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MODELLING OF THE OIL SPILL IN M/V LADY TUNA ACCIDENT AND THE EVALUATION OF THE RESPONSE OPERATION IN SIMULATED CONDITION WITH PISCES-II

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by

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Deniz AYDIN, M.Sc. student of Piri Reis Maritime Transportation and Management Engineering student ID 158013001, successfully defended the thesis entitled **"MODELLING OF THE OIL SPILL IN M/V LADY TUNA ACCIDENT AND THE EVALUATION OF THE RESPONSE OPERATION IN SIMULATED CONDITION WITH PISCES-II"** which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To the women sailors…

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ABSTRACT

MODELLING OF THE OIL SPILL IN M/V LADY TUNA ACCIDENT AND THE EVALUATION OF THE RESPONSE OPERATION IN SIMULATED CONDITION WITH PISCES-II

Oil pollution from ships is an important source of marine pollution and becomes an important problem all over the world. Although there are many national and international laws as well as regulations and implementations related to oil pollution, ship-sourced oil spills continue to cause marine pollution. Also, it is an indisputable fact that the risk of oil pollution will be unavoidable as long as oil is extracted from the sea, transported by ships and stored in the marine environment. Unless we are prepared for these risks, the major environmental disasters caused by oil pollution will continue and our dream of leaving a clean world, which is an invaluable heritage to future generations, will not be realized.

Due to its geographical location as a transit country, Turkey must be prepared for ship accidents and conduct more effective response operation against oil pollution on the sea. For this reason, every effort should be made to prevent oil spills and to remove them effectively as soon as pollution has emerged. In this respect, various computer simulations are used to predict the behavior of the oil spills at sea. This provides better use of available response resources to combat the oil spill in seawater. In this thesis, the grounding accident of ship M/V Lady Tuna that occurred on 18th December 2016 near Çesme coast in Turkey was investigated. The oil spill as result of the accident was modeled with PISCES II (Potential Incident Simulation, Control and Evaluation System) simulator.

As a result of the modelling of the accident with PISCES II simulator, the processes that occur during the interaction of oil with seawater and air as well as the behavior of the oil spreading on the sea surface was observed. The meteorological conditions at the time of the accident and the parameters of the spilled oil were processed into the PISCES II simulator. Later, the process of spreading, evaporation, dispersion, emulsification, variation of viscosity and shoreline interaction in the oil spill on the sea surface were detected. In addition, the response operation to combat oil pollution on the seawater was planned in real time. Thus, the results of the changing pollution and spill statistics are presented as numerical after the response resources controlled the oil spreading. It is assessed that this study will contribute to organizations involved in oil spill response operations.

Keywords: Ship-sourced oil pollution, Oil spill, Oil spill response operation, M/V Lady Tuna, PISCES II.

ÖZET

M/V LADY TUNA KAZASINDAKİ PETROL SIZINTISININ MODELLENMESİ VE MÜDAHALE OPERASYONUN PISCES II İLE SİMULE EDİLMİŞ DURUMDA DEĞERLENDİRİLMESİ

Gemilerden kaynaklanan petrol kirliliği önemli bir deniz kirliliği kaynağıdır ve tüm dünyada önemli bir sorun haline gelmektedir. Petrol kirliliği ile ilgili birçok ulusal ve uluslararası kanunlar, düzenlemeler ve uygulamalar olmasına rağmen, gemi kaynaklı petrol sızıntıları deniz kirliliğine neden olmaya devam etmektedir. Ayrıca, petrol denizden çıkarıldığı, gemilerle taşındığı ve deniz ortamında depolandığı sürece petrol kirliliği riskinin kaçınılmaz olacağı tartışılmaz bir gerçektir. Bu risklere karşı hazırlıklı olmadıkça, petrol kirliliğinin neden olduğu büyük çevresel felaketler devam edecek ve gelecek nesiller için paha biçilemez bir miras olan temiz bir dünya bırakma hayalimiz gerçekleşmeyecektir.

Coğrafi konumu nedeniyle önemli bir geçiş ülkesi olan Türkiye, gemi kazalarına karşı hazırlıklı olmalı ve denizdeki petrol kirliliğine karşı daha etkili müdahale çalışması yürütmelidir. Bu nedenle, petrol sızıntılarını önlemek ve kirlilik meydana geldiği anda etkin bir şekilde ortadan kaldırmak için her türlü çaba gösterilmelidir. Bu bağlamda, petrol sızıntılarının denizdeki davranışını tahmin etmek için çeşitli bilgisayar simülasyonları kullanılmaktadır. Bu da deniz suyundaki petrol sızıntısına müdahale etmek için mevcut müdahale araçlarının daha iyi kullanılmasını sağlamaktadır. Bu tez çalışmasında, Türkiye'nin Çeşme sahili yakınlarında 18 Aralık 2016 tarihinde meydana gelen M/V Lady Tuna gemisinin karaya oturma kazası incelenmiştir. Kaza sonucu meydana gelen petrol sızıntısı PISCES II (Potansiyel Olay Simülasyonu, Kontrol ve Değerlendirme Sistemi) simülatörü ile modellenmiştir.

Kazanın PISCES II simülatörü ile modellenmesi sonucunda, petrolün deniz suyu ve hava ile etkileşimi sırasında meydana gelen süreçleri ve deniz yüzeyine yayılan petrolün davranışı gözlemlenmiştir. Kaza esnasındaki meteorolojik koşullar ve sızan petrolün parametreleri PISCES II simülatörüne girilmiştir. Daha sonra, deniz yüzeyindeki petrol sızıntısında; yayılma, buharlaşma, dağılma, emülsifikasyon, viskozite değişimi ve kıyı şeridi etkileşim süreçleri tespit edilmiştir. Ayrıca, deniz suyundaki petrol kirliliği ile mücadeleye yönelik müdahale operasyonu gerçek zamanlı olarak planlanmıştır. Böylece, petrol yayılımının kontrolünü sağlayan müdahale kaynakları kullanıldıktan sonra, değişen kirlilik ve sızıntı istatistiklerinin sonuçları sayısal olarak sunulmuştur. Bu çalışmanın, petrol sızıntısına karşı müdahale operasyonlarına katılan kuruluşlara katkı sağlayacağı değerlendirilmektedir.

Anahtar Kelimeler: Gemi kaynaklı petrol kirliliği, Petrol sızıntısı, Petrol sızıntısı müdahale operasyonu, M/V Lady Tuna, PISCES II.

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LIST OF ABBREVIATIONS

ADIOS	Automated Data Inquiry for Oil Spills
BSIMAP	Black Sea Integrated Monitoring and Assessment Program
CC	Coordination Committee
CFCP	Coastal Facility Contingency Plan
CLC 92	International Conventions on Civil Liability for Oil Pollution Damage 1992
CP	Centipoise
DWT	Deadweight
ECHO	European Civil Protection and Humanitarian Aid Operations
EMSA	European Maritime Safety Agency
EU	European Union
FUND 92	International Conventions on the Establishment of an International Fund for Compensation for Oil Pollution 1992
GMT	Greenwich Mean Time
GNOME	General NOAA Operational Modelling Environment
GPS	Global Positioning System
IMO	International Maritime Organization
ITOPF	International Tanker Owners Pollution Federation Limited
KW	Kilo Watt
LT	Local Time
MAP	Mediterranean Action Plan
MARPOL	International Convention for the Prevention of Pollution from Ships
MT	Metric Ton
NCP	National Contingency Plan
NKK	Nippon Kaiji Kyokai (Japanese Classification Society)
NM	Nautical Mile
NOAA	National Oceanic and Atmospheric Administration
OC	Operation Committee
OILMAP	Oil Spill Model and Response System
OPA 90	Oil Pollution Acts 1990
OPRC	International Convention on Oil Pollution Preparedness, Response and Cooperation
OSRL	Law Pertaining to Principles of Emergency Response and Compensation for Damages in Pollution of Marine Environment by Oil and Other Harmful Substances
PISCES II	Potential Incident Simulation, Control and Evaluation System II
POLREP	Pollution Reporting System
RCP	Regional Contingency Plan
REMPEC	Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea
UTC	Coordinated Universal Time
VCP	Vessel Contingency Plan

1. INTRODUCTION

Oil pollution in the marine environment is one of the most important threats all over the world due to major oil spill disasters. In the eight year period between 2010 and 2017, there have been 53 spills events that 7 tons and over, 47.000 tons oil spill to seawater; 80% of this amount has spilt in only 10 incidents (ITOPF, 2017). The consequences of oil spill resulted in significant problems that threaten not only a region lying along a shore but also the quality and balance of the aquatic ecosystems.

Due to Turkey's geographical position as a transit country, numerous accidents and collisions occurred, resulted in oil spills in the marine environment. 2017 annual statistics on marine accident and incident report by Ministry of Transport and Infrastructure, Accident Investigation Board revealed that 75 cubic meters of the oil spilled into the Turkish territorial sea in 2017 (Official Statistics of the Sea Accident and Incident, 2017). The major marine accidents which cause oil spills, attract more attention, however there are many other minor oil spill accidents which are disregarded.

M/V Lady Tuna was hard aground on the rock near Fener Island in the Ildır Bay area of Çeşme district near İzmir on December 18th, 2016. Following the incident, approximately 75 cubic meters of fuel oil was found to leak into the sea and it reached the beaches of the Çeşme coast. Most Maritime and Environmental Services Company which is in charge of administrative responsibility of Çeşme Port Authority and Mare Marine Cleaning Service Company conducted cleaning operations after the accident. M/V Lady Tuna was salvaged and refloated on 27th December 2016. (Accident Investigation Report, 2017)

When an oil spill occurs in the marine environment, all efforts must be made by governments and other organizations to prevent oil pollution. The best way to control the oil spill will take place if the response operations and emergency response strategies are already planned to prevent oil spillage as soon as possible. More recently, scientists have added advanced mathematical models which are integrated with computer simulation to better predict oil’s behaviour and to take best decisions for response operations to minimize the environmental effect.

The M/V Lady Tuna grounding accident resulted in pollution at the Çeşme coasts by leaking approximately 75 cubic meters of the fuel oil. The delayed and unorganized response operations following the spillage from the ship increased the oil pollution and stranded oil amount towards the Ildır coast. This oil spill case revealed the insufficiency of the regional emergency response system to control the oil spill just in time and lack of coordination among the relevant institutions. The official organizations and the oil cleaning companies were criticized because of the delayed response operations that increased stranded oil spill amount.

The aim of this study is to investigate the oil spill accident and evaluate the response operation of M/V Lady Tuna. In this concept, two scenarios were prepared in the thesis by using PISCES II (Potential Incident Simulation, Control and Evaluation System II). The first scenario was created without any response resources by modelling the accident of M/V Lady Tuna to observe the movement direction of the oil slick after the accident. The second scenario was reconstructed with the possible response resources after the oil spill. As a result of the simulation, it was possible to obtain the oil spill/pollution statistics; the recovered oil rate, the amount of stranded oil to the coast, the amount of floating oil rate, and other oil spill parameters.

The examination of the real oil spill events raise awareness of the risks of oil pollution and develop an effective response operation framework. The results of the research will be useful for many organizations concerned with response operation and hope to enhance marine oil pollution preparedness and response system.

The chapters of the thesis were selected as; Ship-sourced Marine Pollution, the Factors Influencing Turkey's Preparedness and Response System, Oil Spill Response Methods, Investigation of the M/V Lady Tuna Accident and Modelling of the Oil Spills in M/V Lady Tuna Accident with PISCES II.

2. LITERATURE REVIEW

Previous modelling efforts of oil spills were based on the use of simple formulations to predict the spread and experimental observation. The notable pioneer studies explaining fate of the spilled oil and physical process in the spread of oil on a water surface were improved by Fay (1969 and 1971), Mackay et al. (1980), Lehr et al. (1984), Delvigne at al. (1989) and Fingas et al. (1996). These studies take account of empirical measurements of spreading rates and analytical and theoretical studies of the physical processes.

In recent years, various oil spill models have been formed with computer software systems relied on the formula. The OILMAP (Oil Spill Model and Response System) and GNOME (General NOAA Operational Modelling Environment) are computer programs which provide rapid predictions of the movement of spilled oil by entering both environmental and hydrodynamic data and specifying a spill scenario in the marine environment (OILMAP, 2018; Zelenke et. al., 2012). The OILMAP also provides an oil spill response operation and has 3D modelling capability.

The similar computer software program, named ADIOS (Automated Data Inquiry for Oil Spills) is used by the National Oceanic and Atmospheric Administration Hazardous Materials Response Division (NOAA/HAZMAT). The study of Lehr et al. (2002), which is titled as "Revisions of the ADIOS oil spill model", explained the structural and algorithmic changes between the ADIOS-1 and ADIOS-2 the software program. The new model version of the ADIOS-2 predicts the weathering process of the spilled oil based on the different models. It provides cleanup of the oil on the seawater by using dispersant, in-situ burning and skimming as well as calculate the burn rate and resultant smoke plume.

The oil spill scenarios released around Bay of Samsun were modelled by use of OILMAP and ADIOS software system in the recent study of Toz (2017). Three oil types, fuel oil, diesel oil and crude oil, are modelled in different amounts. The study presented the movement of the spill as well as evaporation and dispersion rates by comparing the different spill sources.

PISCES II (Potential Incident Simulation, Control and Evaluation System II) is one of the computer software programs based on the mathematical modelling of an oil spill in marine environment. The simulation program predicts the oil spill behavior in water depending on spill parameters, the type of oil source, and environmental condition after the spillage. In addition, unlike many other programs, it is possible to manage the response operations in real time on the sea following the spillage. (PISCES II Manual, 2008)

As a result of reviewing the literature on PISCES II, selected articles are summarized. The study of the Lazuga, Gucma and Perkovic (2013) reconstructed an oil spill accident “M/T Baltic Carrier” by use of PISCES II simulator. Two scenarios were modelled in the study and displayed the movement of the oil slick during changing current parameters. In the scenario 2, the boom formations were used after the pollution but the spilled oil was not recovered during the simulation.

Jarzabek and Juszkiewicz (2017) conducted a study on PISCES II program. During the simulation, three types of oil (light Bent Horn, medium Arabian, and heavy Belridge) were preferred in different sea state conditions in order to compare dispersion, evaporation and emulsification rates of the spilled oils. More recently, Toz and Koseoglu (2018) conducted their study with PISCES II by modelling of oil spill in İzmir Bay. In the study, two scenarios were preferred to depend on the type of pollutant which is Marine Diesel Oil (MDO) and Marine Fuel Oil (MFO). In addition, sub-scenarios were presented depend on the spilled amount and environmental factor.

Research has shown that there have been several kinds of research on the prediction of oil spills behavior on seawater by using computer software programs or numerical modelling of oil spills. The scientific oil spill models provide the evaluation of the experienced oil spill incidents in the past and can show the deficiencies of the response operations following the spillage. In spite of many studies presented in the literature on fate of the spilled oil on the sea, only a few of them illustrated the response operations to prevent pollution.

3. METHODOLOGY

3.1. Aim of the Thesis

In the case of a marine oil spill, it is very important to respond immediately to control the spreading of the oil on seawater. When examining the Expert Report and the Accident Investigation Report of the M/V Lady Tuna, the inconsistencies and uncertainties revealed, which indicate important deficiencies in the emergency response operations in the oil pollution event following the accident.

The purpose of this study is to investigate the reports related with the accident and evaluate the response operation by modelling of the M/V Lady Tuna accident with PISCES II simulator. In this concept, two scenario models were conducted for the study in simulated condition. The objectives of the scenarios are to illustrate possible response operations on the sea surface before the oil reaches the coast in order to protect the marine ecosystem and human health.

3.2. The Main Structure of the Thesis

The thesis has been structured in four phases. The flowchart of the phases is displayed in Figure 3.1. The first phase of the thesis presents the research process of the thesis which is the literature overview and the methodology of the study.

The second phase is divided into chapters which provide the background data for the study. Understanding the ship-sourced marine pollution and nature of the oils are important in the beginning. In this conception, the background data for developing a general understanding of oil pollution in the marine environment and key factors affecting spilled oil behavior are presented in Chapter 4.

Turkey’s oil spill prevention policies have been adapted based on the international conventions and regulations. In Chapter 5, the national and international factors affecting Turkey's preparedness and response system against oil pollution are presented. The important element to response oil spills is the careful selection and proper use of response equipments that are most suitable for the type of oil and environmental conditions. In Chapter 6, oil spill response methods or techniques are presented.

In Chapter 7, the response operation of the M/V Lady Tuna oil spill event is evaluated based on the accident reports, articles and news related to the accident. The reports are given below:

- Marine Accident Investigation Report on the grounding of M/V Lady Tuna prepared by Accident Investigation Board, the Ministry of Transport, Maritime Affairs and Communications, 2017.

- The Expert Report of M/V Lady Tuna was submitted to the Republic of Turkey Çeşme Civil Court of the First Instance by Sunlu, Kayacan and Küçükgül, 2017.

In view of the above, third phase of the thesis provides the application of the oil spill model occurred as a result of M/V Lady Tuna grounding accident. Potential Incident Simulation, Control and Evaluation System (PISCES II) program is used to control and predict the propagation of oil spills. The simulation program provides to the planning of the response operation in real time to prevent oil pollution on the seawater. The simulation is performed on the following input data:

- Incident data set-up,
- Environmental conditions,
- Pollution-on water spill,
- Response resources.

The simulation program allows the modeling of the oil spreading, including dispersion in the water, evaporation, and sinking under the influence of simulated hydro-meteorological conditions.

The environmental data (air and water temperatures, wind direction and speed, sea state, the density of water and surface current) were manually put into the model. Hydro-meteorological data for the time of accident was provided by Turkish State Meteorological Service. In phase 3, two scenarios were prepared by using PISCES II simulator.

- The Scenario-1 was created without any response operation to observe the movement direction of the oil slick on the seawater after the accident.

- The Scenario-2 was created with response operation. PISCES II allows the planning of the response operation and oil combat it in real time. In the PISCES, various types of response resources can interact with the modeling of the oil spill. This is containment booms, oil skimming systems, chemical dispersants, shore cleanup equipment, dispersant application equipment and platforms. The Scenario-2 was limited to use of an open water Boom-1 for the oil containment and diversion, an open water Boom-2 which has J shape formation for the oil collection by trawling, three Oleophilic skimmers and three supply vessels.

In phase 4, an overall assessment of the simulation is presented and conclusions are drawn.

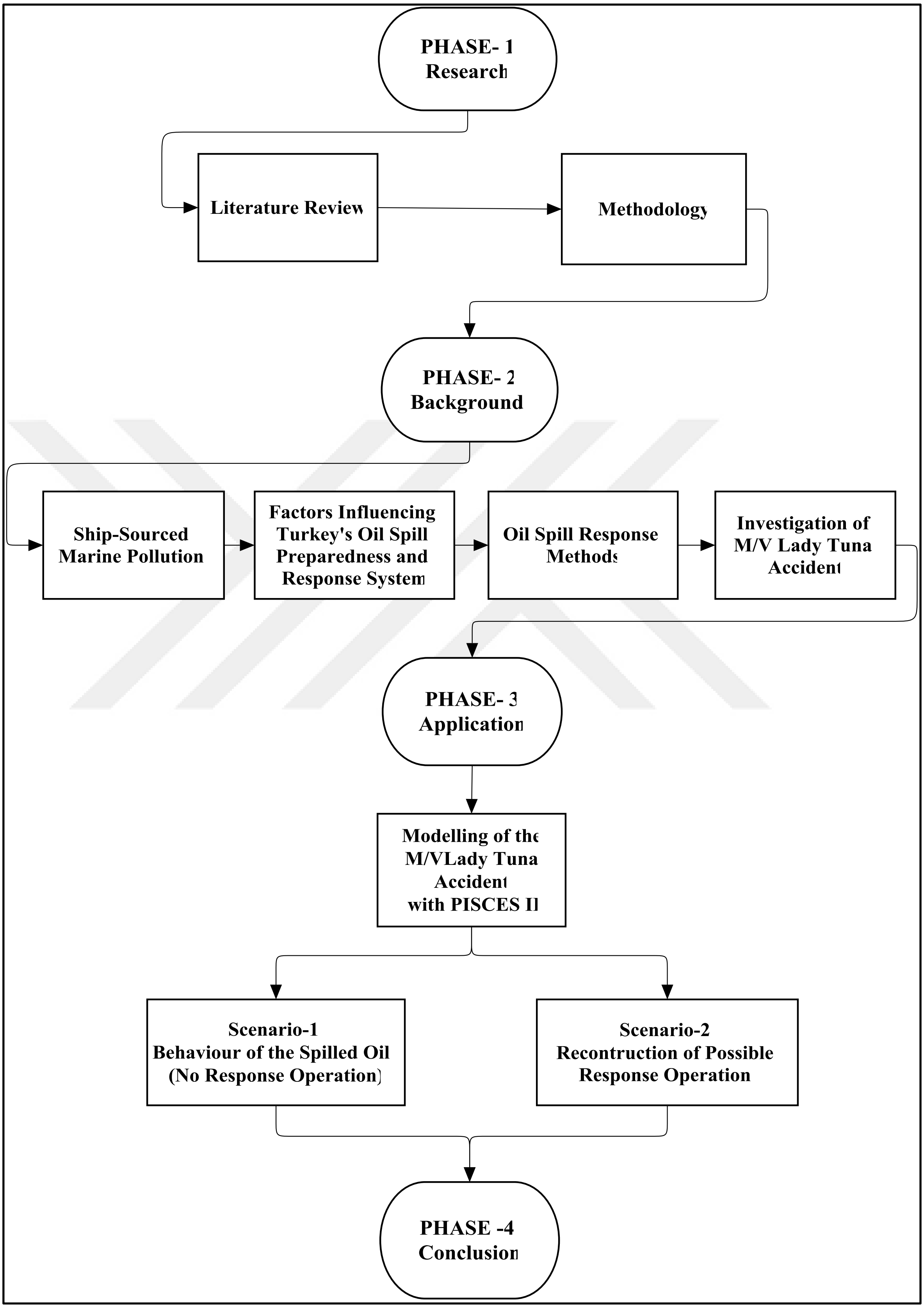


Figure 3.1. Flow chart of the Thesis

3.3. Limitations of the Study

- The direction and speed of the surface current for the moment of the accident in the Ildır Bay have not been measured by Turkish State Meteorological Service. Because there is not a meteorological station which measures the direction and speed of the current in this region. To know more about the dominant wind direction of Ildır Bay, wind statistics for Çeşme were investigated. In this study, the direction of the surface current was assumed towards SW under the effect of the regional dominant wind from NE and NNE direction.

- In the real case, the flow rate of the oil spillage (per hour) from the ship could not be determined. According to the damaged parts of the ship, the amount of the oil spill rate was assumed as 5 tons/per hour.

4. SHIP-SOURCED MARINE POLLUTION

Marine pollution from ships is one of the most noticeable environmental problems in the world. It is important to take serious precautions before pollution reaches irreversible damage level 1to the marine environment. An important source of marine pollution is oil spill incidents caused by ships. The impact of marine pollution on all seas in the world also brings international cooperation to combat oil pollution.

