Environmental Pollution 231 (2017) 578–588

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Management of oil spill contamination in the Gulf of Patras caused by an accidental subsea blowout☆

Panagiotis Eleftherios Makatounis [a, *], Jørgen Skancke [b], Evanthia Florou [c], Anastasios Stamou [a], Per Johan Brandvik [b]

[a] Department of Civil Engineering, National Technical University of Athens, 5 Heroon Polytechniou, Zografou, 157 80 Athens, Greece
[b] Environmental Technology, SINTEF Ocean, 7465 Trondheim, Norway
[c] Medeon SA, 45-47 Voulis, 105 57 Athens, Greece

ARTICLE INFO

Article history:
Received 24 April 2017
Received in revised form
18 August 2017
Accepted 19 August 2017
Available online 29 August 2017

Keywords:
Oil spill contamination
Oil spill modeling
Oil contamination probability
Subsea blowout
Mesolongi
Aitoliko coastal lagoons

ABSTRACT

A methodology is presented and applied to assess the oil contamination probability in the Gulf of Patras and the environmental impacts on the environmentally sensitive area of Mesolongi – Aitoliko coastal lagoons, and to examine the effectiveness of response systems. The procedure consists of the following steps: (1) Determination of the computational domain and the main areas of interest, (2) determination of the drilling sites and oil release characteristics, (3) selection of the simulation periods and collection of environmental data, (4) identification of the species of interest and their characteristics, (5) performance of stochastic calculations and oil contamination probability analysis, (6) determination of the worst-cases, (7) determination of the characteristics of response systems, (8) performance of deterministic calculations, and (9) assessment of the impact of oil spill in the areas of interest. Stochastic calculations that were performed for three typical seasonal weather variations of the year 2015, three oil release sites and specific oil characteristics, showed that there is a considerable probability of oil pollution that reaches 30% in the Mesolongi – Aitoliko lagoons. Based on a simplified approach regarding the characteristic of the sensitive birds and fish in the lagoons, deterministic calculations showed that 78–90% of the bird population and 2–4% of the fish population are expected to be contaminated in the case of an oil spill without any intervention. The use of dispersants reduced the amount of stranded oil by approximately 16–21% and the contaminated bird population of the lagoons to approximately 70%; however, the affected fish population increased to 6–8.5% due to the higher oil concentration in the water column. Mechanical recovery with skimmers “cleaned” almost 10% of the released oil quantity, but it did not have any noticeable effect on the stranded oil and the impacted bird and fish populations.

1. Introduction

The Gulf of Patras is a part of the Ionian system, which is one of the three major petroleum systems in Western Greece (Karakitsios, 2013). Preliminary seismic surveys in the Gulf of Patras have detected interesting oil prone geological structures with the recoverable reserves to be estimated around 200 MMbbls (http://www.ypeka.gr/Default.aspx?tabid=766&locale=en-US&language=el-GR, last access 3 July 2017). The final and detailed seismic survey and exploitation is expected to start soon by the group of companies that undertook the relevant contract (EU, 2015). Since the drilling sites are close to high sensitivity and environmentally protected coastal areas, such as the Mesolongi and Aitoliko lagoons, an oil spill release due to a potential accident may cause significant environmental damages (Beyer et al., 2016; Goovaerts et al., 2016; Hester et al., 2016). Therefore, it is important to assess a priori these damages and determine proper oil spill response methods to manage (avoid or reduce) them. This assessment can be achieved via an Oil Spill Model (OSM) that determines the transient behavior of an oil spill, i.e. its trajectory and corresponding concentrations, from which we can estimate the contamination probability and arrival time in the areas of interest (Hellenic Center of Marine Research (HCMR), 2012), and the effect of applied oil spill response systems.

There exist various OSMs in the literature; see Spaulding (2017)

☆ This paper has been recommended for acceptance by Maria Cristina Fossi.
* Corresponding author.
E-mail address: panmakat@mail.ntua.gr (P.E. Makatounis).

http://dx.doi.org/10.1016/j.envpol.2017.08.076

for a review of the state of the art in OSMs from 2000 to present, which describe the behavior of an oil slick that may be caused by subsea blowouts (Socolofsky et al., 2015) or surface accidents (Papadonikolaki et al., 2014; El-Fadel et al., 2012). Generally, the frequency of blowout spills is lower than that of surface spills; however, the total environmental risk from blowouts is higher due to the (i) larger quantities of released oil (Eckle et al., 2012), and (ii) higher pressures involved that make them very difficult to control (Lamine and Xiong, 2013). Since the oil slick behavior depends strongly on the local weather and ocean circulation conditions, we usually obtain the required data (to be used as input to the OSM) from a weather model (Kallos, 1997) and an ocean circulation model (Blumberg and Mellor, 1987) that are applicable in the specific area of study. To produce realistic results, we define reasonable oil spill scenario characteristics for the (i) spill location, (ii) release duration, (iii) flow rate and (iv) crude oil type; we can select these data based on past and well-studied incidents, such as the Deepwater Horizon blowout (McNutt et al., 2012).

Generally, there are two main types of applications of OSMs. The first type deals with the determination of the contamination probability maps due to an oil slick in the areas of interest; to produce accurate maps, we need to take into account the stochastic nature of the oil slick behavior via the definition of multiple periods (or seasons) of study per year and multiple spill locations to perform the so-called “stochastic” simulations for a sufficient period of time (Alves et al., 2015; De Dominicis et al., 2013; Goldman et al., 2015; Melaku Canu et al., 2015). In the second type of application, we study the detailed behavioral characteristics of a specific oil spill and/or the effectiveness of the available oil spill response methods (Alves et al., 2016), but also for model intercomparison purposes (Socolofsky et al., 2015). In such cases, we perform the so-called “deterministic” calculations for just one oil spill for a specific period and specific weather and ocean circulation conditions.

