Predicción de Vertidos. A Coruña: las Jornadas Científico-Técnicas de Lucha Contra la Contaminación Marina.

STIVER, W., & MACKAY, D. (1984). Evaporation Rate of Spills of Hydrocarbons and Petroleum Mixtures. Environment Science & Technology.

SEMBLANZA DE LOS AUTORES



J.M. Calvilla es Licenciado en Física y Doctor en Toxicología, Contaminación y Seguridad en el Transporte Marítimo por la Universidad de La Laguna (España). Su área de investigación está centrada en la Contaminación Marina por Hidrocarburos, la modelización de vertidos accidentales y la elaboración de Planes de Contingencias. Investigador del Grupo I+D CONSEMAR (Contaminación y Seguridad Marina), Universidad de La Laguna.