Ship-sourced marine pollution can generally be divided into two groups, the first one occurs during the operation of ships and the second one as a result of incident. Formation of marine pollution during the operation of ships have various reasons such as sewage waters, ballast water discharge, bilge water disposal, the garbage thrown into the sea, antifouling paints, cargo discharge residues. (Figure 4.1)

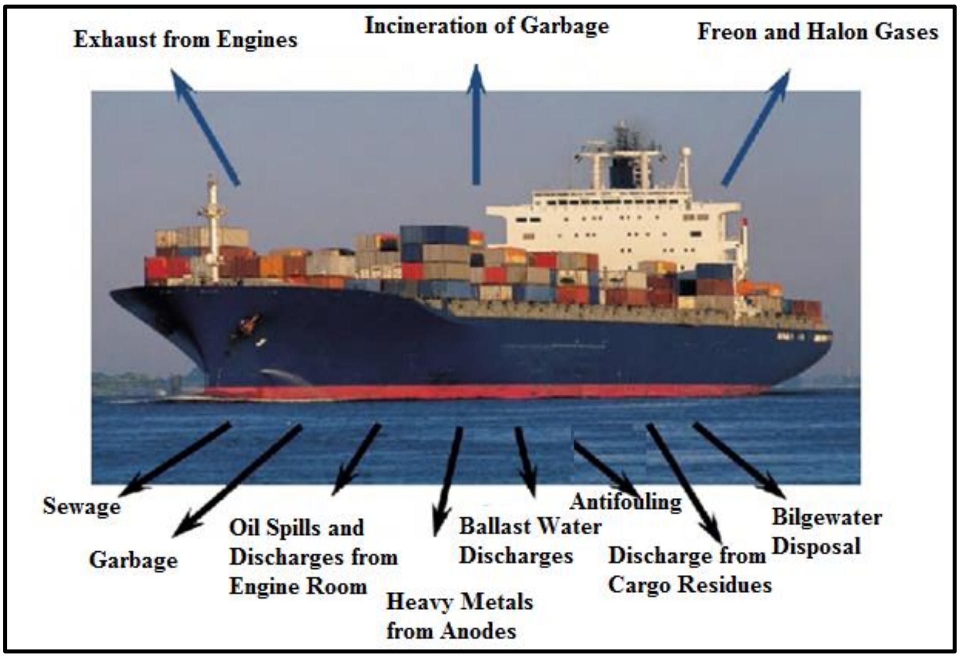


Figure 4.1. Ship-sourced Marine Pollution (Potters, 2013).

Oil or petroleum products are the most important threat to marine pollution as a result of ship accidents. Oil pollution from ships takes place in two basic ways. The first is marine accident that occurs during the operation of oil tankers. Another cause of ship-based oil pollution is the result of other ships accident outside the tanker.

The consequences of oil spills result in significant problems that threaten not only a region lying along a shore but also the quality and balance of the aquatic ecosystems. The impact of the oil pollution on the sea is long lasting and environmental catastrophe for the ecological balance, fishing activities, industry and tourism activities of the region.

4.1. Key Factors Affecting Spilled Oil Fate and Behaviour

The behaviour and condition of oil in marine environment is controlled by many processes. The properties of spilt oil change on the sea water over time, so it is important to know physical, chemical and weathering process of the oil when prediction behaviour of the oil. In addition, it is advantageous information to know properties and amount of spilled oil during the response operation.

4.1.1. Physical and chemical properties of oil

The crude oils named according to the region where they are removed and have a wide range of physical and chemical properties due to their various compositions and components (Fingas, 2000). Basic physical properties affecting fate and behaviour of the oil after the spillage are;

Specific gravity; is defined as the ratio of the density of a substance to the water density at a given temperature. When calculating the specific gravity, water is often used to compare the gravity of substances. To a large extent, the oils have a specific gravity below of 1 so lighter than seawater which is about 1.025. Thus, the oils float in the sea water, but the heavier oils sink or sediment under the water. (USEPA, 1999; ITOPF, 2002)

Solubility; is the measure of how much oil will be molecularly solved in the water column. Solubility is generally small amount when compared to the evaporation rate belong to the properties of the oil. The solubility takes an important when the oil has a toxic effect on marine life (Fingas, 2000).

Viscosity; is defined resistance to flow and shear due to gravity. This means that low viscosity products can flow easily. The characteristics of the oil, temperature and pressure affect the viscosity of the oil. The viscosity of many liquids decreases with increasing temperature. (Fingas, 2000).

The viscosity of the oil is important when decides the response resources such as boom, skimmer… Two liquid viscosity measurements are available;

1) Dynamic viscosity; refers to the resistance of the fluid layers against the sliding motion, convert to Centipoise (cP) or milliPascal second (mPas).

2) Kinematic viscosity; the ratio of dynamic viscosity to the density of the fluid the ratio of the dynamic viscosity to the density of the fluid, convert to CentiStokes (cSt) or Stoke cm^2/s (Boufadel et al., 2015).

Surface tension; called oil/water interfacial tension. In combination with viscosity, the surface tension is used as an indicator of how fast and how much oil will spread to water (USEPA, 1999).

Pour point; is the temperature below which oil will not flow like the wax content of the oil (ITOPF, 2002).

4.1.2. Weathering process of spilled oil

The behavior and condition of crude oil or processed oil in the marine environment is controlled by physical, chemical and biological processes that interact with each other for many reasons. The weathering process (spreading, evaporation, dispersion, emulsification, oxidation, biodegradation, dissolution and sedimentation) occurs when oil is exposed to environmental conditions such as in sea system (Figure 4.2). (ITOPF, 2002)

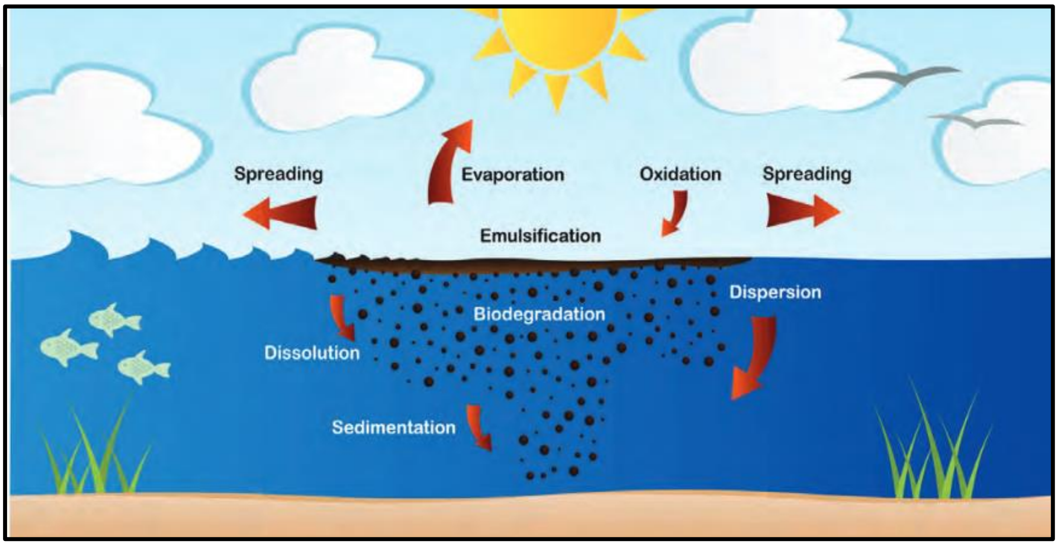


Figure 4.2. Weathering Processes Affecting Oil at Sea (ITOPF, 2002).

The movement of oil in the marine environment usually takes place in two directions. The movement in the horizontal direction occurs as a spread and causes the sea surface to be covered with oil or stranded to shoreline. The movement in the vertical direction occurs when the oil disperse or dissolute in the seawater. As a result of the movement, the oil sinks towards the bottom and becomes part of the sediment on the seabed.

As shown in Figure 4.3, the ratio of the weathering processes takes place at different rates and at different start times. For example, spreading, evaporation, dispersion process takes place immediately in hours or days, but biodegradation, emulsification process takes place slowly over months or years.

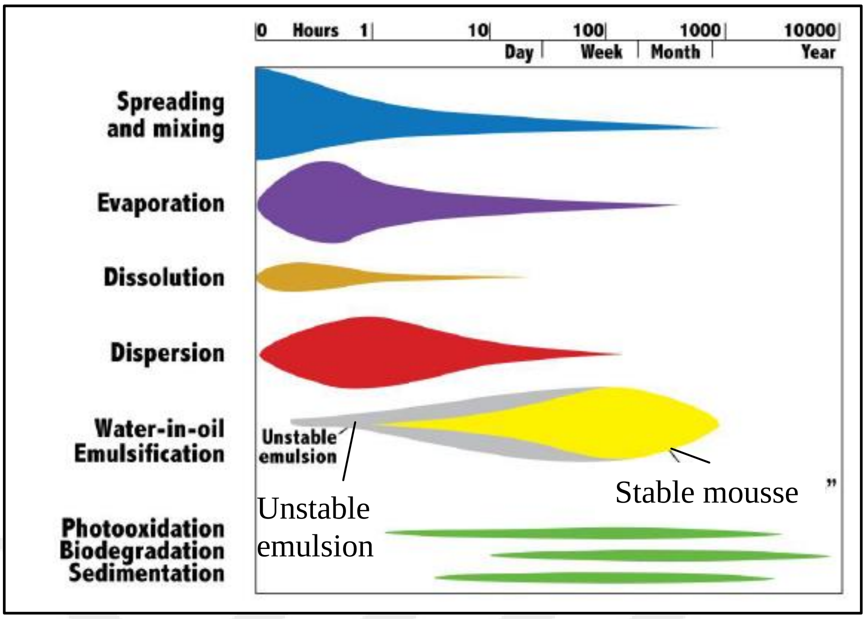


Figure 4.3. Weathering Processes over Time after an Oil Spill into Water (AOSRT, 2014; Boufadel et al., 2015).

Spreading: The exception of petroleum products which have a higher density than sea water, they usually float on the surface when the oil enters in the marine environment and begin to spread. The viscosity of the oil and the amount of spilled oil affect the spreading speed of the oil on the sea (ITOPF, 2002). Low viscosity oils spread much faster than high viscosity oil. The effects of winds and currents significantly affect the spread of oil and resulting movement that can be calculated with sum of two vectors shown in Figure 4.4 (Hault, 1972; Fingas, 2013). The wind-sourced current speed is assumed as 3% (1%–6%) of wind velocity (Soltanpour et al., 2013).

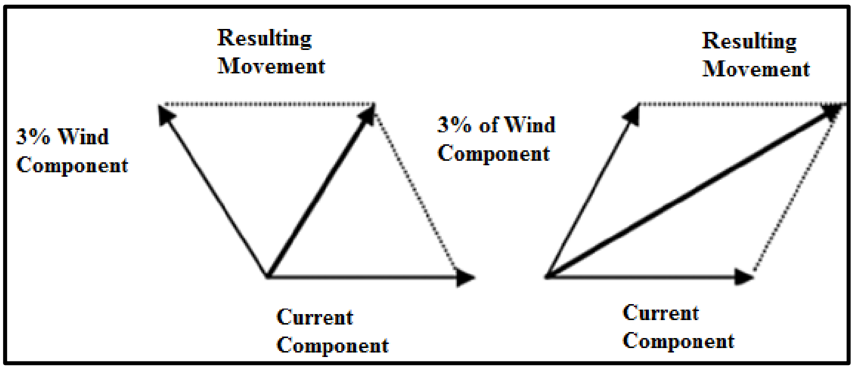


Figure 4.4. The Resultant Oil Movement's under the effect of Surface Current and Wind Drift Vectors (Fingas, 2013).

Evaporation: One of the most important processes which responsible for the loss of spilled oil mass is the evaporation after incidents (Jordan and Payne 1980). The rate and magnitude of the evaporation depends more on the proportion of the low boiling point components in the oil (ITOPF, 2002). The initial spreading rate, wind, current, weather temperature, and floating oil amount on the sea increase evaporation. Heavy oils have insignificant evaporation properties.

Dispersion: The natural distribution is the process of converting some oil into minute drops as a result of wave movement, these drops remains suspended in the water column. Natural dispersion rate of oil depends on the sea state being inversely dependent on oil viscosity. (PISCES II Manual, 2008)

Photo-oxidation: The oxidation is supported by sunlight and occurs throughout the entire duration of the spill, but the overall effect on the spill is less compared to other weathering processes (ITOPF, 2002)

Emulsification: Water penetrates into the spilled oil mass, resulting in a mixture of "water in oil". Emulsification causes the initial volume of contaminants to increase from three to four times (PISCES II Manual, 2008).

Sedimentation and sinking: The oil may submerge in water by means of dispersion or emulsification and eventually sink in the water column to the sea bed. Shallow waters like coastal areas or the waters of river mouths ensure advantageous condition for sedimentation of oil. (ITOPF, 2002)

Biodegradation: Sea water contains a number of marine microorganisms that can metabolize oil compounds. These microorganisms obtain oxygen and essential nutrients from the water so biodegradation occurs at an oil/water interface. (ITOPF, 2002)

5. FACTORS INFLUENCING TURKEY'S OIL SPILL PREPAREDNESS AND RESPONSE SYSTEM

In order to decrease oil pollution as a result of marine accidents in the world, the scopes of studies on the prevention of ship-sourced oil pollution have been expanded by international organizations.

A number of national and international agreements as well as major oil spill incidents influence the Turkey's oil pollution response system and policies ultimately implemented by the government. This chapter presents the national and international factors affecting Turkey's preparedness and response system against oil pollution by the ship.

5.1. Major Oil Spills of the Maritime World

The major marine incidents that have led to environmental disasters have shown that changes in preparedness and response strategies are very important. Therefore, the response operations should be made immediately following the oil spill incident. In particular, some of the marine accidents have caused great reaction for the public, depending on the location of the accident area, the amount of pollution caused by oil and loss of lives.

The summary of 20 largest spills since the Torrey Canyon in 1967 is presented in Table 5.1. (spill sizes are rounded to the nearest thousand). "Exxon Valdez" (in the 35th position with) and "Hebei Spirit" (in the 131st position) oil spills are included for comparison (ITOPF, 2017).

Table 5.1. Major oil spills since 1967, (ITOPF, 2017).

Position	Ship name	Year	Location	Spill size (tons)
1	ATLANTIC EMPRESS	1979	Off Tobago, West Indies	287,000
2	ABT SUMMER	1991	700 NM off Angola	260,000
3	CASTILLO DE BELLVER	1983	Off Saldanha Bay, South Africa	252,000
4	AMOCO CADIZ	1978	Off Brittany, France	223,000
5	HAVEN	1991	Genoa, Italy	144,000
6	ODYSSEY	1988	700 NM off Nova Scotia, Canada	132,000
7	TORREY CANYON	1967	Scilly Isles, UK	119,000
8	SEA STAR	1972	Gulf of Oman	115,000
9	IRENES SERENADE	1980	Navarino Bay, Greece	100,000
10	URQUIOLA	1976	La Coruna, Spain	100,000
11	HAWAIIAN PATRIOT	1977	300 NM off Honolulu	95,000
12	INDEPENDENTA	1979	İstanbul Strait, Turkey	95,000
13	JAKOB MAERSK	1975	Oporto, Portugal	88,000
14	BRAER	1993	Shetland Islands, UK	85,000
15	AEGEAN SEA	1992	La Coruna, Spain	74,000
16	SEA EMPRESS	1996	Milford Haven, UK	72,000
17	KHARK 5	1989	120 nm off Atlantic coast of Morocco	70,000
18	NOVA	1985	Off Kharg Island, Gulf of Iran	70,000
19	KATINA P	1992	Off Maputo, Mozambique	67,000
20	PRESTIGE	2002	Off Galicia, Spain	63,000
35	EXXON VALDEZ	1989	Prince William Sound, USA	37,000
131	HEBEI SPIRIT	2007	South Korea	11,000

Despite the growth in crude, petroleum and gas loading, it is noticed that there is decline in number of tanker spills (Figure 5.1). The researches have shown that developments of the international regulations and conventions on Preparedness, Response, and Cooperation for prevention of pollution from ships have contributed to downward in oil spills event (ITOPF, 2017).

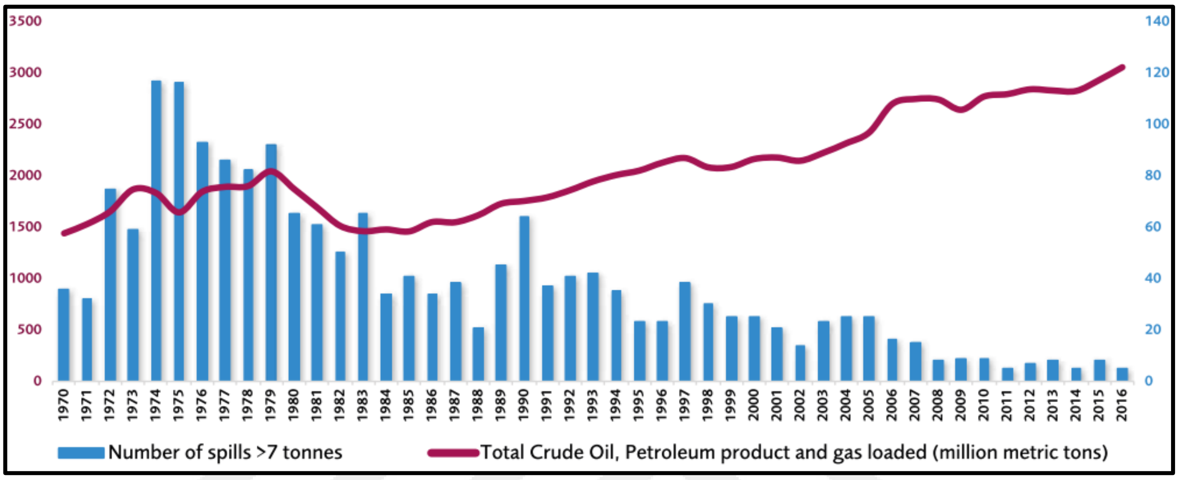


Figure 5.1. Decline in Number of Tanker Spills vs. Growth in Crude, Petroleum and Gas Loaded (ITOPF, 2017).

5.2. Major Marine Accidents Resulting in Oil Spills at Turkish Seas

Turkey is a peninsula country and has a coastline of about 8,000 km. The Anatolian peninsula is the westernmost point of Asia, divided from Europe by the İstanbul and Çanakkale straits which have an important place in its geographical structure and filled with many parameters due to its strategic importance such as political, economic, military and many fields. According to the ship transition statistics of Turkish straits in 2018, 41.103 vessels passed on the İstanbul strait and 43.999 vessels on the Çanakkale strait (Marine Accident Statistics of Turkey, 2018).

Turkey has benefited from the advantages of being surrounded by sea on three sides but has the high risk to experience ship-based oil pollution events because of heavy traffic in its straits. Collision caused by poor visibility and strong current is the most common type of marine accident occurred in Turkey straits (TUDAV, 2018).

One of the unforgettable incident because of the collision occurred in 1979 between Evriyali (10,000 dwt) cargo ship and Independenta (165,000 dwt) tanker ship which caused spillage of the 94,000 tons of crude oil. The other important marine accidents causing serious environmental damage and oil pollution in the İstanbul Strait are summarized in Table 5.2.

Table 5.2. Important Ship-Based Oil Pollutions in the İstanbul Strait (Ünlü, 2016; Turan, 2009).

Date	Ship Name and Flag	Accident Area	Spilled Oil Size
15.11.1979	M/T Independenta (Romania) M/V Evriali (Greek)	Haydarpaşa	30,000 tons of oil burned; 64 tons oil spilled.
25.03.1990	M/T Jambur (Iraqi) M/V Da Tung Shan (Chinese)	Sarıyer	2,600 tons of oil spilled.
13.03.1994	M/T Nassia (Philippines) M/V Shipbroker	Sarıyer	20,000 tons of oil burned; 9,000 tons of oil spilled.
07.12.1999	M/V Semele M/V Şipka	Yenikapı	10 tons of oil spilled.
29.12.1999	M/T Volganef 248 (Russia)	Florya	1,500 tons of oil spilled.
05.09.2002	M/V Şahin 3	İstanbul Strait	More than 26 tons of oil spilled.
06.10.2002	M/V Gotia	Emirgan Dock	18 tons of oil spilled.
10.11.2003	M/V Svyatoy Panteleymon (Georgia)	Anadolu Feneri	Around 500 tons of oil spilled.
19.01.2010	M/V Orçun-C	Kilyos	121 tons of oil spilled.

Many factors cause the occurrence of marine incidents but “collisions” is announced the first reason of the accidents (26%) resulting in oil spills as recorded by The International Tanker Owners Pollution Federation Limited (ITOPF) from 1970 to 2016 (ITOPF, 2017). Ministry of Transport, Maritime Affairs and Communications, Search and Rescue Coordination Centre of Turkey reported the official statistics of the sea accident cases for 2017, “engine failure/drift ” category accounts for 42%, “collision/contact” 34%, ”sinking” 23%, “grounding” 21%, “fire/explosion” 18% in the Turkish search and rescue area (Official Statistics of the Sea Accident and Incident, 2017).

5.3. National and International Regulations Interested in Oil Pollution

Especially after the major marine accidents leading to oil pollution by the ships during operational or accident related events, the prevention of oil pollution in the seas was one of the most important issues in the international law. The accidents that caused environmental disasters have led to changes in new regulations in order to take necessary measures to prevent and response oil pollution.

The problem of oil pollution arising from ships has made international cooperation mandatory because of its comprehensive structure and a problem that cannot be solved by national regulations alone. So, the IMO (International Maritime Organization) Convention entered into force in 1958 in order to developing international regulations that are followed by all shipping nations.

The International conventions covered by IMO relating to prevention of marine pollution by oil are MARPOL 73/78 and OPRC, 1990.

- International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 (MARPOL 73/78).
- International Convention on Oil Pollution Preparedness, Response, and Cooperation, 1990 (Law OPRC, 1990).

MARPOL 73/78, the International Convention for the Prevention of Pollution from Ships, is one of the key IMO conventions for prevention of the marine environment from pollution. In 2003, Turkey became party to MARPOL 73/78, Annex I related to Prevention of Pollution by Oil.

After the MARPOL Convention, Turkey did not make any special arrangements for applying oil pollution prevention for many years, the general rules on the subject preferred for the method of applying the response operation.

The OPRC Convention was adopted in 1990 and entered into force in 1995 by IMO. Turkey is party to OPRC convention in 2003 by Law No. 4882 in order to enhance national capabilities concerning oil pollution and in cooperation with other countries whose interests are affected by oil pollution incident, together with. In this case, an important step was taken by Turkey expected.

The purposes of this Convention as the following;

- Oil pollution reporting process and emergency plans,
- The processes after receiving an oil pollution report,
- The preparedness and response procedures for national and regional by the parties,
- International cooperation in preparedness and response to the parties by providing technology, equipment, personnel training.... (Law OPRC, 1990)

After a short time, Turkey released the Law No. 5312, Pertaining to Principles of Emergency Response and Compensation for Damages in Pollution of Marine Environment by Oil and Other Harmful Substances (OSRL) in the number of Official Gazette 25752 of March 11, 2005.

The purpose of this Law is to establish; concerning response and preparedness in emergency incidences result from ships or operations of coastal facilities; the principles for determining and compensating for damages; about fulfillment of international commitments; powers, duties, and responsibilities of the officials of institutions, organizations, ships, and facilities as lay down in the Law.

Section-2 of the OSRL Law mentions the powers, duties and responsibilities of the Ministry of Environment and Forestry and Office of Undersecretary of Maritime Affairs (Law OSRL, 2005).

The responsibilities of Ministry of Environment and Forestry are;

- Preparing emergency response plans and fulfill the plans in coastal areas,
- Determination of the type and effect of pollution as well as rehabilitation of the areas affected by post incident pollution.

The responsibilities of Undersecretary of Maritime Affairs are;

- Implementation of emergency response plans to prevent pollution of the marine environment involving marine vehicles,
- Preparation and response issues in case of pollution incidents,
- The issue of compensation for damage and notification of guarantees of financial liability. (Law OSRL, 2005)

The response operations to combat oil spills are carried out by activating the appropriate emergency plan, taking into account the intervention level of the incident. The national, regional and local levels emergency response plans include responsibilities of the national organizations or authorities.

In addition, there are issues about actions to be taken after the oil spill, preparedness, response capability and the response resources, and other matters in an emergency situation after the oil pollution. Oil Pollution Response System of Turkey is presented in Figure 5.2.

- National Contingency Plan (NCP) is arranged for activities and international cooperation in emergency response for the Level-3 after the major oil pollution or other harmful substance which the serious threat posed to the marine environment (Law OSRL, 2005; Turan, 2009). The national authorities should inform all states whose interests are affected or likely to be affected by such oil pollution incident, together with (Law OPRC, 1990).

- Regional Contingency Plans (RCP) is arranged for response to the Level-2 that is medium dimension oil pollution incidents that can be controlled by the regional entities. It is applied by the responsible governor. (Law OSRL, 2005; Turan, 2009)

- Vessel Response Plan is implemented in the case of an event at pollution, level 1. In order to prevent a small amount of pollution that may occur as a result of operational activities on a ship, the principles of the prevention and response processes were determined by the ship response plan.