In the present work, we apply a modeling methodology that combines stochastic and deterministic oil spill simulations using the oil spill model OSCAR (Daling et al., 1990; Reed et al., 1995a, 1995b, 2000; Reed and Hetland, 2002): (i) to assess the oil contamination probability in the Gulf of Patras and the possible environmental impacts on the Mesolongi – Aitoliko coastal lagoons, and (ii) to examine the effectiveness of the available oil spill response methods; this study is the first regarding oil spill modeling in the Gulf of Patras and the first worldwide that combines stochastic with deterministic simulations.

2. The area of study

We performed oil spill simulations in the 100 km × 97 km area of study, which is shown in Fig. 1; it is surrounded by the islands Kefalonia, Ithaki, Zakynthos and Lefkada (not shown in Fig. 1) on its western side, and continental Greece on the east. Numerous touristic zones, fisheries and environmentally protected areas are located within the area of study. Significant wetlands include the Strofylia wetland (west coast of Peloponnese), Laganas beach (south coast of Zakynthos island), where the loggerhead sea turtles (Caretta-Caretta) migrate to lay their eggs in summer, the Petalas wetland (west coast of mainland) and the Mesolongi - Aitoliko lagoons (the total area of the lagoons is equal to 170 km^2 and the total volume is equal to approximately 0.17 km^3), which constitute the main focus area for this study. This lagoon system is part of an extensive wetland complex in the northern region of the Gulf of Patras (Fig. 1) that is protected under the RAMSAR international convention for wetlands (http://www.ramsar.org/wetland/greece, last access 3 July 2017). The Aitoliko lagoon, to the north, has a mean depth of 12 m and a maximum depth of 33 m (Leftheriotis et al., 2013); its bottom layers are permanently anoxic due to limited water circulation, while occasionally, advection to the surface causes total anoxia, resulting in massive mortality of aquatic organisms (Gianni et al., 2011). The Mesolongi lagoon has a mean depth of 0.5 m, while its maximum depth is approximately 2.5 m (Leftheriotis et al., 2013). Human intervention has altered severely the geomorphological and hydrological features of the Mesolongi-Aitoliko area (Greek Ministry of Environment, 1998), with various effects on biotic and abiotic factors of the ecosystem. However, unique features of estuarine ecosystems, like sand dunes, salt marshes and mudflats, still exist providing shelter to various species. The lagoon is very important for migratory wintering and breeding birds; more than 280 different species have been observed in the area during the year (Greek Ministry of Environment, 1998). Vegetation in the area includes rare and endangered species. Human activities include extensive fishing and fish farming. Fish can generally be divided in those that spend their whole life cycle in the lagoon and those that spawn in the open sea and enter the lagoon to find food and shelter (Nikolaidou et al., 2005).

3. Presentation and application of the methodology

In the present section, we describe and apply the proposed methodology in a series of 9 steps.

Step 1. Determination of the computational domain and the main areas of interest. The computational domain of OSCAR covers the area of study that is shown in Fig. 1; we have employed 11 layers in the vertical direction with the following water depths: 0.0–3.0 m, 3.0–8.0 m, 8.0–13.0 m, 13.0–18.0 m, 18.0–25.0 m, 25.0–40.0 m, 40.0–65.0 m, 65.0–115.0 m, 115.0–125.0 m, 225–475.0 m and 475.0–825.0 m, and a horizontal resolution equal to 100 m × 100 m, which resulted in a total number of surface cells that is equal to approximately 10^6 cells. The bathymetry of the area was obtained from the US Navy Digital Bathymetric Data Base (DBDB1) that has a nominal resolution of 0.017°, by bilinear interpolation via the application of the ocean circulation model that is briefly described in step 3. The main areas of interest are the environmentally sensitive Mesolongi – Aitoliko coastal lagoons that are also shown in Fig. 1.

Step 2. Determination of the drilling sites and the oil release characteristics. Currently, there is no legal framework in Greece for offshore oil drilling activities in the Gulf of Patras; moreover, there is no information on the locations of oil reserves. Therefore, we determined at a preliminary level, the drilling sites A, B and C that are shown in Fig. 1 that are away from a buffer zone of 5 km from ship routes, coasts and protected areas. Since the corresponding sea water depths at sites A, B and C are 130 m, 177 m and 70 m, respectively, we expect that the plume of the oil rises fast to the surface without being trapped in the water column. Moreover, since offshore drilling has not started yet, there is no information on the potential blowout and oil characteristics. Therefore, in the calculations, we assumed that the temperature of oil is equal to 60 °C, the diameter of the release is equal to 0.3 m, and the flow rate is equal to 10000 m^3/d; this value of flow rate is reported in the environmental impact study by the Hellenic Center of Marine Research (HCMR, 2012) and is practically equal to the flow rate of the Deepwater Horizon blowout (average flow rate = 8400 m^3/d), but with a much shorter duration of release (McNutt et al., 2012; Zhao et al., 2015). Also, we used the oil characteristics of the Oseberg Blend, a low viscosity (5 cP at 40 °C), light paraffinic oil with API equal to 37.2 and specific gravity equal to 0.839.

The characteristic diameters of the initial oil droplet size distribution were estimated equal to $D_{95} = 7.8$ mm and $D_{max} \approx 11.2$ mm, using an algorithm that employs the modified