- Coastal Facilities Response Plan is compulsory near coastal areas for preparedness and response activities that might cause marine pollution by petroleum or other noxious substances. The plan specifies efficient procedures and strategies for all intervention level and includes responsibilities of the personnel as well as the list of minimum response equipment. (Law OSRL, 2005)

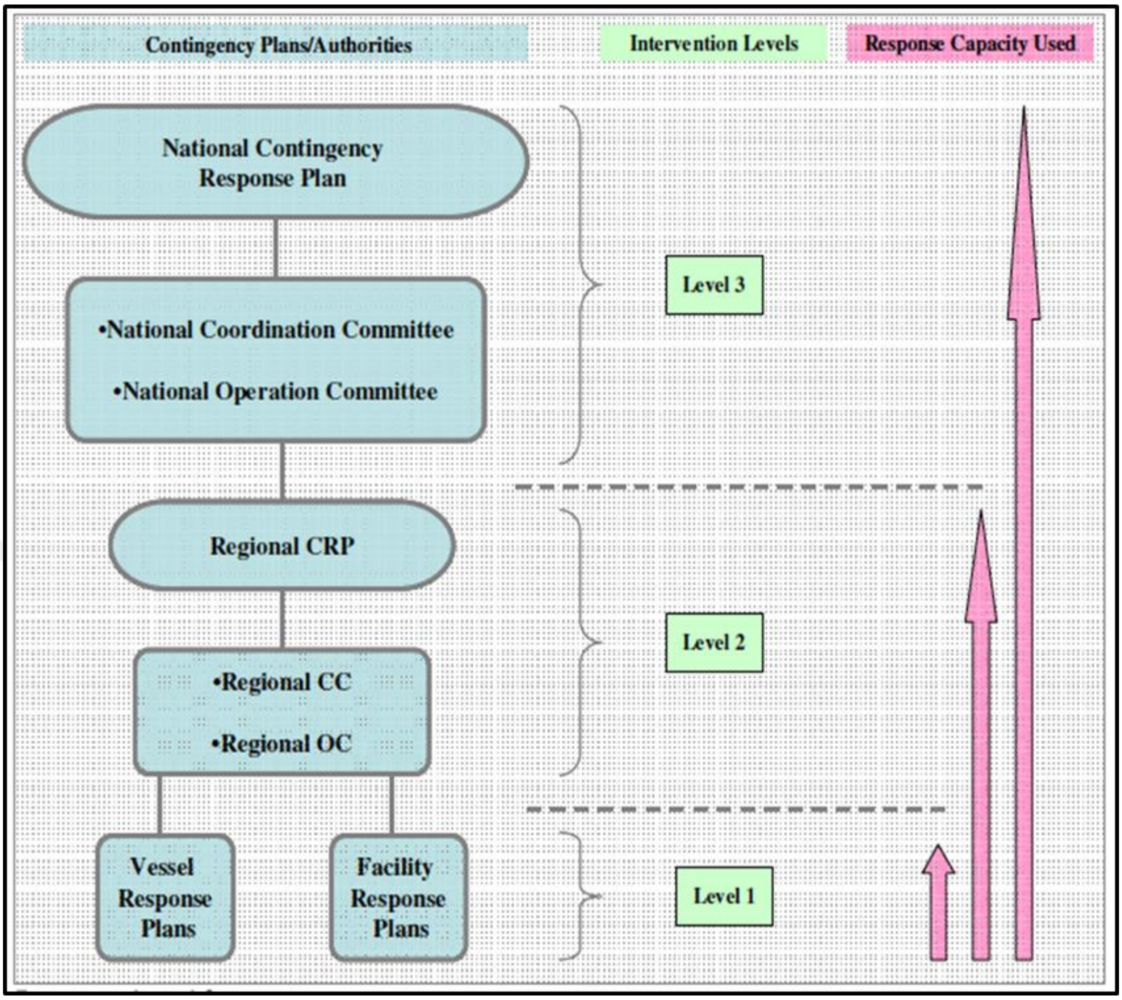


Figure 5.2. Oil Pollution Response System of Turkey (Turan, 2009).

In addition, Turkey contracted party to two regional conventions;

- Barcelona Convention,
- Bucharest Convention.

The Barcelona Convention and Emergency Protocol for protection of the marine environment and coastal region of the Mediterranean were adopted in 1995. The Contracting Parties are now 22. They are determined to protecting the marine environment by preventing and reducing pollution and eliminating as much pollution as possible. The Helsinki and Barcelona conventions, and Lisbon and Bonn Agreements that covered the regional seas around Europe are shown Figure 5.3.

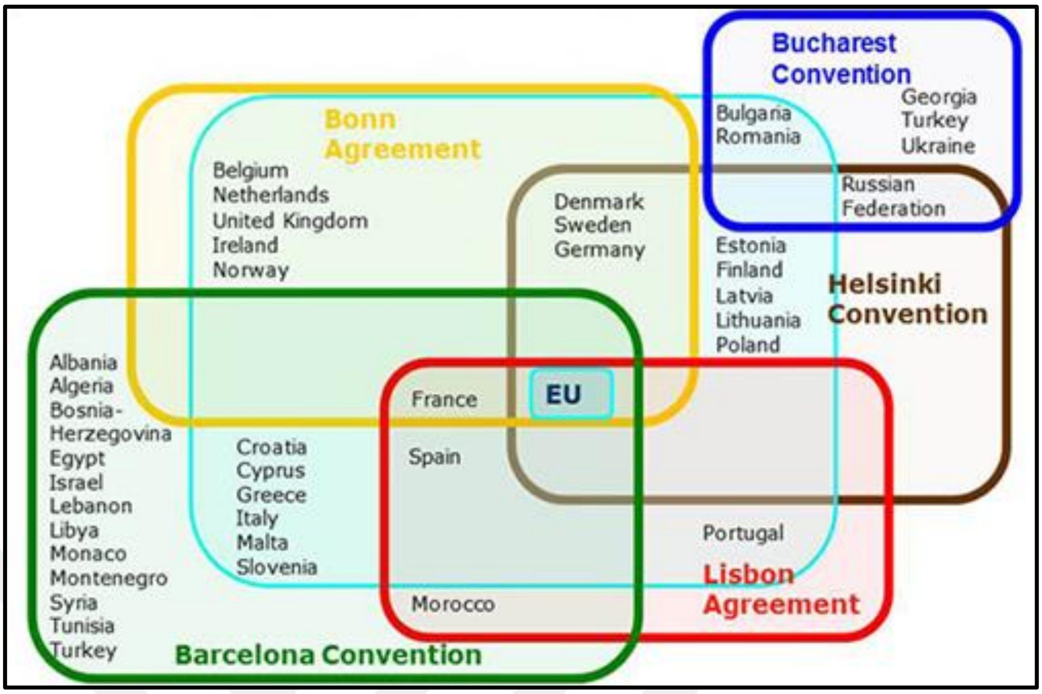


Figure 5.3. International Framework for Combating Marine Pollution (ECHO, 2017).

The Convention on the Protection of the Black Sea against Pollution (Bucharest Convention) was signed in 1992 by the Black Sea countries (six legislative assemblies) which are Russia, Turkey, Ukraine, Georgia, Bulgaria and Romania. The Parties countries to the convention conduct a new project on development and implementation of the Black Sea integrated monitoring and assessment program (BSIMAP) for years 2017-2022 (URL-1).

Some of the important European maritime organizations and agencies have played a vital role in the response to marine pollution to create international frameworks for combating marine pollution. The aim of these organizations is to ensure safe and clean marine transport in international waters for all nation ships.

The European Maritime Safety Agency (EMSA) is one of the European Union's decentralized agencies and has established contracts with commercial vessel operators for at sea oil recovery services around the European coastline are depicted in Figure 5.4 (EMSA, 2017).

REMPEC (Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea) is administered by IMO in cooperation with United Nations Environment Program. It provides regional assistance any party required to deal with a pollution incident. In addition, the any Party affected by a marine pollution can request REMPEC through the official communication channel or through the Pollution Report (POLREP) Part III. (REMPEC, 2017)

Turkey is the EU candidate countries and boundary to the EU member countries. So, Turkey takes advantage from this organizations and agencies interested in marine pollution. The contracted vessels or response resources of EMSA are available to Member States and neighboring countries in need of additional means of at sea oil recovery.

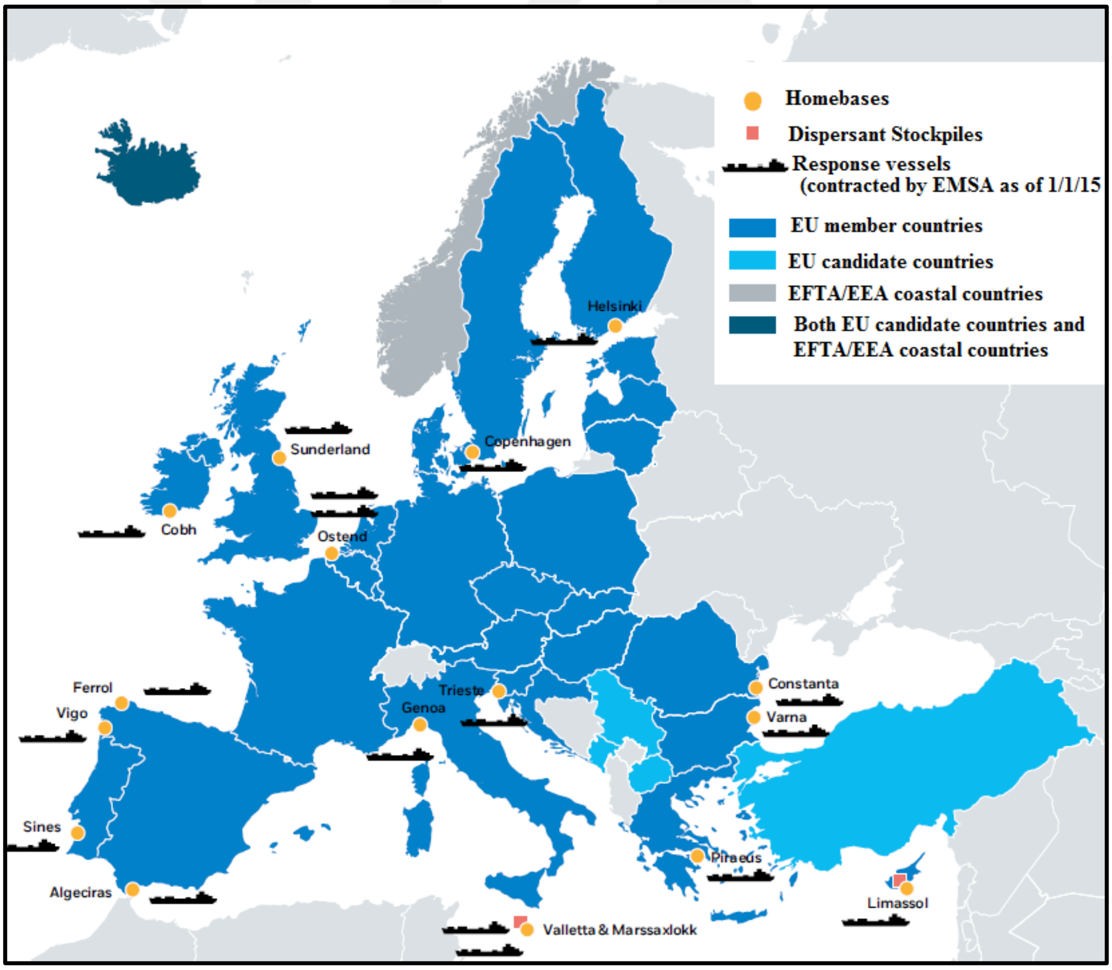


Figure 5.4. Network of EMSA Contracted Vessels Supporting the Efforts of Coastal States (EMSA, 2017).

6. OIL SPILL RESPONSE METHODS

Every accident that causes oil pollution is unique and there is no single way to combat oil pollution. The methods to be used in the response operation against oil pollution in the seas and the selection of appropriate equipment are very important in order to effective and efficient response strategies without losing time. In the process of making this decision about the response strategy or method need to consider situations like properties of the oil, amount of the spilled oil, the environmental condition of the region and distance to the coast. The most commonly used oil response techniques in the world are the physical, chemical and thermal methods (Larson, 2010).

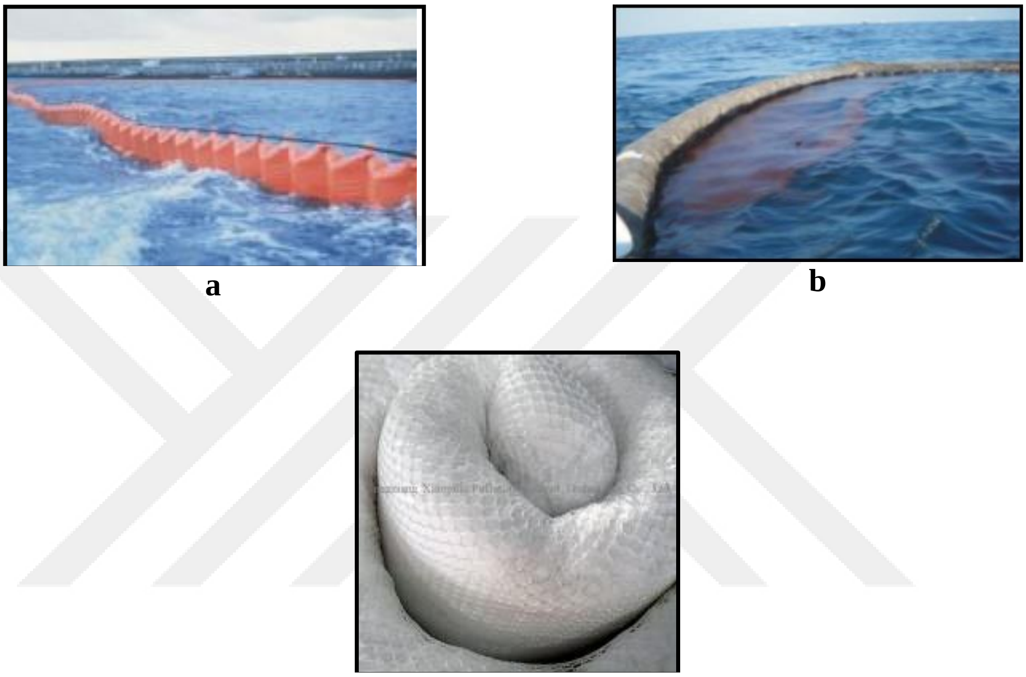
6.1. Physical Response Methods

Physical response method provides containment and recovery of an oil to collect in the form of layer on the sea surface. This is the most important advantage of the method. The most effective operation can take place under calm weather conditions. Large logistic support is needed for transfer of the response equipment and recovered oil after the operation. The method doesn’t change physical and chemical properties of the oil or water. Boomers and Skimmers are the most commonly used equipment for physical response (Fingas, 2011; Vergetis, 2002).

6.1.1. Boomers

They are flexible penetrable barriers able to move and used for containment and recovery of the oil on the seawater. Each boom model is designed in a number of preset properties. Therefore, it is important to decide on the appropriate boom type to prevent the oil from spreading to the sea surface. The amount of oil passed through the boom can depends on, the rate of oil film, sea state, efficiency, height and depth of the boom

(PISCES II Manual, 2008). The important thing is that the thickness of the oil film does not exceed the boom thickness when it decides to choose an effective boom for the operation. The boom models can provide containment, collection, fire resistance and oil absorption are presented in Figure 6.1.



a b

c

Figure 6.1. Models of Boom, a) Fence Boom b) Fire Resistant Boom c) Oil Absorbent Boom (OSS, 2010; URL-2).

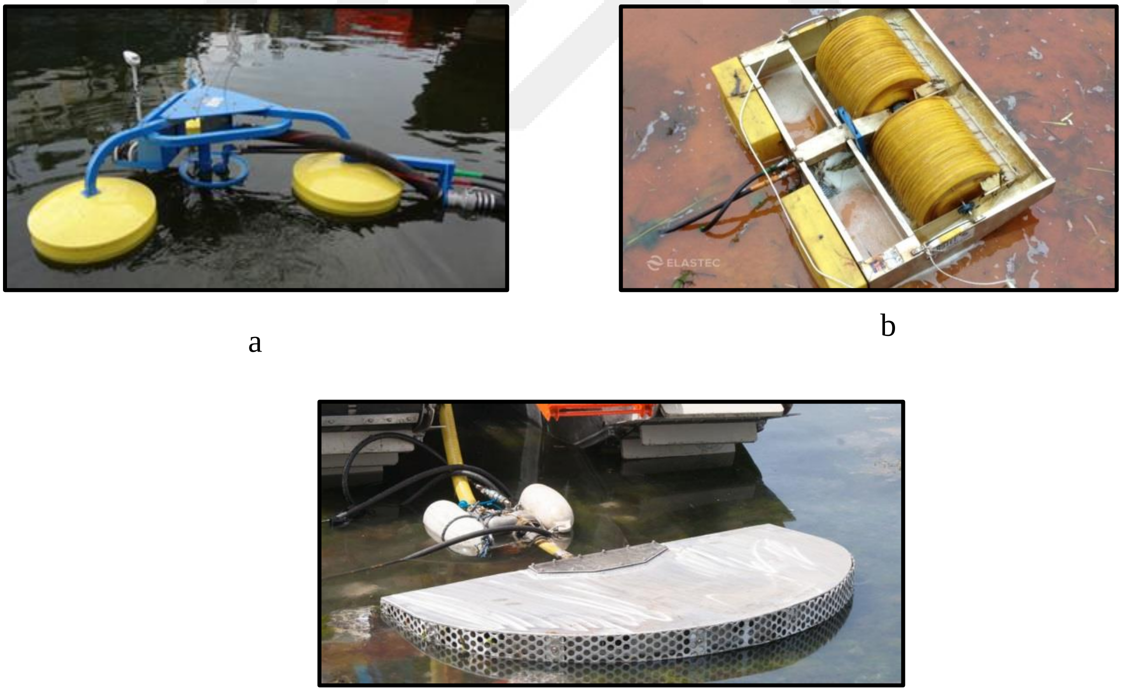
6.1.2. Skimmers

The oil skimmers are used to remove floating oil from the point where they are located on the surface of the water. Skimmers can be deployed on the water with self-propelled (by anchoring), operated from the coast or operated from vessels (Nomack and Cleveland, 2010). Different types of skimmers affect skimmers efficiency such as storage capacity, recovery rate, sea state, oil viscosity, etc. (PISCES II Manual, 2008). Removed oil can discharge a storage tank for recycling or disposal. Skimmers can be divided into three types according to the techniques of working (Figure 6.2).

- Weir skimmers; the oil, on top of the water is trapped in a well inside so it drives like a dam. The recovered oil can transfer to storage tanks by pumping.

- Oleophilic skimmers; designed with drums, rope-mop, disks, brushes and belt type to remove the oil from the water surface. The advantages of the Oleophilic skimmers are that they are flexible and can recover oil at any thickness. (Dave and Ghaly, 2011)

- Suction skimmers; operate with vacuum pumps or air venture system that suck up oil through wide floating heads and transfers it into storage tanks. They can operate efficiently on smooth water where surrounded by boom barrier. (Dave and Ghaly, 2011; Ventikos, et al. 2004)



a b

c

Figure 6.2. Skimmer Types; a) Weir Skimmer b) Oleophilic (Drum) Skimmer c) Suction Skimmer (URL-2).

6.2. Chemical Response Methods

The chemical response method used to control oil spills includes: dispersants and solidifiers. The purpose of the solidifier is to prevent the oil from spreading by making it more viscous, solid (Vergetis, 2002). The solidifiers may generally be applied for minor oil leakage or on the shoreline. To speed up the process of natural oil dispersion, oil is subjected to dispersant action which separate the oil spills into small droplets (MAP, 2009). Since there are some disadvantages of applying the dispersant, some restrictions have been introduced, as follows;

- Coastal use prohibited,
- Level 1 usage prohibited,
- Usage forbidden except pre-approved products,
- Distance from coast > 1 Nautical Mile,
- Minimum depth > 20 meters,
- Oil viscosity between 2000 – 5000 cSt,
- Sea water temp > + 5°c,
- Adequate and proper equipment required NEBA (Net Environmental Benefit Analysis) and authorized expert decision. (MAP, 2009)

6.3. Thermal (Burning) Response Method

Thermal response operation is the situ-burning method for spilled oil that can annihilate large amount of oil quickly. On the other hand, it affects the aqua life badly and leaves residues that may adversely affect the ecosystem. The specialized equipment like fire resistant booms must be used to encircle the fire area. (Buist *et al*., 1999; Mullin and Champ, 2003)

7. INVESTIGATION OF THE M/V LADY TUNA ACCIDENT

M/V Lady Tuna is a Panamanian registered fish processing ship which has a 4538 gross tonnage volume and a 2993 KW engine power (Figure 7.1). She was built in Japan in 2007. She came to Ildır Bay for tuna fish harvesting from the fish farms. The planned voyage would be to Port Said in Egypt after the completion of the harvest. At the time of the accident, there were 1223 tons of processed tuna fish on board the vessel. Tuna farms are located at Karaburun in Izmir Gulf and these fish farms have an increasing degree of importance among the tuna farms operating in the littoral countries of the Mediterranean Sea. The information about the vessel, navigation and accident are presented in Table 7.1. (The Accident Investigation Report, 2017)

The information related with the incident data was obtained from Investigation Report of M/V Lady Tuna Marine Accident prepared by the Ministry of Transport, Maritime Affairs and Communications Accident Investigation Board.

Figure 7.1. The Fish Processing Vessel, M/V Lady Tuna
(The Accident Investigation Report, 2017).

Table 7.1. Information about the Vessel, Navigation and Accident (The Accident Investigation Report, 2017).

Ship Name	M/V LADY TUNA
Flag	Panama
Class Society	NKK
IMO Number	9453438
Type of Ship	Fish Processing Vessel
Owner	WANG TAT Corporation Pte. Ltd. Singapore
Operator	SHINKO KAIUN Co. Ltd. Tokyo/Japan
Place and Year of Build	Kyokuyo Shipyard Co. Shimonoseki/Japan - 10.12.2007
Gross Tonnage	4538 GT
LOA	120, 75 m
Main Engine Power	MAN B&W – 2993 KW
Last Port of Call	Ildır Bay /Turkey
Destination Port	Port Said / Egypt
Cargo on Board	1223 MT Processed Tuna Fish
Number of Crew	33 persons
Type of Sea Passage	High Seas
Date/Time of Accident	18.12.2016 / 13:40 LT (GMT +3)
Type of Accident	Very Serious Marine Casualty
Location of Accident	Ildır Bay /Çeşme -İzmir
Injured/Fatality/Loss	None
Oil Pollution	Fuel oil (180) approximately 75.38 cubic meters.

7.1. Area of the Accident

Gulf of Ildır is located between Karaburun Peninsula and Çeşme Canal in the west of Turkey. Maximum depth is 70 m (east of the Toprak Island). North coastal strip of Ildır Gulf is very narrow and shows a sudden deepening structure (Meriç et al., 2012). The coasts from Karaburun southward to Ildır Bay are a narrow shallow sea (Eryılmaz, M., 2003). The accident happened near Fener Island in the Ildır Bay district of Çeşme province of İzmir (Lat: 38° 23.26' N-Long: 026° 25.42' E) is shown in Figure 7.2. İstikbal and Erkan (2018), in their article, point out that this coast area surrounded by the fish farms are usually a kind of high-risk marine environment because of shallow waters and islands that are difficult to the navigation of the large tonnage vessels. In the case of an oil spill accident, it threatens marine environment, fish farms, human health, tourism, aesthetic appeal and economy of the region tragically. Unfortunately, the effects are long-lasting for the region and the marine life.

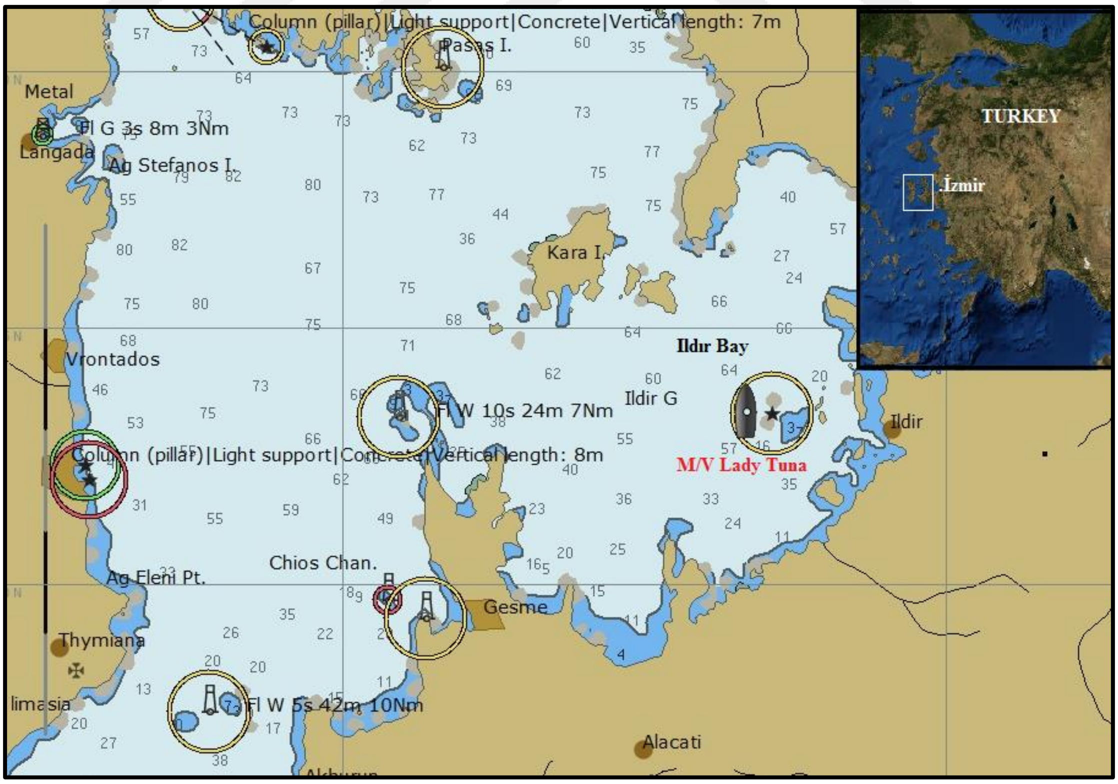


Figure 7.2. The Position of the Accident Point (URL-3).

7.2. Course of Events in the Accident

M/V Lady Tuna arrived to the Ildır Bay for harvest season of the tuna fish on December 2nd, 2016. She completed tuna fish harvest in 15 days and waited for the completion of customs formalities at the south of the Sagun fish farm (38^o 24' N - 026^o 24.9' E) at anchorage position, in order to go to her next port of call, Port Said in Egypt. (The Accident Investigation Report, 2017)

A voyage plan was prepared by the Second Officer for the passage to the anchorage area of customs clearance formalities (38° 22.9 'N - 026° 27' E).The ship's Master ordered the preparation of the engines at 13:18 LT hours. The Chief Officer was ready at the forecastle deck for anchoring maneuver. On the bridge, there were the Master, 2nd Officer and 3rd Officer. Master was in front of the radar, Second Officer was at the helm, and Third Officer was in charge of the engine controls. (The Accident Investigation Report, 2017)

The vessel heave up the anchor at 13:30 LT in order to go position at 38^o 22.9' N-026^o 27' E for completion of the custom control formalities of the ship on December 18th, 2016. When the vessel was under way, master saw three small fishing vessels on starboard bow side of the vessel and altered the course to port side so as to avoid the collision. But, Master could not realize the shallow waters on their port side and hard grounded at 13:36 LT on the shoal west of Ufak Island position at 38^o 23.26' N - 026^o 25.42' E while the ship was still under way at a speed of 11.7 knots. (The Accident Investigation Report, 2017)

First, the Master of the ship ordered to stop the engine, followed by a slow astern order in order to refloat and move the vessel from the position where she grounded. Upon seeing that the ship was not moving, he ordered to stop the engines and finished with the maneuvers. The view of the vessel after she grounded on the shoal is shown in Figure 7.3. (The Accident Investigation Report, 2017)

Figure 7.3. The View of the Vessel After She Grounded on the Shoal (The Accident Investigation Report, 2017).

7.3. Events at the Aftermath of the Accident

Master ordered to stop the engines at 13:42 LT. He first reported the accident to the agent of the ship named Link Shipping Agent and then their Manager Shinnko Kaiun Co. Ltd., Tokyo Company at 13:45 LT. (The Accident Investigation Report, 2017)

Soon after, the Chief Officer of the ship reported a fuel oil leak from the ship to the Master at 13: 55 LT. At the same hour, Chief Engineer reported to the Master that there was damage at the fuel tanks and there was fuel leakage to the sea. Meanwhile 3rd Officer prepared the Emergency Check List for a grounding casualty. Damaged parts of the ship on the Transverse Plan and the Longitudinal Plan are shown in Figure 7.4 and Figure 7.5. (The Accident Investigation Report, 2017)

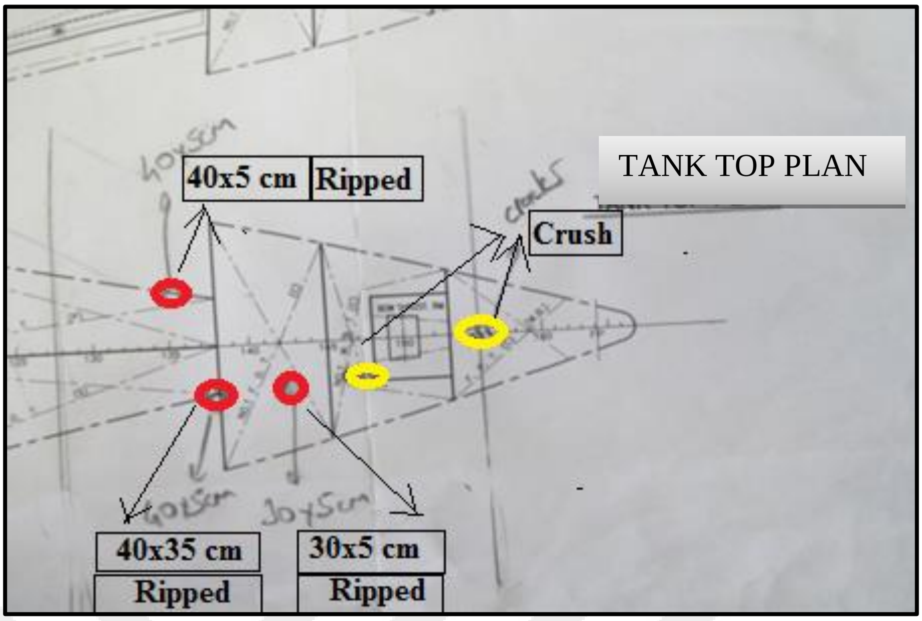


Figure 7.4. Damaged Parts of the Ship as Shown on the Transverse Plan (The Accident Investigation Report, 2017).

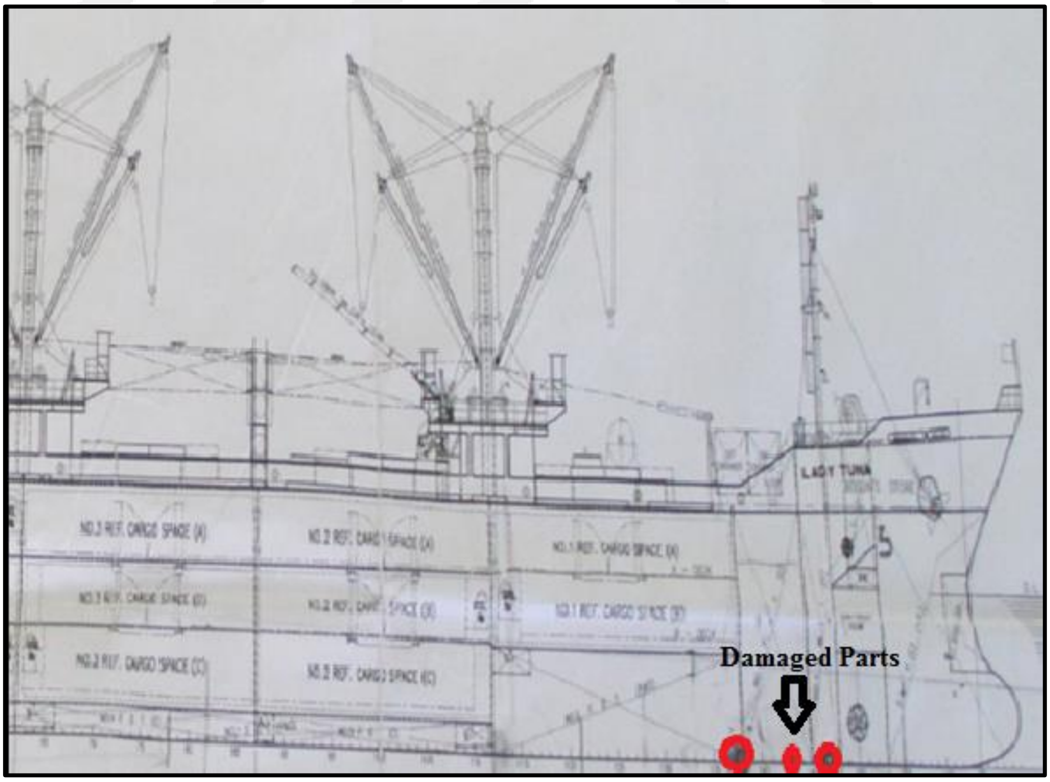


Figure 7.5. The Damaged Parts of the Ship as Shown on the Longitudinal Plan (The Accident Investigation Report, 2017).

After the soundings were taken from the tanks, it was determined that there was damage to fore-peak tank, No.1 center ballast tank, No.1 center fuel tank, No.2 port and starboard fuel tanks and there was leakage from the fuel tanks to the sea. Damaged parts of the vessel are displayed in Table 7.2. The pictures of damaged part was recorded with the diver's camera are shown in Figure 7.6 (The Accident Investigation Report, 2017).

Table 7.2. The Damaged Parts of the Ship (The Accident Investigation Report, 2017).

Fore Peak Tank	Crush
No:1 Center Ballast Tank	Crush
No:1 Center Fuel Oil Tank	30 cm x 5 cm Ripped
No:2 Port Side Fuel Oil Tank	40 cm x 5 cm Ripped
No: 2 Starboard Side Fuel Oil Tank	40 cm x 5 cm Ripped

Figure 7.6. Damaged Parts as Recorded by the Diver's Camera (The Accident Investigation Report, 2017).

7.4. The Accident Reports and Response Operation of the M/V Lady Tuna

The Marine Accident Investigation Report on the grounding of M/V Lady Tuna prepared by the Ministry of Transport, Maritime Affairs and Communications, Accident Investigation Board reported the following information about the pollution fighting and the salvage operations of the ship. After the accident, the master of the ship informed to the agency about the oil pollution and reported that response operation was urgently necessary. There was no attempt by the ship to prevent oil pollution. (The Accident Investigation Report, 2017)

At 15.00 LT (1,5 hours later after the accident), ship’s agent asked the pollution response company Most Maritime and Environmental Services which is based at Ulusoy Port, in the administrative responsibility area of Çeşme Port Authority, to make the necessary preparations. Çeşme Port Authority ordered the ship’s agent to start necessary pollution response activities at 17:30 LT (4 hours later after the accident). Most Shipping started to encircle the fish farms with barriers at 20:30 LT and they completed to encircle the ship to the containment of pollution with barriers with two skimmers at 22:30 LT (Figure 7.7) (9 hours after the fuel oil leakage from the ship). The Accident Investigation Report, 2017)

Figure 7.7. Containment of the Leaking Fuel by the Barriers (URL-4).

Distance from the Ulusoy Çeşme Port to the accident position is about 12 NM by the sea and about 20 km by the land road (Figure 7.8). In addition, the accident position is very close to the other international ports by the seaway and land road. İzmir Alsancak Port is about 90 km and Nemrut Port (Aliağa) is 150 km to the Ildır. It means the response equipment could be delivered to the accident area more quickly by the seaway and land road.

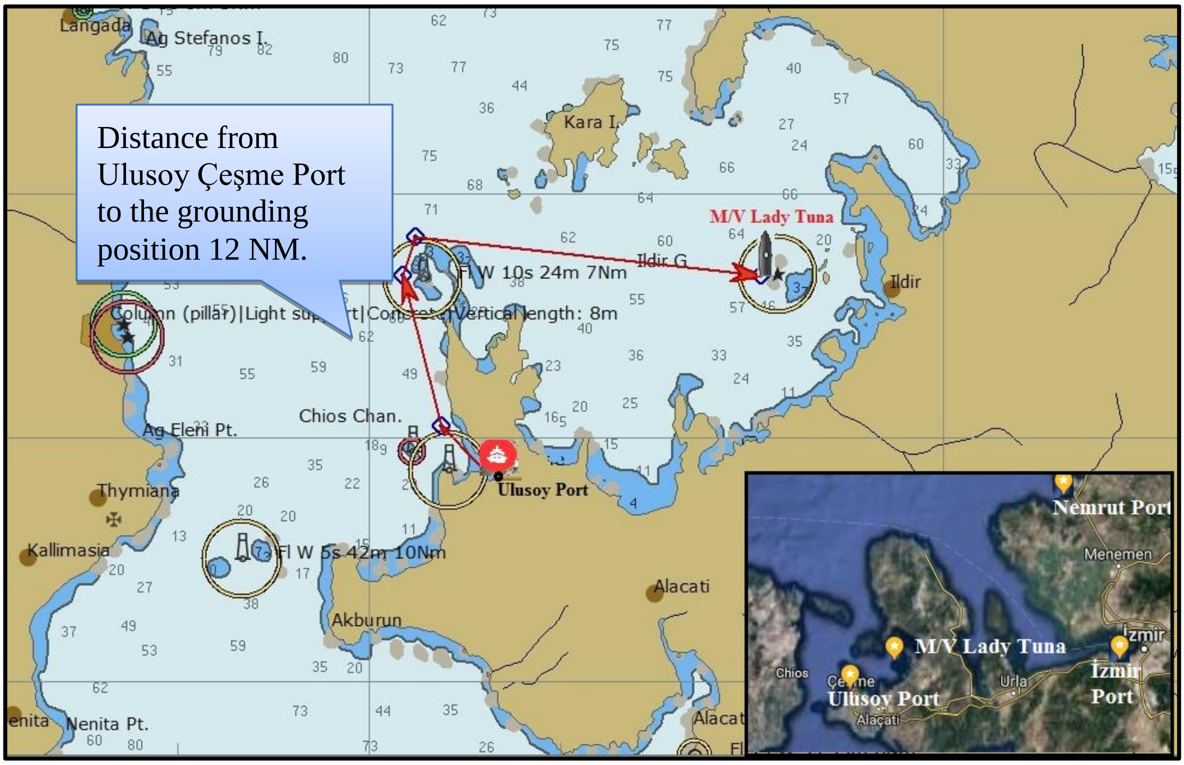


Figure 7.8. Distance from Ulusoy Çeşme Port to the Grounding Position (URL-3).

As of 12:00 LT on 19th December 2016, another company "Mare Marine Cleaning Service Company" started to work for a more effective pollution response. As of 16:00 LT, the damages at No.1 center ballast tank, No.2 port and starboard fuel tanks were closed but the damaged part of No.1 center fuel tank could not be reached and repaired, as this part was positioned over the rocks where the ship had grounded (The Accident Investigation Report, 2017).

In the following days, both of the authorized companies continued their pollution fighting efforts both at sea (inside the bay) and at shore-line (Figure 7.9) where the pollution had stranded (The Accident Investigation Report, 2017).

Figure 7.9. Pollution on Shore Caused by Fuel Leakage and Pollution Fighting Activities (Mare Marine Cleaning Services INC. Publication, 2017).

On 24th December 2016 (6 days after the accident), tanker ship PETROL-1 (Figure 7.10) came alongside M/V Lady Tuna in order to discharge the fuel in her damaged parts and discharging operation was completed on 26th December 2016 (8 days after the accident) (The Accident Investigation Report, 2017).

Figure 7.10. The Transfer Operation of the Fuel Oil to the PETROL-1 Tanker Vessel (The Accident Investigation Report, 2017).

Salvage operations were started at 09:00 LT on 27th December 2016 (9 days after the accident), together with the involvement of the officials from the Coastal Safety General Directorate. M/V Lady Tuna was refloated from her grounding position at 22:30 LT on 27th December 2016, she was anchored in the same location and she spent the night there. On 28th December 2016, an underwater survey was carried out under the supervision of the class surveyor and a planning was made for the temporary closure the accident damages. Between 29th December 2016 and 14th January 2017, cleaning of the ship's side and deck were continued weather permitting, and completed. 12-15 January 2017, ship's underwater temporary repairs were carried out and completed. On 20th January 2017, upon permission from the ship-owner, Captain and ship's agent, cleaning company stopped their work for the cleaning of the ship's side and deck. On the same day, ship heave up anchor with the permission of the Harbour Master and was started to be towed by two tugboats to Beşiktaş Shipyard at Yalova for the completion of her repairs. (The Accident Investigation Report, 2017)

On the other hand, the Expert Report of M/V Lady Tuna submitted to the Republic of Turkey Çeşme Civil Court of the First Instance presented following subjects (Sunlu, Kayacan and Küçükgül, 2017).

During the accident, the violent storm that started on 18.12.2016 continued for a week by increasing its intensity while the fuel oil from M/V Lady Tuna vessel continued to flow into the sea. The physical insufficiency of the barrier placed around the ship and the extreme weather conditions could not prevent the spilled fuel from spreading in the north-south direction (reach the coasts 8-10 km away). In the information note submitted to the Court in the letter numbered 54450012-659-E.8652 dated 13.02.2017, it was stated that the ship was refloated her grounding position on 27.12.2016 (9 days later) at 22:30 LT (Sunlu, Kayacan and Küçükgül, 2017).

The accident investigation report which was prepared by Turkish Coast Guard was stated that; on 18.12.2016 at 14.00 LT hours, the information about the location of M/V Lady Tuna (on the grounded) was taken and they went to the accident point at 15:00 LT. After the necessary examinations, they had informed the Çeşme Harbor Master about the accident. At 21:00 LT, the coast guard boat was gone to the region again after informed that the sea pollution occurred around the ship. The sea surface was covered with a black petroleum-derived material. They have recorded that the first barrier was encircled to the ship on the date of 19.12.2016 at 00:30 LT. In other a word, the inadequate first barrier was encircled to the ship 11 hours after the accident. (Sunlu, Kayacan and Küçükgül, 2017)

According to the captain's statement, the time of the accident was recorded in the ship's logbook at 13:30 LT .The insufficient boom (barrier) was encircled to the ship at 00:30 LT on 19 December 2016 (11 hours later) to control the pollution arising from the ship. Because of the bad weather condition, the second barrier was encircled 20 hours later after the spillage. (Sunlu, Kayacan and Küçükgül, 2017)

In the above official documents, it is clear that the information about the date and time of the incident is inconsistent. There are differences and inconsistencies in the documents of the official institutions about how the fuel oil pollution started in the event and after the event. In addition, there are discrepancies in the documents that the measures are carried out within the knowledge and authority of the institutions. But a good investigation report should explore the extent of the relation between the documents and reality at all appropriate levels.

7.5. Examination and Evaluation of the M/V Lady Tuna Accident

When investigating the reports on the grounding of M/V Lady Tuna, lots of uncertainties were observed. There are differences and inconsistencies in the documents of the official institutions about when the fuel oil pollution started and how they conducted the response operation following the accident. The official organizations and the oil cleaning companies were criticized because of the delayed response operation that increased stranded oil spill amount towards the Ildır coast. This oil spill incident revealed insufficiency of Turkey's response system to provide adequate cleanup and damage remedies as soon as the pollution has emerged.

7.5.1. Fish farms

M/V Lady Tuna came to Ildır Bay for tuna fish harvesting from the fish farms (Figure 7.11). The planned voyage would be to Port Said in Egypt after the completion of the harvest. At the time of the accident, there were 1223 tons of processed tuna fish on board the vessel. (The Accident Investigation Report, 2017)

Areas where fish farms are located are usually not far from the shore and this is a challenge for the navigation of ships. The need for an expert navigator with the local knowledge and experience is of great importance with regard to maritime safety. Pilotage and where necessary towage services for berthing or unberthing maneuvers to fish farms with a berth is therefore an essential solution for maritime safety (İstikbal and Erkan, 2018). In addition, the some of the shallows, especially the shoals where the ship had grounded, are not marked with lighted buoys at the Ildır Bay where large tonnage vessels are navigating. (The Accident Investigation Report, 2017)

Figure 7.11. Tuna Fish Farms (The Accident Investigation Report, 2017).

After this accident, the Turkish Maritime Administration (Ministry of Transportation, Maritime Affairs and Communication) considered that it was necessary to make amendments to the current legislation, including preventive measures for maritime accidents near fish farms (İstikbal and Erkan, 2018). A new Article, the Article 3.1 added to the "Regulation on the Amendment of the Regulation on the Ports" and published in the Official Gazette dated on April 8, 2017 and numbered 30032 ruled that "All tankers and vessels or sea vehicles carrying dangerous cargo which are 500 GT or above, all Turkish flagged vessels and sea vehicles of 1000 GT or above, all foreign flagged vessels and sea vehicles of 500 GT and above, commercial and private yachts of 1000 GT and above will be subject to compulsory pilotage while arriving to or departing from the coastal facilities and fish farms ". (Regulation on the Amendment of the Regulation on the Ports, 2017)

According to the Port Instructions issued by the Çeşme Port Authority, it is made obligatory for the ships to complete their customs clearance at the anchorage area which is shown by the Harbour Master or at the coastal facility. In addition, Çeşme Harbour Master (Port Authority) started to determine and the marking of the shoals in the area and works are still underway. (The Accident Investigation Report, 2017)

7.5.2. Safety of navigation

Look-out: Especially in narrow and congested waters, the presence of a look-out is always essential for ensuring a safe navigational watch. The M/V Lady Tuna's bridge team did not make use of all the suitable instruments that are available to them to carry out a full and sustainable look-out.

As the 2nd and 3rd Officers were busy with another task and there wasn't a look-out other than the Captain, while the collision prevention maneouver was being conducted, whether the ship was passing too close to the shoals could not be observed by means of marking on the map at close intervals or plotting on the radar. It is assessed that this situation is one of the factors that led to the accident. (The Accident Investigation Report, 2017)

The voyage plan: The safe carrying out of a voyage plan is based on a reliable assessment of all information about the proposed voyage, the identification of risks and the assessment of the identified critical areas.

It is seen that the section of the course determined in the related voyage plan was determined without leaving a safe distance to the relevant shoals in any probable collision avoiding situations (Figure 7.12). It can be assessed that the reason for this can be, when preparing the voyage plan, navigational hazards and shoals were not given enough consideration. (The Accident Investigation Report, 2017)

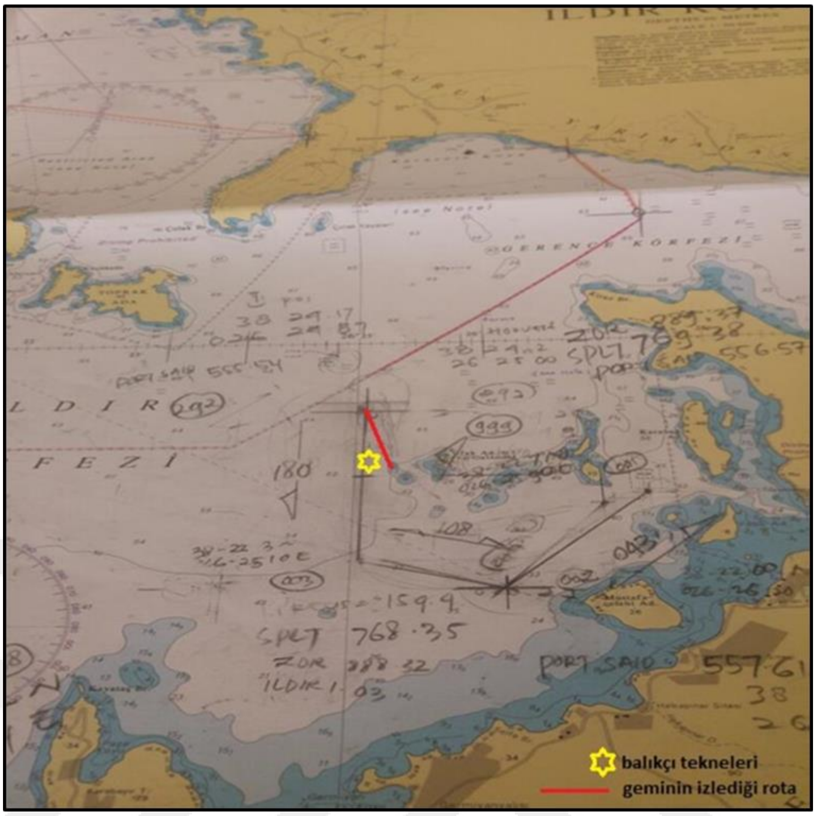


Figure 7.12. The Planned Route According to the Voyage Plan (The Accident Investigation Report, 2017).

As seen in the accident report of the ship and other documents related to the accident, the LADY TUNA bridge team did not have a full and sustainable lookout. The presence of other navigational hazards was not tracked on the map and radar while the avoidance maneuver was being carried out.

Safe Speed: The voyage records of the ship which are available to the investigators show that the vessel reached to a speed of 11.6 knots in a very short time period of 7 minutes, which is an evidence that she did not proceed at a safe speed that would make it possible to evaluate the current conditions (The Accident Investigation Report, 2017). In the light of the investigation reports of the accident, it is considered that the safe speed rule was ignored by the Captain and this was a causal factor in this accident.

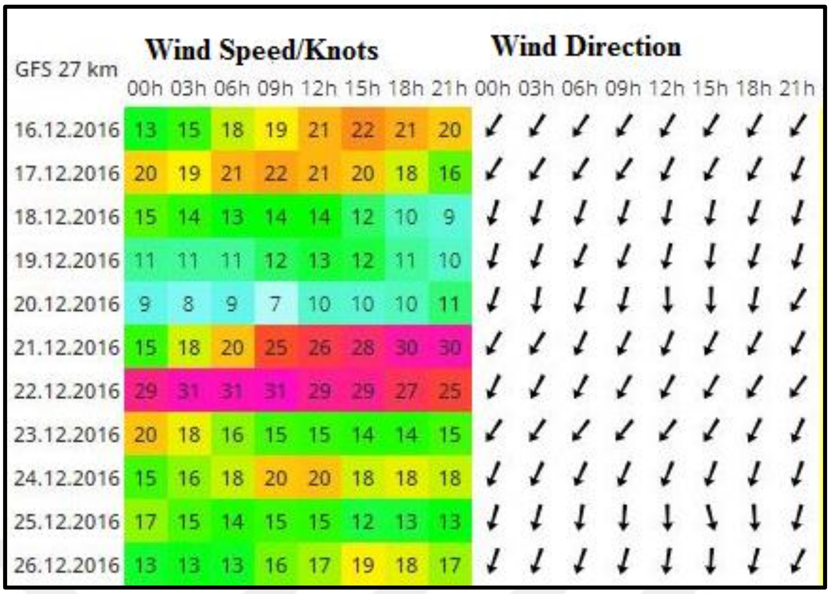
7.5.3. The Oil Spill Response Operation of the M/V Lady Tuna Accident

Following the oil spillage from the vessel, certain measures should have been taken before the arrival of the pollution on the coast and the environmental sensitive areas. At the end of M/V Lady Tuna accident, it was revealed that responsible firms licensed by the Turkish states for oil spill prevention are only beginner levels to conduct effective spill response strategies. The following deficiencies with the response activities have been criticized by local people and the media.

- Delayed response operation was managed following the accident,
- Insufficiency of the personnel for professional response operation,
- The inadequacy of the available response equipment after the fuel spillage,
- Lack of coordination and communication between the organizations and officials,
- The insufficiency of the regional emergency response system to control the oil spill just in time.

The weather report of the Çeşme station after the accident is presented in Figure 7.13. It shows that the violent storm occurs after the accident when the fuel oil continued to flow into the sea from M/V Lady Tuna vessel. It has been thought that the physical insufficiency of the barrier placed around the ship and the extreme weather conditions increased the volume of the spilled oil (Figure 7.14). It is clear; the delayed response operation was managed following the accident.

As a result of the oil spills event, Ministry of Transport, Maritime Affairs and Communications, General Directorate of Marine and Inland Water Regulatory Affairs, has canceled the authority certificate of 9 of the 12 companies which were authorized by the Ministry. (Numbered: 36712415-160.03.02-E. 12358 dated 09.02.2017) (URL-5). Most Maritime and Environmental Services and Mare Marine Cleaning Services Companies, managed the pollution response operation of the M/V Lady Tuna, were among the companies whose license has been canceled by the Ministry.



GFS 27 km	00h	03h	06h	09h	12h	15h	18h	21h
	Wind Speed/Knots							
16.12.2016	13	15	18	19	21	22	21	20
17.12.2016	20	19	21	22	21	20	18	16
18.12.2016	15	14	13	14	14	12	10	9
19.12.2016	11	11	11	12	13	12	11	10
20.12.2016	9	8	9	7	10	10	10	11
21.12.2016	15	18	20	25	26	28	30	30
22.12.2016	29	31	31	31	29	29	27	25
23.12.2016	20	18	16	15	15	14	14	15
24.12.2016	15	16	18	20	20	18	18	18
25.12.2016	17	15	14	15	15	12	13	13
26.12.2016	13	13	13	16	17	19	18	17

Figure 7.13. Wind Speed and Direction Report from the Ilıca/Çeşme Weather Station (www.windguru.cz, 2018).

Figure 7.14. The Containment Booms were used to Control the Oil Pollution (URL-6, 2017).

8. MODELLING OF THE OIL SPILLS IN M/V LADY TUNA ACCIDENT WITH PISCES II

Oil spill is not only threatening marine ecology but also destroy human health and the economy. Every effort should be made to prevent oil spills and to remove them effectively after they have emerged. The best solution is a highly coordinated oil clearance method when the response operation measures are planned and appropriately applied.

In this concept, the oil spill that occurred as result of M/V Lady Tuna grounding accident near the Çesme coast on 18th December 2016 was modelled and reconstructed the possible response operation to prevent oil pollution in simulated conditions with PISCES II. The program was used to portray different spill scenarios on electronic maps.

8.1. Computing Oil Spill Trajectories and PISCES II System

The computing oil models are based on two approaches, Lagrangian or on the Eulerian (Fay, 1969). PISCES II, oil simulation model, uses the Lagrangian (Shen and Yapa, 1988; Lardner, 1988) approach which is more appropriate and effective for numeral oil spill model by means of the software system.

The weathering process like spreading, evaporation, dispersion, emulsification, a variation of viscosity and shoreline interaction in the oil spills are calculated numerically with PISCES II in a short time. The effects of winds and currents significantly affect the spreading of oil and resulting movement that can be calculated with sum of two vectors (Hault, 1972; Fingas, 2013). The wind-sourced current speed is calculated as 3% (1%–6%) of wind velocity (Soltanpour et al., 2013).

PISCES II program is used to control and predict the propagation of oil spills based on the mathematical modelling. The simulation program also provides to the planning of the response operation in real time to prevent oil pollution on the seawater.

See the Figure 8.1 as below for general appearance of the instructor's workplace main window in PISCES II.

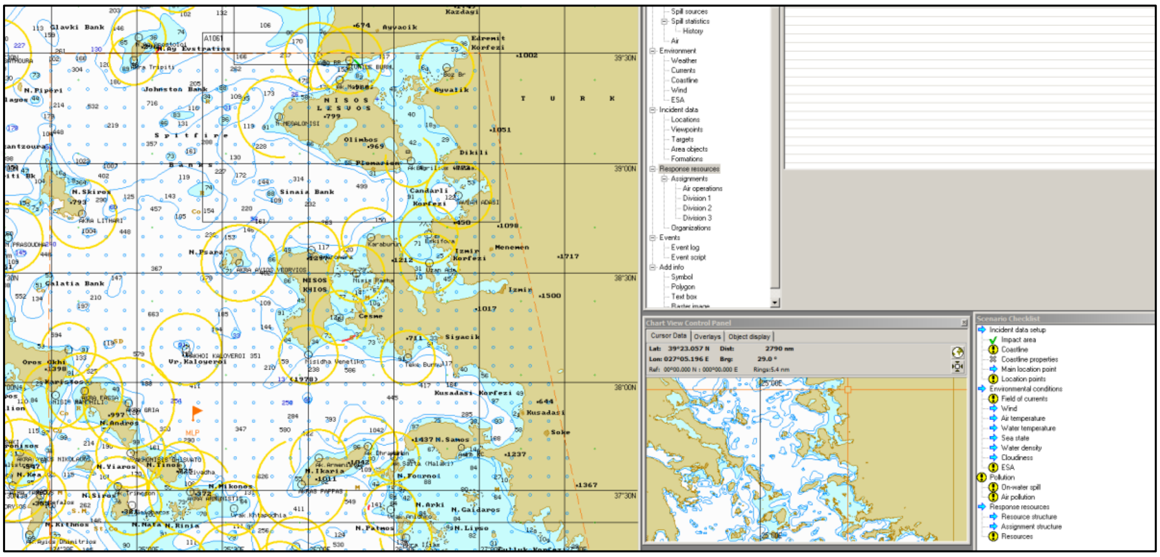


Figure 8.1. The instructor's Workplace Layout of PISCES II.

PISCES II simulates not only the oil slick and environment objects, but various objects taking part in spill cleanup activities too. Information directly related to the incidental oil spill response operations is combined under the "Incident data" category. These are the location points, objectives, areas, the operation cost summary and the dynamic response resource assignment structure. The simulation takes into account the following factors:

- Incident data set-up; coastline, location point, impacted area, coastline properties etc.
- Environmental condition in impacted area; current, wind, sea state etc.
- Pollution/ Spill parameters; on water spill and air spill,
- Response resource structure.

Finally, the layout to create response resources including containment and recovery of oil spill during the exercise is displayed in Figure 8.2. In the PISCES, five types of response resources can interact with the modelling of the oil spill: containment booms, oil skimming systems, chemical dispersants, shore cleanup equipment and dispersant application equipment. Other types of response resources (platforms, generic equipment and personnel) do not have a direct effect on the spill model behaviour and are used for the display of status of different oil spill response operation participants.

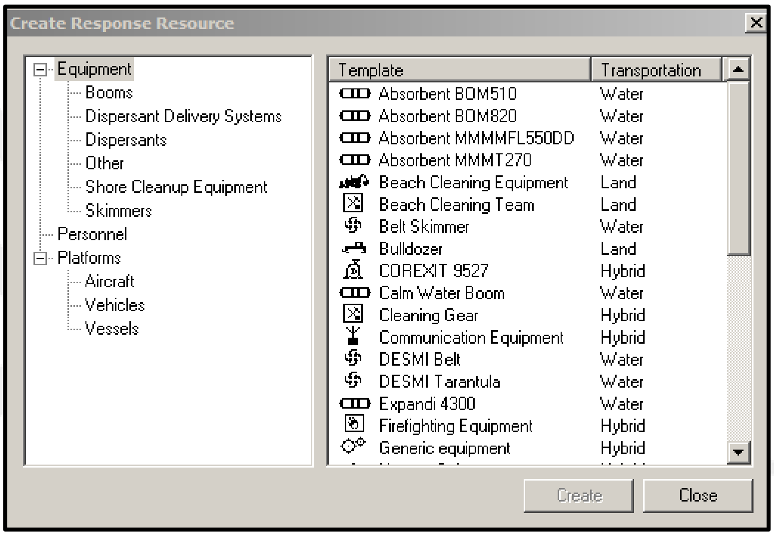


Figure 8.2. Creating Response Resources.

8.2. Scenario-1: Behaviour of the Spilled Oil on Seawater (No Response Operation)

In the first Scenario, PISCES II which is one of the most effective tools to predict the propagation of oil spills was used to simulate the behaviour of the oil spill on the seawater surface. It is very important to know the expected fate and behavior of spilled oil as soon as possible while combating against marine oil pollution.

The Scenario-1 was started at 10:40 UTC on 18 December 2016 and ended 22:40 UTC on 19 December 2016 (36 hours) in simulated condition with PISCES II (UTC +3 to convert local time in the 2016 year). The information about scenario duration was presented in Table 8.1.

Table 8.1. The Duration of Scenario-1 with PISCES II.

Scenario	Time (UTC)	Date	Time from Scenario Start
Begin	10:40	18.12.2016	36 hours
End	22:40	19.12.2016	

The "Scenario Checklist" window displays a list of parameters to be specified and actions to be performed to prepare the scenario. The scenario checklist and chart view control panel are displayed in Figure 8.3. The tasks in the list are divided for convenience into several categories:

- Specification of impact area,
- Specification of environmental conditions,
- Pollution parameters,
- Response resources.

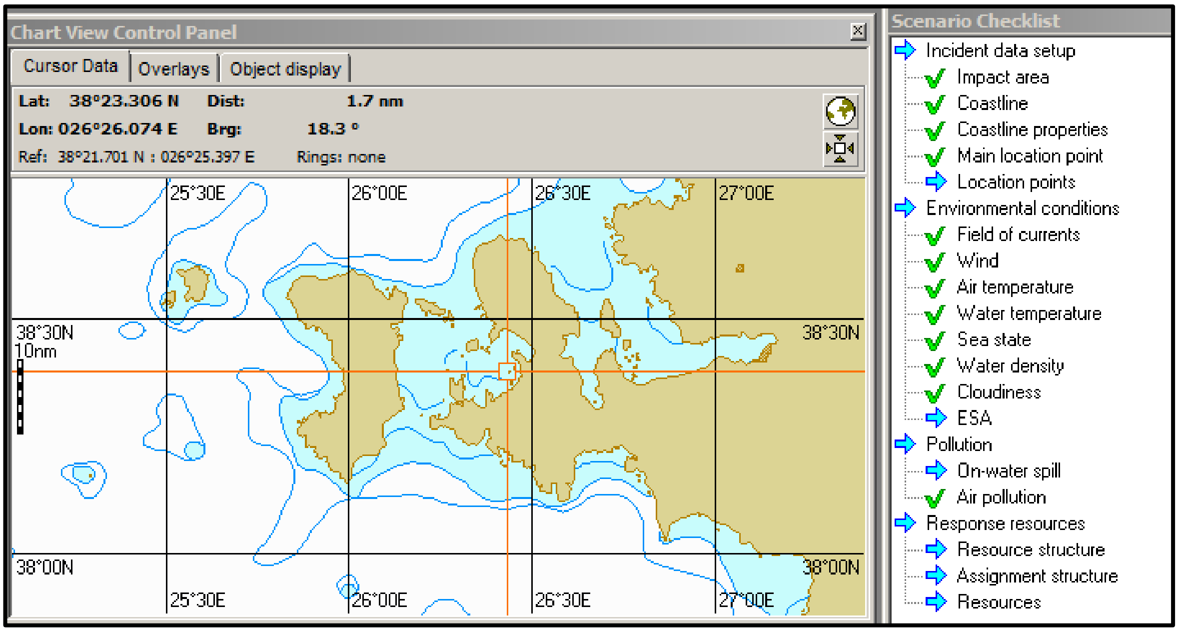


Figure 8.3. The Scenario Checklist Layout.

Firstly, the scenario was started to set up the incident data. They are the impact area, coastline, main location point and location points. Impact Area is a polygonal area, within which the program computes environment conditions and oil spill behaviour for the scenario. The impact area boundaries are shown in the form of a thin orange-colored dashed line displayed in Figure 8.4.

The information related to the incident data was obtained from the Investigation Report of M/V Lady Tuna marine accident prepared by the Ministry of Transport, Maritime Affairs and Communications Accident Investigation Board. Unfortunately, in the investigation report, there is only general environmental data provided for the moment of the accident.

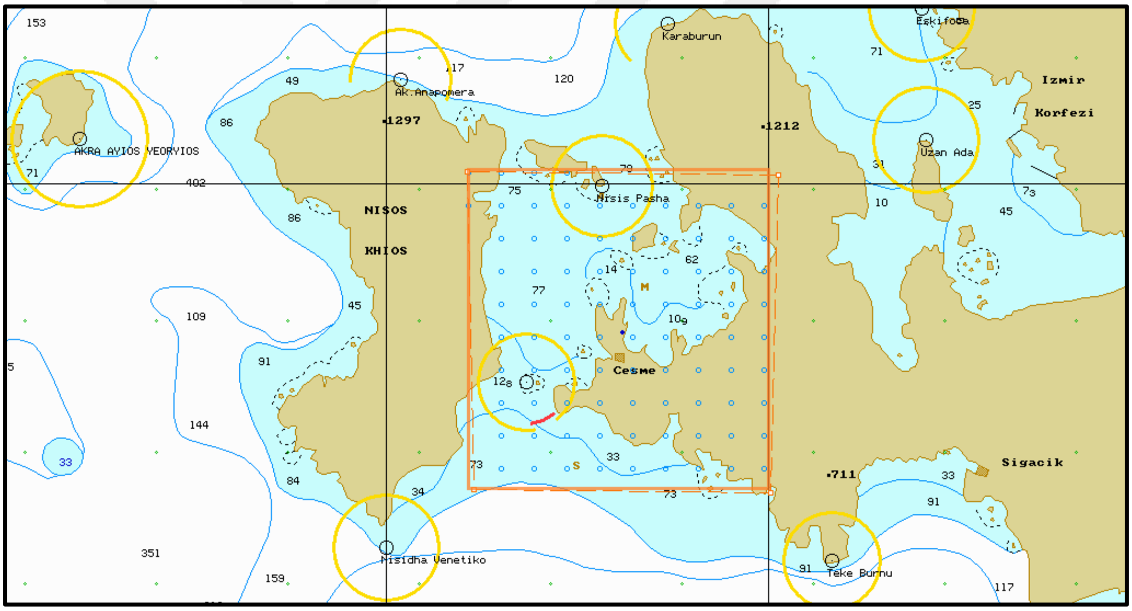


Figure 8.4. Determining the Impact Area of the Oil Spill on the Chart.

The essential meteorological conditions (temperature, wind, sea current, density, sea state) which directly effect on the weathering process of the spilled oil on sea surface examined as follows.

i. Air temperature, water temperature, sea state, cloudiness, seawater density; the environmental data (Table 8.2) was obtained from archive document of Meteorological Data Information Sales and Presentation System, Turkish State Meteorological Service

(MEVBIS, 2017). Seawater density is 1029 kg/m^3 in winter for Ildır Bay (Eryılmaz E. and Eryılmaz F.Y., 2016). The location of the meteorological station of Turkish State Meteorological Service is displayed in Figure 8.5 (mevbis@mgm.gov.tr, 2016).

Table 8.2. The Environmental Data (MEVBIS, 2017; Eryılmaz E. and Eryılmaz F.Y., 2016).

Air temperature	9 °C
Water temperature	13,9 °C
Seawater density	1029 kg/m^3
Cloudiness	0
Sea state	3 feet

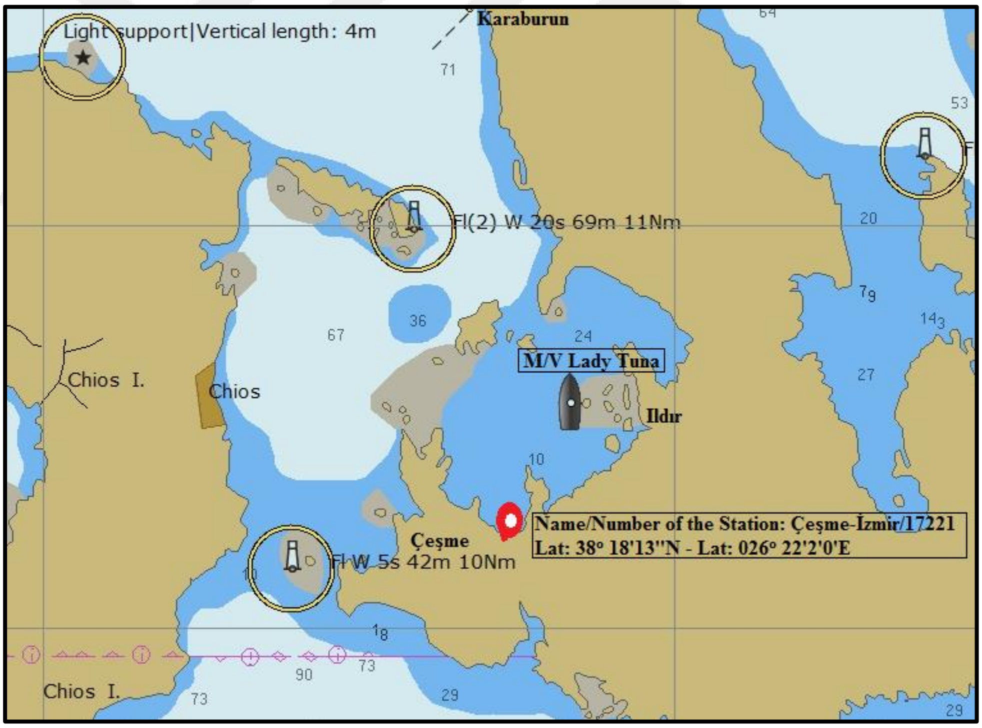


Figure 8.5. The Location of the Meteorological Station, (URL-3).

ii. The wind direction/speed; the temporal changes in wind direction and speed for the moment of the accident (Table 8.3) were obtained from archive document of Meteorological Data Information Sales and Presentation System (MEVBIS, 2017).

Table 8.3. Direction and Speed of the Wind Imported to the PISCES II (MEVBIS, 2017).

Date	Time (UTC)	Wind Direction (From)	Wind Speed (knts)
18.12.2016	11:00	27°	5,8
18.12.2016	12.00	19°	6,4
18.12.2016	13:00	22°	6,2
18.12.2016	14:00	21°	6
18.12.2016	15:00	30°	5,2
18.12.2016	16:00	56°	4,8
18.12.2016	17:00	69°	4
18.12.2016	18:00	70°	4,6
18.12.2016	19:00	67°	5,2
18.12.2016	20:00	58°	4,6
18.12.2016	21:00	63°	4,4
18.12.2016	22:00	65°	4,4
18.12.2016	23:00	70°	4,8
19.12.2016	00:00	60°	4,4
19.12.2016	01:00	66°	5,6
19.12.2016	02:00	70°	4,8
19.12.2016	03:00	64°	4,8
19.12.2016	04:00	65°	5
19.12.2016	05:00	58°	5,4
19.12.2016	06:00	54°	7,4
19.12.2016	07:00	54°	8,6
19.12.2016	08:00	56°	8
19.12.2016	09:00	57°	9
19.12.2016	10:00	25°	6,2
19.12.2016	11:00	29°	4,2
19.12.2016	12:00	0°	5,2
19.12.2016	13:00	28°	5
19.12.2016	14:00	9°	5,8
19.12.2016	15:00	42°	4,8
19.12.2016	16:00	67°	3
19.12.2016	17:00	66°	3
19.12.2016	18:00	78°	3,6
19.12.2016	19:00	67°	4,2
19.12.2016	20:00	54°	3,2
19.12.2016	21:00	41°	2,4
19.12.2016	22:00	49°	3,2
19.12.2016	23:00	58°	3,6

The effects of wind and currents significantly affect the drifting of the oil at the sea surface. The direction and speed of the surface current for the moment of the accident in Ildır Bay have not been measured by Turkish State Meteorological Service. Because there is not a meteorological station which measures the direction and speed of the current in this region.

The general pattern of current varies depending on meteorological conditions and wind direction in considerable duration affect the surface current on the sea. To know more about the dominant wind direction of Ildır Bay, wind statistics for Çeşme were displayed in Figure 8.6. The speed and direction of regional wind were identified in accordance with the highest wind frequencies of which NE direction for the month of December. The location of the weather station of Çeşme is displayed in Figure 8.7 (www.windfinder.com, 2018).

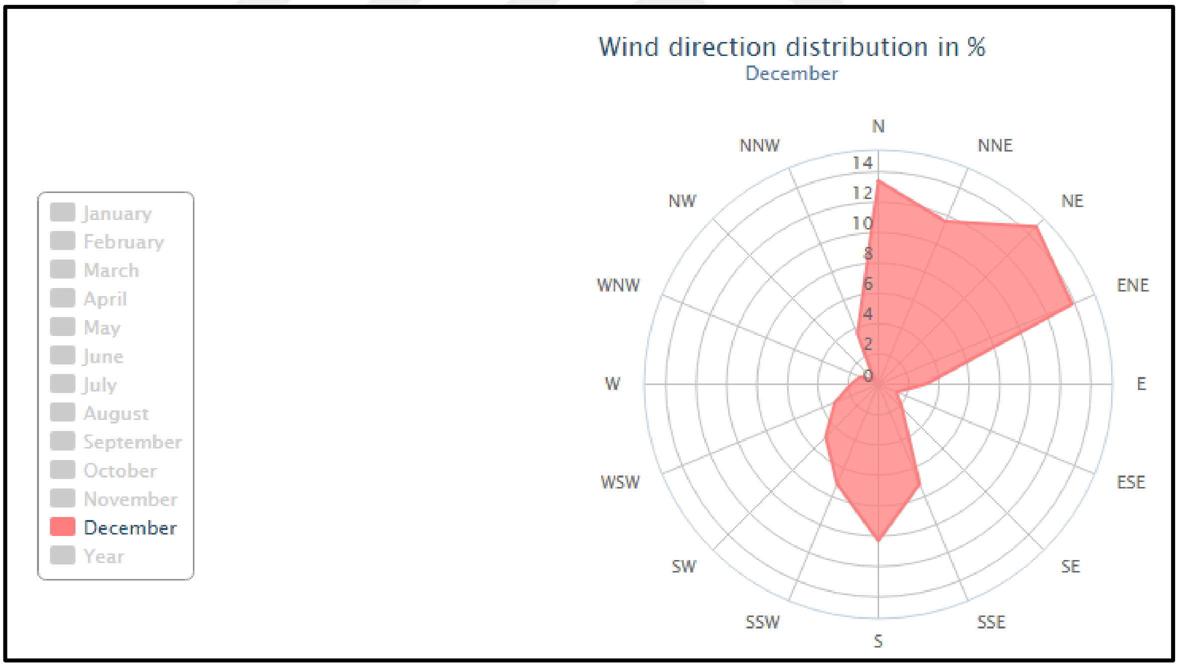


Figure 8.6. Wind Direction Distribution of Çeşme, (2013-2018) (www.windfinder.com, 2018).

Figure 8.7. The Weather Station of Çeşme (www.windfinder.com, 2018).

iii. The current direction/speed; in this study, the directions of the surface currents were adopted towards SW (225°) under the effect of the regional wind from NE and NNE direction. The dominant wind direction from NE for the moment of the accident on 18th December 2016 is displayed in Figure 8.8. The surface current speed of the region was adopted 0,16 kts (8,5 cm/sn) (Eryılmaz E. and Eryılmaz F.Y., 2016). In this case, the oil slick spreading was close to the real case.

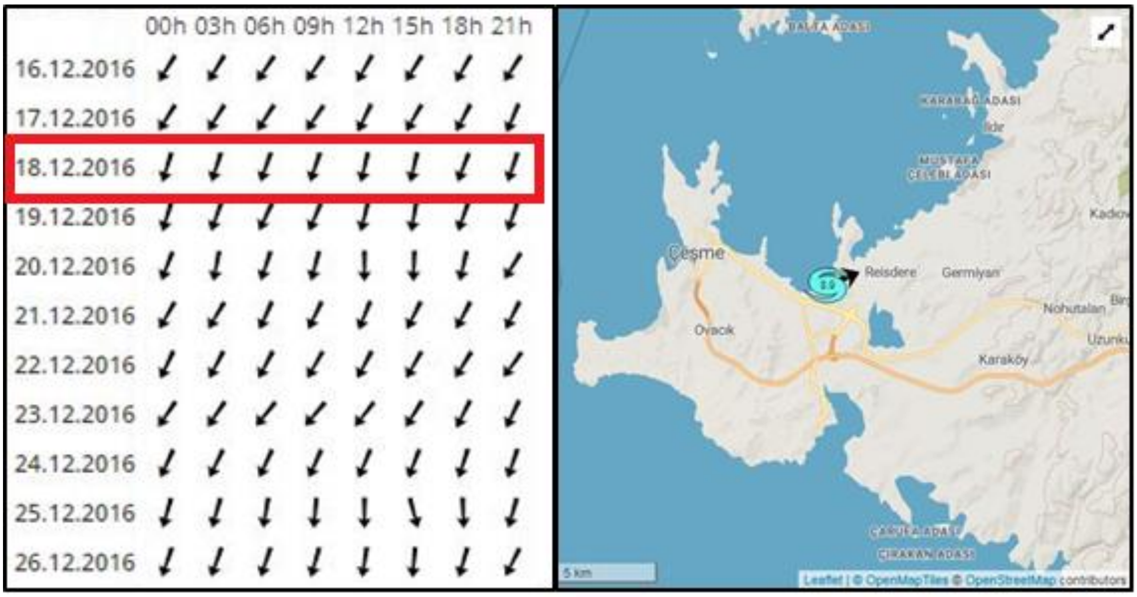


Figure 8.8. Wind Direction of Ilıca/Çeşme and Station Position (www.windguru.cz, 2018).

Thirdly, the spill parameters and the pollution on seawater were defined to set spill characteristics. PISCES II simulates three types of spills:

- Leak source; featuring leakage rate depending on time and the source route,
- Point source; featuring oil mass and spill coordinates, assuming that the entire oil mass is released at once,
- Area source; featuring oil mass and the initial slick form. Here it is assumed that the entire oil mass is instantaneously distributed as a flat layer over the specified area.

The use of one source type or another depends on the available information and the required level of detail required by the scenario's objectives (PISCES II Manual, 2008). In the thesis, the leak source type was modeled in the scenario because the entire oil mass was not instantaneously distributed after the accident. The accident position and the leak source parameter are displayed in Figure 8.9. In addition, the characteristics of fuel oil ‘‘IFO 180’’ used in the experiment are presented in Table 8.4.

iv. In the real case, the flow rate of the oil spillage (per hour) from the ship could not be determined. According to the damaged parts of the ship, the amount of the oil spill rate was assumed as 5 tons/per hour. After 14 hours and 30 minutes following the accident, it was assumed that 72,5 tons fuel oil leaked from the ship's tanks.

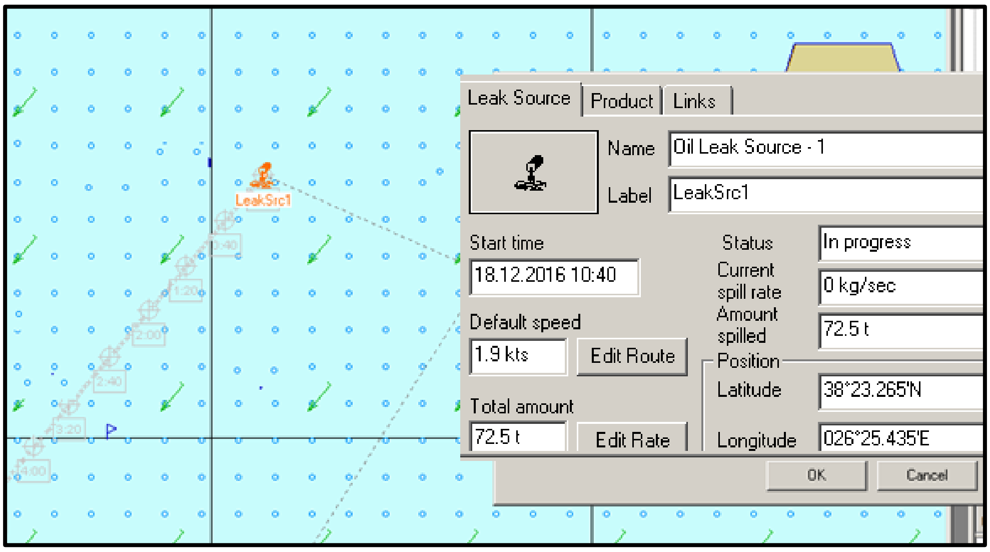


Figure 8.9. Setting Leak Source Parameters.

Table 8.4. Characteristics of the IFO 180 used in the Experiment (PISCES II Manual, 2008).

Name of the product	IFO 180
Type	Refined
Group	IV
Density	968 kg/m^3
Viscosity	2324 cP
Maximum constent of water	25 %
Emulsification constant	0 %
Pour point	-10 ^oC
Flash Point	91 ^oC

The environmental data were manually placed in the model and then the software simulation started with the combining of other related components. Thus, the simulation was performed on the following data:

i. Incident Data Set-up:

- Date of accident; 18th of December 2016, 13:40 Local Times (GMT +3),
- Accident position; Lat: 38° 23, 26′ N / Long: 026° 25, 42′ E,
- Impact area was defined,
- Coastline properties, parcels, length and coastline type, sand,
- Main location points and location points were set near the accident point.

ii. Environmental Conditions:

- Field of current: Direction 225° (towards SW), speed 0,16 kts,
- Field of wind: Direction from NE, (details are presented in Table 8.3),
- Air temperature: 9 °C,
- Water temperature: 13,9 °C,
- Sea state: 3 feet,
- Seawater density: 1029 kg/m^3,
- Cloudiness: 0.

iii. Pollution-on Water Spill:

- Type of oil: IFO 180,
- Amount spilled: 72.5 tons (75 m^3),
- Rate: 5 tons/ per hour.

In the first scenario, no response resources were used during the simulation. As soon as the oil is spilled, it immediately starts to spread on the sea surface. The fate of spilled oil water movement rapidly breaks up oil films, which drift on the water surface as shown in Figure 8.10. During the simulation in one hour, amount of spilled and floating oil were 5 tons/per hour, evaporation and dispersion of the spilled oil did not begin.

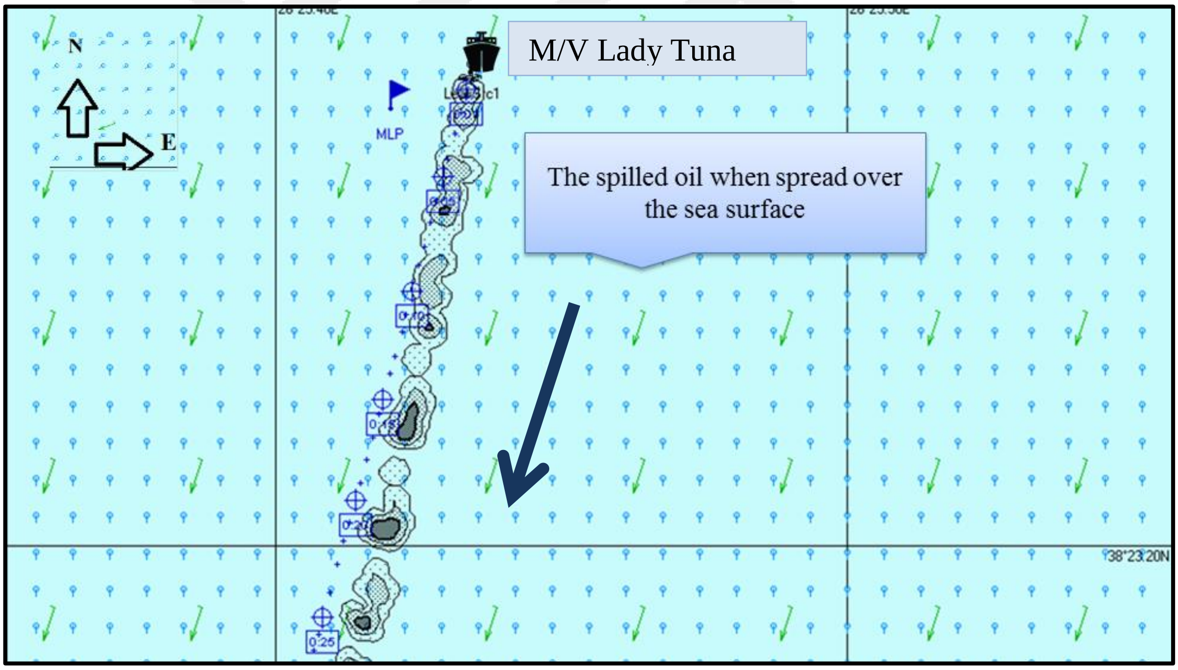


Figure 8.10. Scenario-1: Movement of the Oil Spread over the Sea Surface (Δt: 1h).

While, evaporation results in the fast reduction of the spilled oil volume, the emulsification increases the volume of the spilled oil (Fathalla, 2007). The more light oil fraction, the faster evaporation, and less oil afloat. The evaporation of the oil slick started at a very small rate about three hours later following the spillage in the model because the heavy fuel oil (IFO 180) has insignificant evaporation rate. The spill and pollution parameters at 16:40 UTC (six hours after the accident) are presented in Table 8.5.

The effects of winds and currents significantly affect the spread of oil. The movement of the oil slick after the accident was towards SW direction which drifts in response to the wind and the current (Figure 8.11).

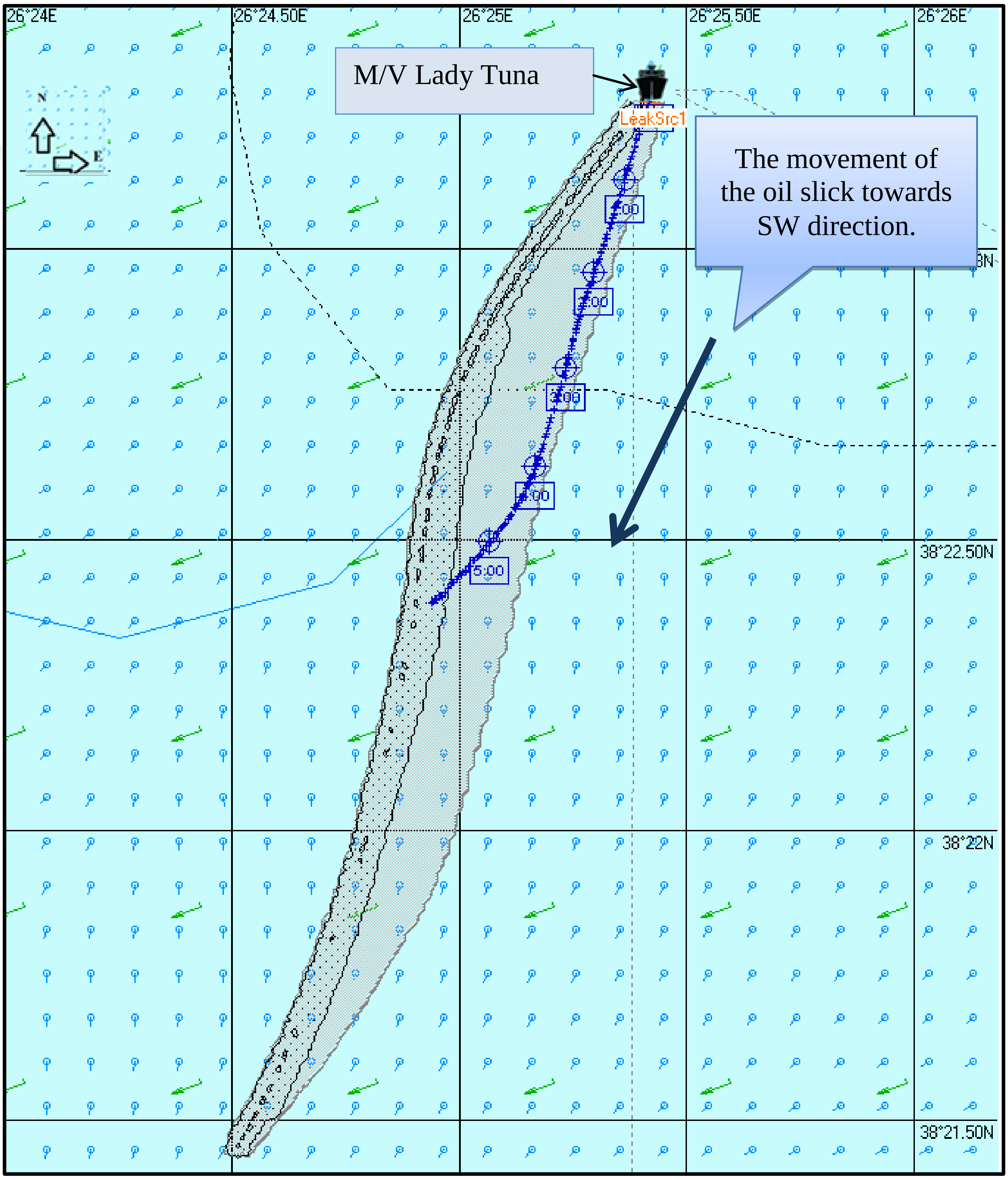


Figure 8.11. Scenario-1: The Movement Direction of the Oil Slick (Δt: 6 h).

Table 8.5. The Oil Spill Parameters of Scenario-1 after 6 hours.

Oil	Quantity (ton)	Percentage (%)
Amount spilled	30,0 t	100 %
Amount floating	29,8 t	99,4 %
Amount evaporated	0,2 t	0,52 %
Amount dispersed	0,0	0,05%
Amount stranded	0,0	
Amount floating mixture	35,6 t	
Max thickness of slick oil	1,4 mm	
Slick area	0384882 m^2	
Viscosity of slick oil	2149 cP	

The program showed the information “Oil impact on land” on the window screen. It means that the amount of stranded oil increased after this. The oil reached on the Paşalimanı coast about 12 hours later following the spillage. There is about 3,5 NM far away from the accident position as shown in Figure 8.12. It is compatible with the information as İzmir's Directorate of Environment and Urbanization “the area surrounding Paşalimanı was the most affected by pollution”.

Natural dispersion is a process of transformation of some part of oil into minute drops as a result of wave motion, these drops remaining in a suspended state in the water column (PISCES II Manual, 2008). The rate of dispersion is largely dependent upon the nature of the oil (the viscosity) and the sea state, so the dispersion started at a very low rate about 11 hours from the spillage because of the high viscosity rate of the fuel oil in the model and the gentle-moderate weather condition.

The area shown in gray indicates the area where oil is spreading for up to 12 hours from the beginning of the scenario. The amount of spilled oil was 60 tons after 12 hours from the accident. The oil reached on the Paşalimanı coast about 12 hours after the accident but this was a too small amount of the spilled oil (0,02 %). The pollution and spillage parameters after 12 hours from the accident are presented in Table 8.6.

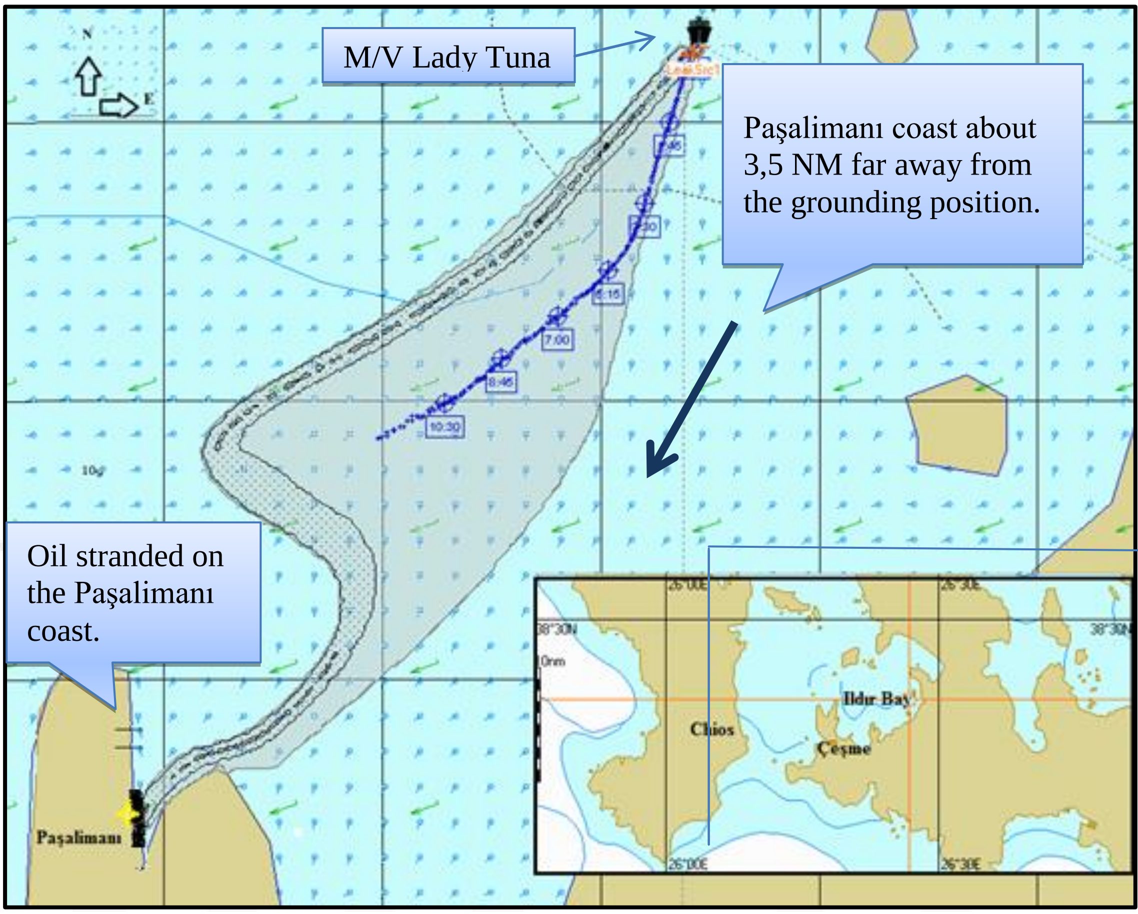


Figure 8.12. Scenario-1: The Oil Stranded on the Paşalimanı Coast (Δt: 12 h).

Table 8.6. The Oil Spill Parameters of Scenario-1 after 12 hours.

Oil	Quantity (ton)	Percentage (%)
Amount spilled	60,0 t	100 %
Amount floating	59,0 t	98,5 %
Amount evaporated	0,8 t	1,41%
Amount dispersed	0,1	0,09 %
Amount stranded	0,0	0,02 %
Amount floating mixture	73,9 t	
Max thickness of slick oil	0,8 mm	
Slick area	129276 m^2	
Viscosity of slick oil	2685 cP	

The spreading process resulted in increase of the slick area. The movement direction of the oil slick after 24 hours from the accident showed that oil stranded from Paşalimanı coast towards the Boyalık Bay, the Yıldızburnu coast (about 6 NM far away from the accident position), the Setur Çeşme Marina and the beachs of the Ilıca (Figure 8.13).

Amount of stranded oil was 26.4 tons (36.4%) after 24 hours from the spillage. Moreover, the evaporated and the dispersed oil rate increased very slowly because of high viscosity of the spilled oil type (Table 8.7).

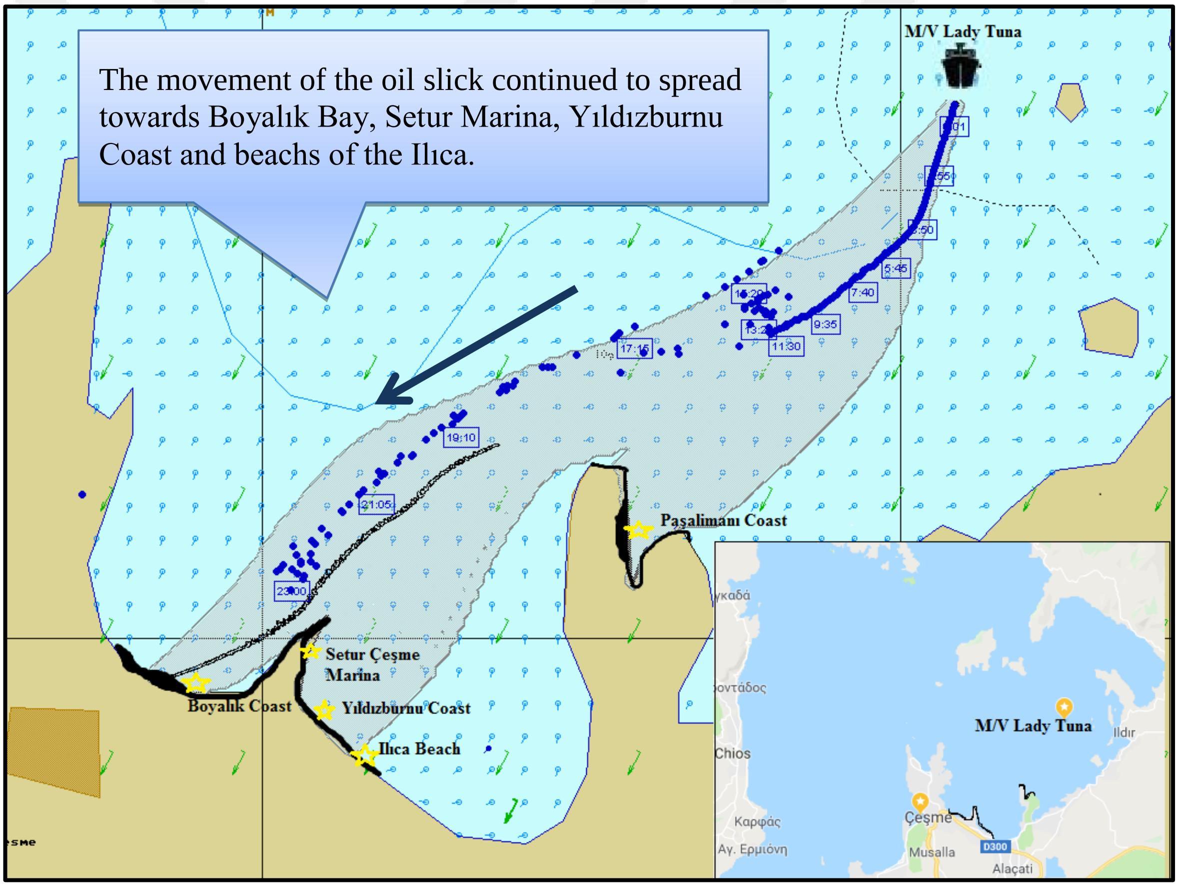


Figure 8.13. Scenario-1: The Movement Direction of the Oil Slick (Δt: 24 h).

Table 8.7. The Oil Spill Parameters of Scenario-1 after 24 hours.

Oil	**Quantity (ton)**	**Percentage (%)**
Amount spilled	72,5 t	100 %
Amount floating	43,7 t	60,3 %
Amount evaporated	2,0 t	2,82 %
Amount dispersed	0,4 t	0,49 %
Amount stranded	26,4	36,4 %
Amount floating mixture	59.2 t	
Max thickness of slick oil	5,1 mm	
Slick area	167600 m^2	
Viscosity of slick oil	3843 cP	

The Scenario-1 was created without any response resources by modelling the accident of M/V Lady Tuna to observe the movement direction of the oil slick after the accident. The Scenario-1 ended 36 hours after the accident on 19 December 2016 (22:40 UTC). The pollution and spill parameters are presented in Table 8.8 after 36 hours following the spillage. The main results of this scenario are as follows:

- As the amount of spilled product increased, the spilled area grew and the oil stranded the coasts of the Ildır. The oil slick continued to spread towards the Boyalık Bay, the Setur Marina, the Radisson Blue Resort Hotel beach, the Ilıca Motel beach, the Yıldızburnu coast, the Sherotan Çeşme Hotel beach and the Ilıca’s public beachs.

- The display of oil pollution in gray color indicates the size of the entire polluted area from the start of the scenario until 36 hours following the spillage.

- The movement of the oil on the surface of the sea is shown in Figure 8.14, depending on the environmental conditions, the properties and amount of the spilled oil.

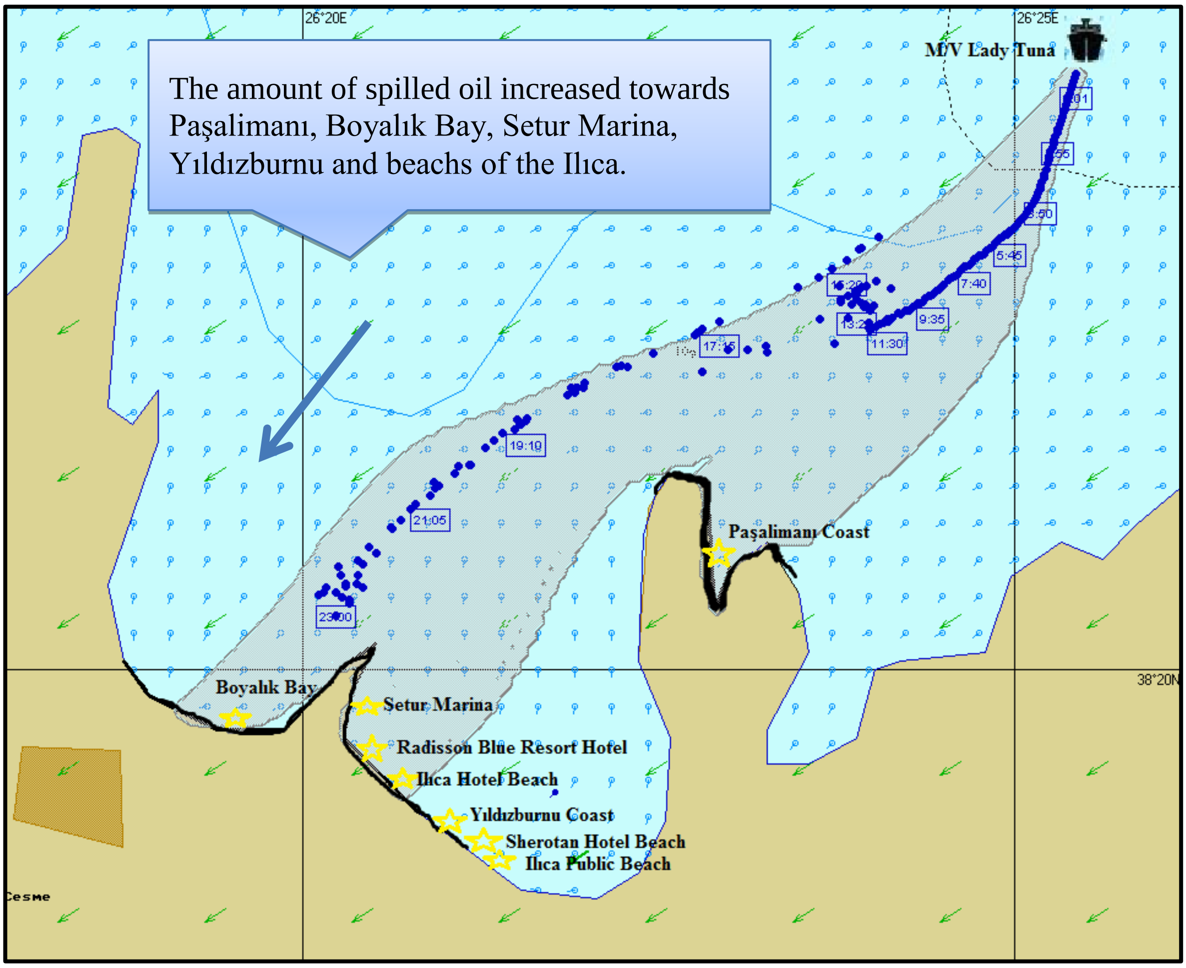


Figure 8.14. Scenario-1: The Movement direction of the oil slick (Δt: 36 h).

Table 8.8. The Oil Spill Parameters of Scenario-1 after 36 hours.

Oil	**Quantity (ton)**	**Percentage (%)**
Amount spilled	72,5 t	100 %
Amount floating	18,4 t	25,4 %
Amount evaporated	2,3 t	3,18 %
Amount dispersed	0,4 t	0,51 %
Amount stranded	51,4 t	70,9 %
Amount floating mixture	24,9 t	
Max thickness of slick oil	17,4 mm	
Slick area	5705 m^2	
Viscosity of slick oil	4010 cP	

In addition, Çubuk M. (2017) studied on the recent pollution events and presented the M/V Lady Tuna oil spill problem and polluted areas that close to the simulation study (Figure 8.15).

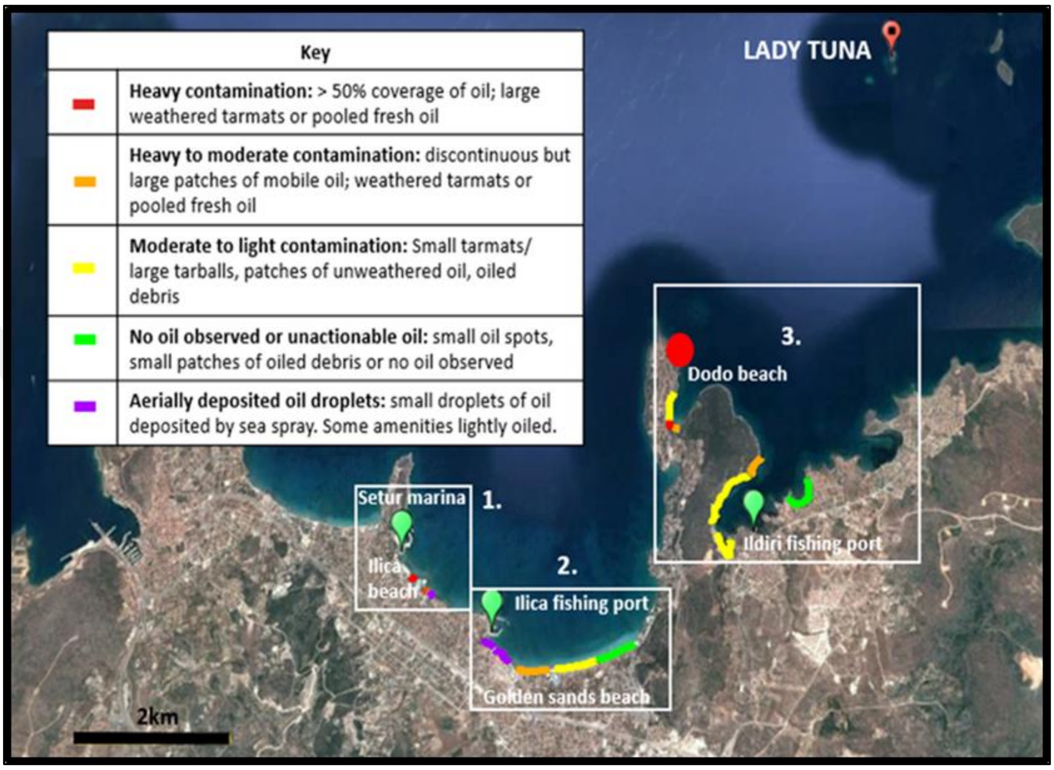


Figure 8.15. The Polluted Areas after the Accident (Çubuk, M., 2017).

The Scenario-1 ended 36 hours after the accident and from this time spreading of the oil will continue depending on meteorological conditions especially wind direction and the surface current on the sea. As a result of the study, it was available to determine and compare the spill and pollution statistics occurred after the incident in the simulated condition as graphically (Figure 8.16). So, the following results are obtained in the Scenario-1;

- After 14 hours and 30 minutes following the accident, 72,5 tons fuel oil leaked from the ship’s tanks (5 tons/per hour).

- The amount of stranded oil (which began about 12 hours after the spillage), is 51,4 tons (70,9 % of the spilled oil) as well as the floating oil amount is 18,4 tons (25,4 % of the spilled oil).

- The remaining amount of the spilled oil were dispersed (0,51 %) and evaporated (3,18 %). It means the evaporation and dispersion rate is very low due to the nature of the oil (IFO 180, the heavy fuel oil) as well as the moderate sea state.

- The amount of floating oil increased until 14 hours following the accident. After this time the floating oil rate decreased because the oil reached on the coast as well as the fuel leakage ended after 14 hours and 30 minutes.

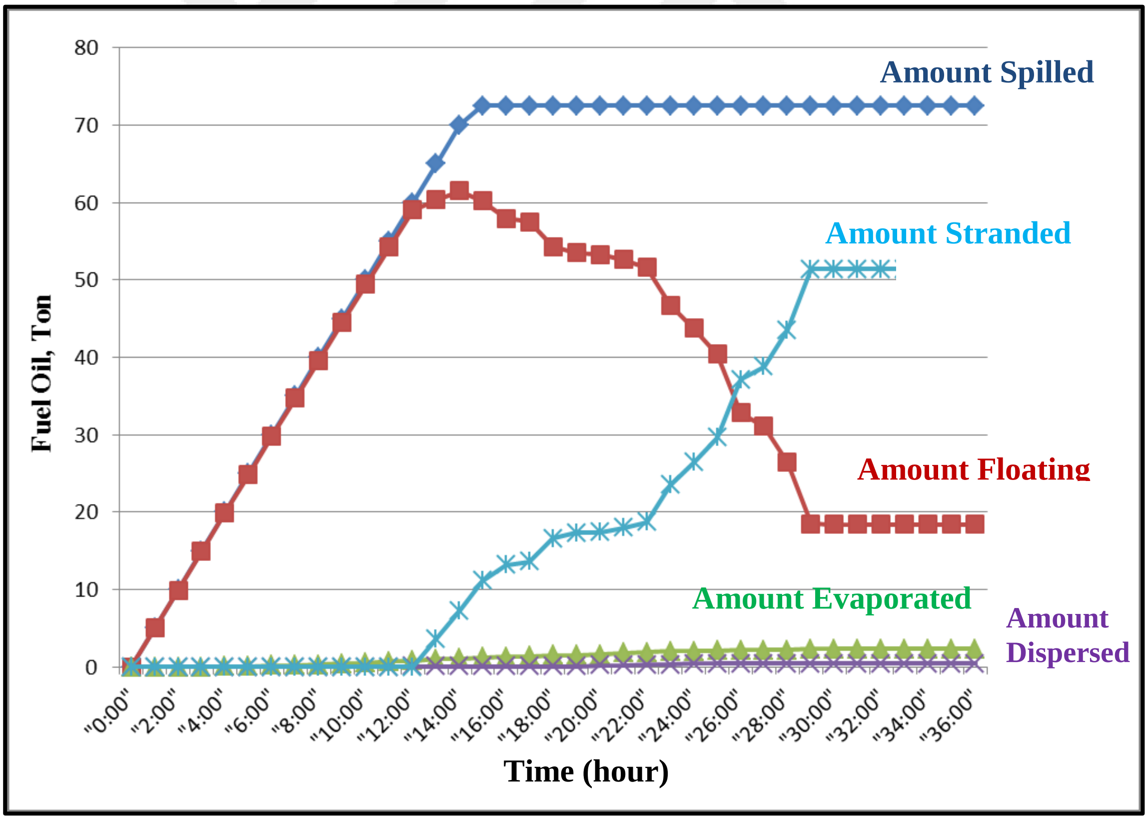


Figure 8.16. The Graphic of the Spill/Pollution Statistics of the Scenario-1.

8.3. Scenario-2: Reconstruction of Possible Response Operation with PISCES II

The simulator PISCES II provides an illustration of the possible response operation on seawater. The important factors in responding to the oil spills are the selection of the most suitable response resources to the oil properties.

The sea state and the weather at the scene are equally crucial, as meteorological conditions affect the behavior of spilled oil and effectiveness of response operation (Kassab, 2010).

- The information about the Scenario-2 duration is presented in Table 8.9.

Table 8.9. Duration of the Scenario-2 with PISCES II.

Scenario	Time (UTC)	Date	Time from Scenario Start (hours)
Begin	10:40	18.12.2016	15 hours
End	01:40	19.12.2016	

In the PISCES II, various types of response resources can interact with the modelling of the oil spill. This is containment booms, oil skimming systems, chemical dispersants, shore cleanup equipment, dispersant application equipment and platforms. During the simulation of oil recovery operation, oil response equipment’s parameters were presented in Table 8.10.

Table 8.10. Individual Parameters of the Response Resource Types (PISCES II Manual, 2008).

Model Data of the Skimmer Type		**Model Data of the Boom Type**		**Features of the Boat**	
Type	Oleophilic Skimmer	Type	Open Water Boom	Type	Oilfield Supply Vessel
Storage Capacity	11 m^3	Height	1.97 ft	Max Speed	14 kts
Recovery Rate	3,54 tons/hour	Depth	3.61 ft	Draft	1 m
Sea factor	0.0, 1.0; 0.8, 1.0 ; 1.3 0.5	Slack	5%	LOA	20
Recovery Radius	20 m	Absorbent Capacity	0 m2	Range	200 nm
Max Speed	1.9 kts	Length	1000 m		

The oil skimmers remove the floating oil from the point they are located. Model selection of the skimmer determines the rated capacity of the skimmer and the dependence of oil skimming efficiency on the oil viscosity and the wave height.

See table 8.11 below for characteristics of the Oleophilic skimmer presented in PISCES II. The wave height of the sea at the time of the accident is adopted as 3 feet. The viscosity of the oil IFO 180 is 2324 cP in the program.

Table 8.11. The Characteristics of the Oleophilic Skimmer
(PISCES II Manual, 2008).

Skimmer Model	Dependence of oil skimming efficiency on the wave height		Dependence of oil skimming efficiency on the oil viscosity	
	Wave height (feet)	Efficiency (%)	Viscosity (cP)	Efficiency (%)
Oleophilic	0	100	0	10
	2.62	100	500	40
	4.27	50	1500	90
	5.91	0	2500	60
			5000	10
			10000	0

PISCES II presents booms as flexible penetrable barriers able to move. The amount of oil passed through the boom depends not only of the latter's efficiency, but also of the ratio of oil film, thickness next to the boom and the boom height/depth. If the oil film is above or below the boom, the latter can pass oil even if its efficiency is 100 %. If the oil film thickness doesn't exceed the boom thickness, then the amount of oil passed through the boom depends just on its efficiency (PISCES II Manual, 2008). So, the open water boom which has 1.97 feet height and 3.61 feet depth was selected depending on the wind, the current and the amount of oil passed through the boom.

The possible response operation was simulated by PISCES II. The incident data, the environmental conditions and the amount of spillage on seawater are the same as in the first scenario. The only difference was that the response resources were created to containment and recovery of an oil spill during the simulation. These were an open water Boom-1 for the oil containment, an open water Boom-2 arranged J shape formation for the oil collection by trawling, three Oleophilic skimmers and three oilfield supply vessels. The event log of the recovery process is presented in Table 8.12

Table 8.12. Event Log of the Recovery Process.

Time (UTC) 18.12.2016	**The Response Resources**
10:40	The fuel oil began to leak.
3 h after spillage 13:40	The Oil Containment Boom Formation-1 Deployed; Oleophilic Skimmer-1 and Skimmer-2; An Oilfield Supply Vessel.
5 h after spillage 15:40	J Shape Boom Formation-2 Deployed; Oleophilic Skimmer-3; Two Oilfield Supply Vessels.
7 h after spillage 17.40	Oleophilic Skimmer-1 and Skimmer-2 exceed storage capacity (11 m^3); Oleophilic Skimmer-1 and Skimmer-2 Rearranged.

The accident occurred at 10:40 UTC (13:40 LT) on 18 December 2016. The open water Boom-1 and the Oleophilic skimmers were placed on the sea at 13:40 UTC. The deployed Boom-1 prevented spreading of the oil slicks. The Oleophilic Skimmers-1 and Skimmer-2 removed the floating oil from the point they located in the boom formation. An oilfield supply vessel assisted the operation.

Before the response resources start to the task, about 15 tons oil spill to seawater in three hours. Oil spill parameters of the scenario after five hours from the spillage are presented in Table 8.13. During the simulation, 10 tons oil, which is 40,2 % of the spilled oil, were recovered after the response operation (Figure 8.17).

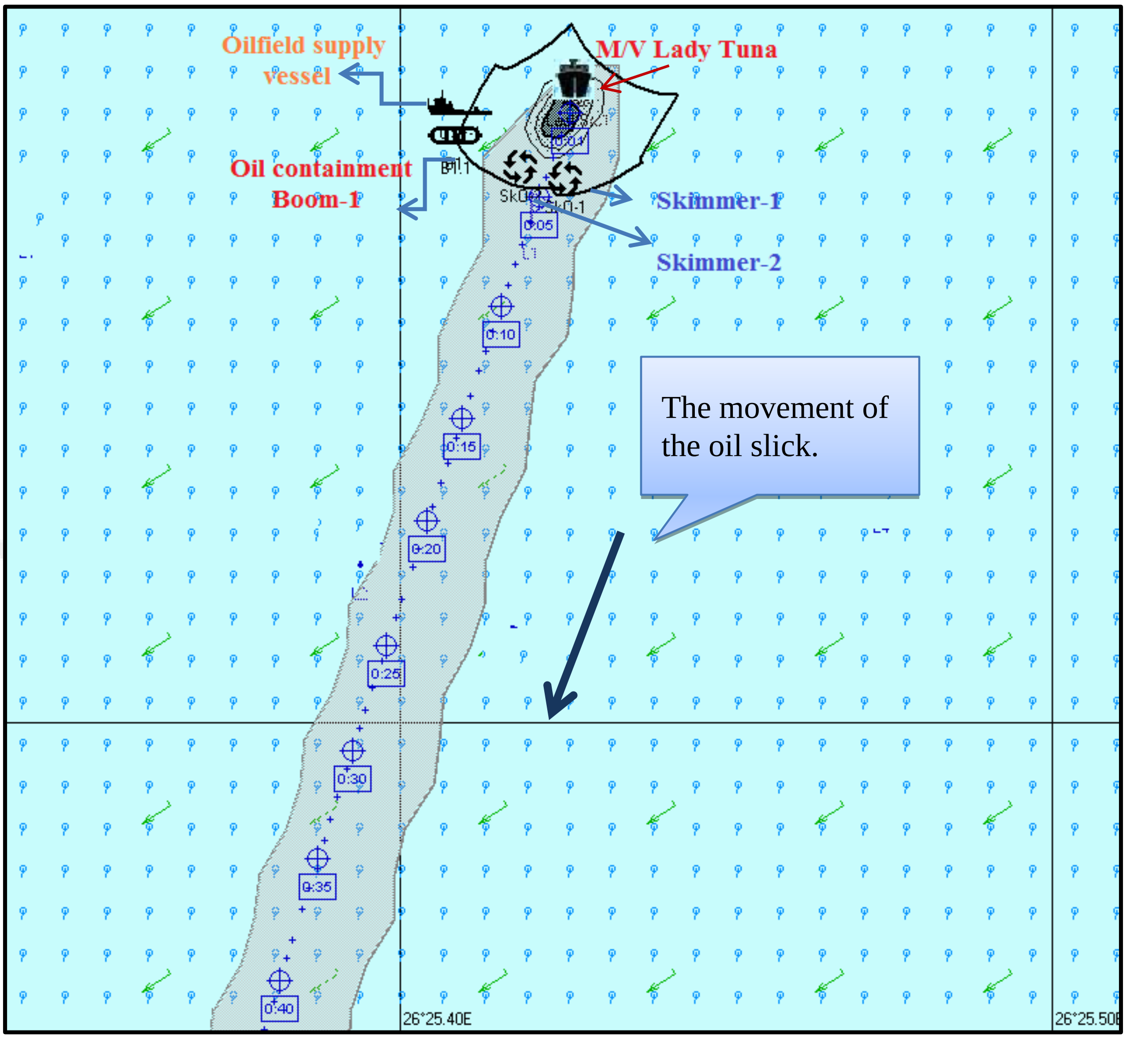


Figure 8.17. Response Operation with Oil Containment Boom Formation-1 and Skimmers.

Table 8.13. The Oil Spill Parameters of the Scenario-2 after 5 hours.

Oil	**Quantity (ton)**	**Percentage (%)**
Amount spilled	25,0 t	100 %
Amount floating	14,8 t	59,5 %
Amount evaporated	0,1 t	0,27 %
Amount dispersed	0	0,03%
Amount stranded	0	0
Amount recovered	10,0 t	40,2 %
Amount floating mixture	18,6 t	
Amount recovered mixture	10,1 t	0,4 %
Max thickness of slick oil	1,2 mm	
Viscosity of slick oil	2352 cP	

The one J shape Boom Formation-2 was placed on the scene with the Oleophilic Skimmer-3 and two Oilfield supply vessels as a single unit at 15:40 UTC (5 hours after the spillage). Movement of the J shape Boom Formation-2 was controlled by two Oilfield supply vessels and it allowed the oil collecting by trawling (Figure 8.18). J shape Boom Formation-2 (300 m open water boom) was adjusted in the direction of the oil leak and moved with an Oleophilic skimmer towards the leakage source.

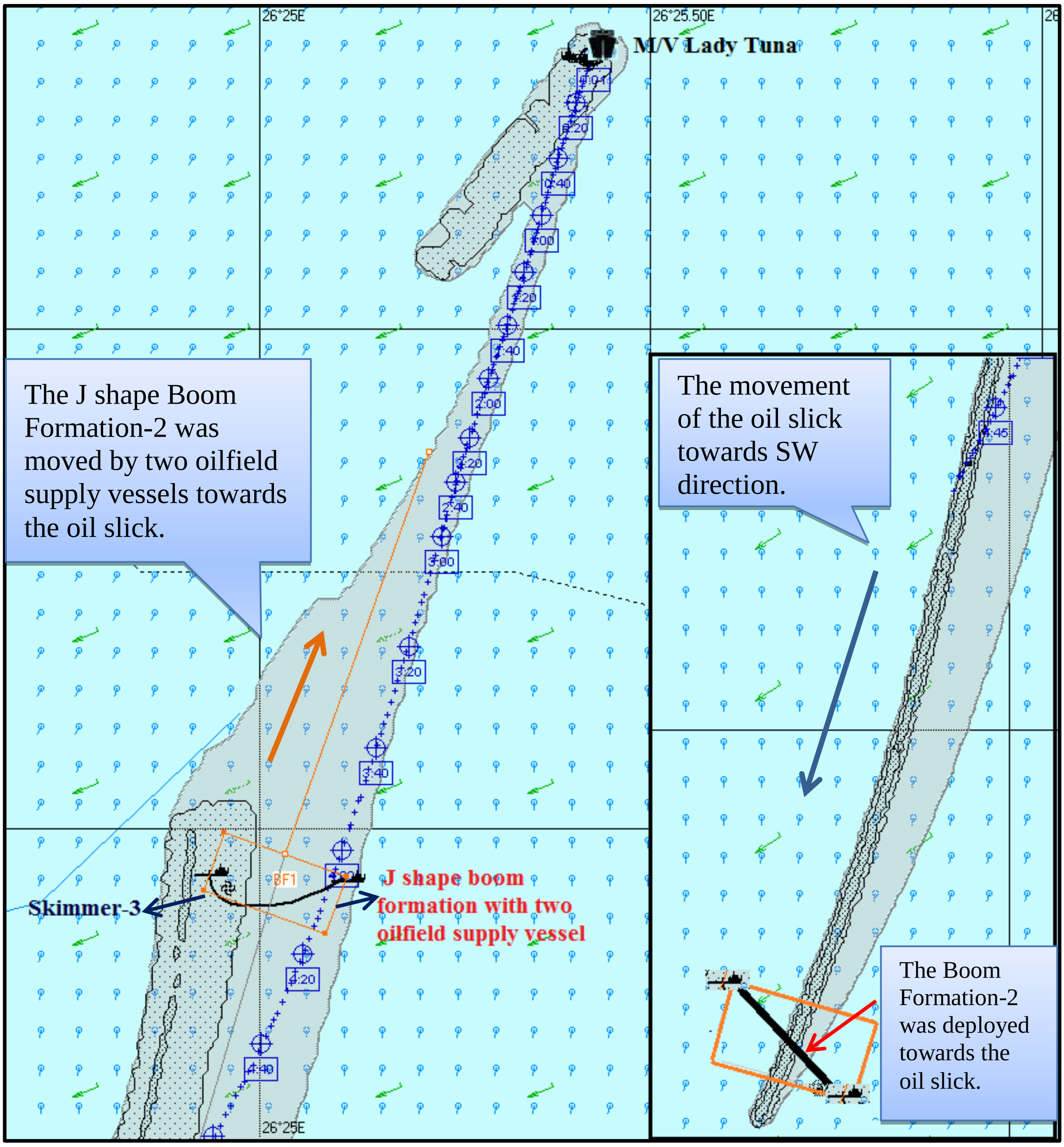


Figure 8.18. The Movement of the J Shape Boom Formation-2 with the Skimmer-3.

When the amount of collected water/oil mixture reaches the skimmer maximum capacity, the turnaround cycle is start, on which completion the oil collection continues or can be rearranged with different skimmers. At 17.40 UTC (about 7 hours later after the spillage), the Oleophilic Skimmer-1 and Skimmer-2 (combined with the containment boom-1) removed the floating oil and exceed the storage capacity which is 11 m^3. Therefore the Oleophilic Skimmer-1 and Skimmer-2 were rearranged as combined with the Boom Formation-1. The pollution footprint displayed that the deployed Boom Formation-1 provided oil containment and diversion. Because of the oil which passed through the Boom-1, the J shape Boom-2 was moved towards the direction of the oil leak with an Oleophilic skimmer (Figure 8.19).

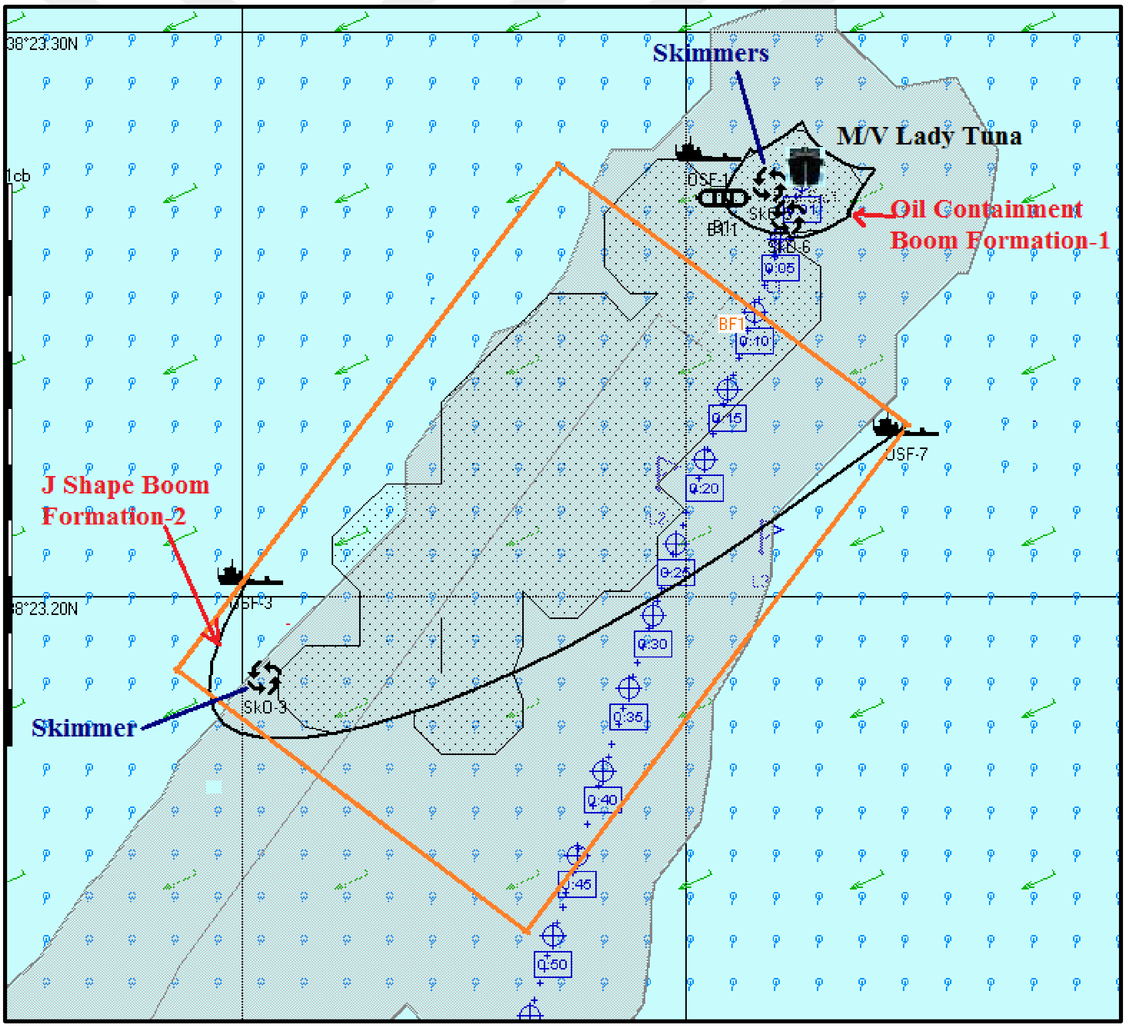


Figure 8.19. The Response Operation with Oil Containment Boom Formation-1 and J Shape Boom Formation-2

At the end of the 9 hours, the skimmers removed the floating oil from the point they located, about 31,5 tons oil on-water was recovered (69,7 % of the spilled oil) in simulated condition. Oil spill parameters after 9 hours from spillage are presented in Table 8.14.

Table 8.14. The Oil Spill Parameters of the Scenario-2 after 9 hours.

Oil	**Quantity (ton)**	**Percentage (%)**
Amount spilled	45,2 t	100 %
Amount floating	13,5 t	29,8 %
Amount evaporated	0,2 t	0,48 %
Amount dispersed	0,0 t	0,03 %
Amount stranded	0 t	0 %
Amount recovered	31,5 t	69,7 %
Amount floating mixture	17,8 t	
Amount recovered mixture	31,9 t	1,17 %
Max thickness of slick oil	0,8 mm	
Slick area	378042 m^2	
Viscosity of slick oil	2783 cP	

The "Local Area Statistics" window shows statistics for the polygon area. The local statistics of the given area was presented in Figure 8.20 displayed maximum thickness and area of the patch, amount of oil product afloat and stranded. It displayed pollution statistics of the Paşalimanı coast where is the first impacted coast from the oil spill (about 3,5 NM far away from the accident position).

The features of PISCES II provides for better illustration of responses operation by creating response resources like skimmers and booms. It allowed to clearly documenting the spilled oil parameters, the stranded oil shoreline, and the forecasted time for which the oil spill will reach the shoreline.

In the second scenario, when the response resources were organized in simulated conditions, 58.8 tons oil was recovered. So, the amount of the oil which reached the shore reduced after the response operation. The illustrated response operation allowed making a conclusion about the pollution and spill parameters of M/V Lady Tuna accident is displayed in Table 8.15.

The display of oil pollution in gray color indicates the size of the entire polluted area from the start of the scenario until 15 hours following the spillage. After using the resources of response on the sea, it is observed that the direction of oil has changed.

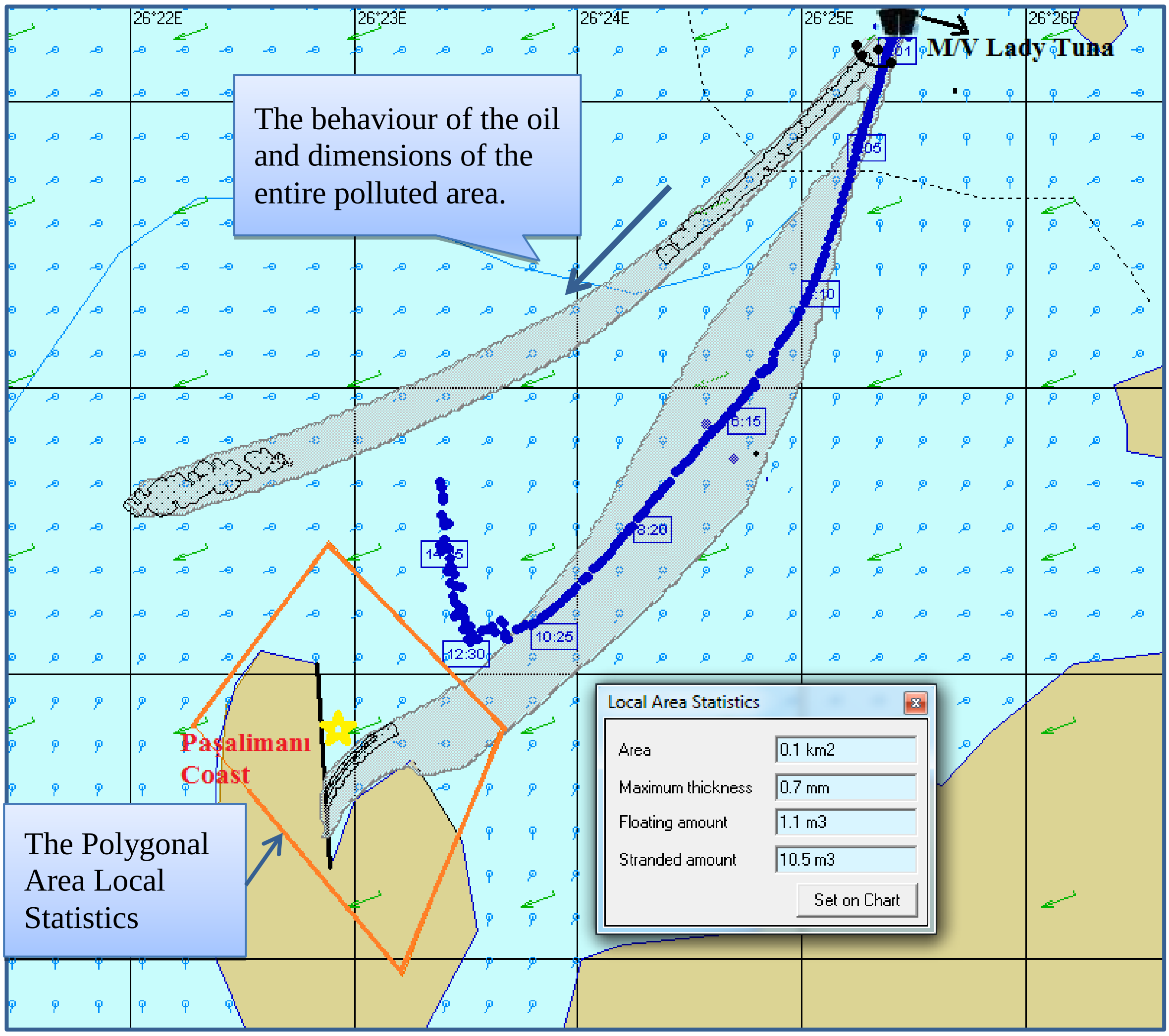


Figure 8.20. The Behaviour of the Spilled Oil and Local Area Statistics (Δt: 15 h).

Table 8.15. The Oil Spill Parameters of the Scenario-2 after 15 hours.

Oil	Quantity (ton)	Percentage (%)
Amount spilled	72,5 t	100 %
Amount floating	3,3 t	4,6 %
Amount evaporated	0,4 t	0,55 %
Amount dispersed	0,0 t	0,03 %
Amount stranded	10,0 t	13,7%
Amount recovered	58,8 t	81,1 %
Amount floating mixture	4,5 t	
Amount recovered mixture	59,3 t	0,81 %
Max thickness of slick oil	0,8 mm	
Slick area	388922 m^2	
Viscosity of slick oil	2918 cP	

The main objective of the Scenario-2 is to illustrate actions to response oil pollution on the sea surface before it reaches the shoreline where it will create the most amount of destruction. It is important for the coordinators must determine which sites to priorities for response actions and eliminate false alarms.

The simulation PISCES II showed a significant influence on the efficiency of oil spill recovery from the surface of the sea. Results of the spill/pollution statistics are graphically presented in Figure 8.21. So, the following results are obtained in the Scenario-2;

- After 14 hours and 30 minutes following the accident, 72.5 tons fuel oil leaked from the ship’s tanks. The oil stranded on the Paşalimanı coast (3,5 NM far away from the accident) about 12 hours after the spillage.

- Because the containment Boom-1 with two skimmers was deployed around the ship after 3 hours following the spillage, the only 15 tons of oil spread to seawater in three hours.

- The J shape Boom Formation-2 with one Oleophilic skimmer was placed on the scene and recovered about 5 tons oil on the sea by trawling. But, 10 tons oil reached the coast. Because, the oil slick area was more than the booms' radius; the effectiveness of the skimmer reduced due to floating oil-water emulsification process and the Oleophilic skimmer has 20 m recovery radius which restricted removing of the floating oil.

- Thanks to the response operation, the amount of the oil which reached the shore reduced. The spill statistics presented that 81,1 % of the spilled oil (58.8 tons) was recovered when the oil spill response actions was taken without losing time.

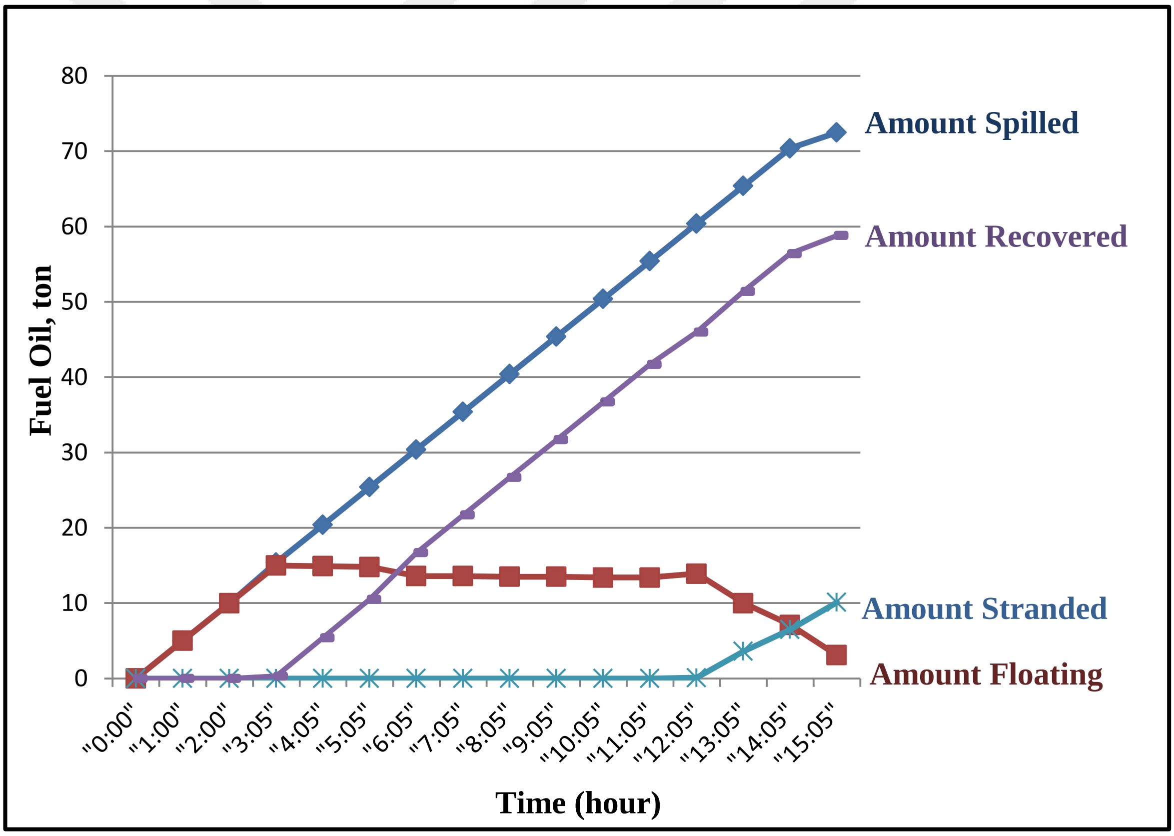


Figure 8.21. The Graphic of the Spill/Pollution Statistics of Scenario-2 by Creating the Response Operation.

CONCLUSIONS

In order to reduce the oil pollution incidents in the world, the studies on the investigation of the marine accident resulted in the oil spill are very important. The M/V Lady Tuna grounding accident which resulted to leak about 72,5 tons fuel oil (IFO 180) polluted the world-famous turquoise blue sea of Çeşme.

The following results were obtained by examining the reports about the accident and the news obtained from the press.

- Even if, the right after the accident, ship's Captain reported the pollution to the ship's agent that an immediate action/response was necessary, the response operation was started very late following the accident. Therefore, the spilled oil amount from the ship increased the marine pollution.

- According to the accident investigation report on the grounding of M/V Lady Tuna, the response company started to encircle the ship with a barrier about 9 hours after the oil leakage in order to control the pollution arising from the ship. On the other hand, according to the captain's statement from the court report, the insufficient boom (barrier) was encircled to the ship 11 hours after the spillage. This situation shows that the differences and inconsistencies in the documents of the official institutions about when the response company started the operation to control pollution.

- The response company reached the accident region 7th hours after the accident, but firstly they began to encircle the fish farms with barriers. About 9 hours after the spillage, they began to encircle the ship around with a barrier (which is not efficient in high sea condition). Whereas, first of all, they should have started the response operation against the leak source. As a result, the response operation was delayed at least 2 hours. This caused more than 10 tons of the fuel to spill.

- The response company “Most”, which is based at Ulusoy Port, in the administrative responsibility area of Çeşme Port Authority was managed the response operation. Distance from the Ulusoy Çeşme Port to the accident position is about 12 NM by the sea. It is a distance that can be taken within one hour by the supply vessel loaded with response resources. Whereas, the response company reached the accident region 7th hours after the accident.

- According to the report, 9 hours after the spillage, the ship was encircled with a boom as well as the two skimmers removed the floating oil from the point they were located. But, in 9 hours, 45 tons of fuel spilled into the sea and moved away from the ship towards the southwest direction due to the wind and the current in the region. At the end, the oil remained on the ship was only 27,5 tons. It means the response operation was focused on the remained oil. Therefore, 45 tons of spilled oil stranded towards the Ildır coast.

- On 24th December 2016 (6 days after the accident), the tanker ship discharged the fuel in her damaged tanks and discharging operation was completed on 26th December 2016. The weather report shows that the violent storm increased three days after the accident. It created a greater danger to the damaged ship and the environment. The discharge operation of the fuel on the ship normally should be made shortly after the accident.

- As a result, many inconsistencies have been observed with regard to the response activities of the M/V Lady Tuna; these are deficiencies in the implementation of the response plans, inadequacy of the available response resources, delays in the collection and distribution of response resources as well as communication and coordination problems between institutions and authorities.

In the other phase of the study, the M/V Lady Tuna grounding accident was modelled with PISCES II and the following results are achieved;

- The trajectories of the spilled oil after accident showed that the oil spread under the effect of the SW wind direction and surface current on the sea.

- After 14 hours and 30 minutes following the accident, 72,5 tons fuel oil leaked from the ship’s tanks. Firstly, the oil stranded on the Paşalimanı coast (3,5 NM far away from the accident) about 12 hours later following the spillage. There is the nearest the coast towards SW the direction of the current and wind. And then, the oil slick continued to spread towards the Boyalık Bay, the Settur Çeşme Marina, the Radisson Blue Resort Hotel beach, the Ilıca Motel beach, the Yıldızburnu coast, the Sherotan Çeşme Hotel beach and the Ilıca public beaches.

- The spill statistics revealed that the evaporation and dispersion oil amount were very low rate dependent upon the nature of the oil (IFO 180, the heavy fuel oil) as well as the moderate sea state. Therefore the most of the oil slick on the sea stranded towards the Ildır coast.

- The main objective of the response operation following the oil spill incident is not to allow the oil to reach the coastline where it creates the most destruction to the environment. Therefore, one open water boom and two Oleophilic skimmers were deployed around the leak source after 3 hours from the spillage by one oilfield supply vessel. But, the spilled oil (about 15 tons) spread to seawater in three hours before the response resources deployed on the sea. So, the one J shape boom formation was deployed in the direction of the oil leak and moved with one Oleophilic skimmer towards the leakage source. The movement of the J shape boom formation was controlled by two oilfield supply vessels and it allowed the oil collecting by trawling.

- The simulation PISCES II showed a significant influence on the efficiency of oil spill recovery from the surface of the sea. The spill statistics revealed that 81,1 % of the spilled oil (58,8 tons) was recovered and the stranded oil was limited to 10 tons after the response operation was managed without losing time. Thus, the spilled oil didn't spread on the sea and cause less damage to the marine environment.

- Before the response operations are planned, the nature of the spilled oil, the effectiveness of the response resources and sea condition should be considered during the operation.

- So, the Oleophilic skimmers and Open Water Boom models were selected dependent upon the high viscosity of the spilled oil (IFO 180) and the sea state after the accident.

- In the case of early response to the oil spill following the accident; the response resources can be prepared by professional personnel within 1 hour after the accident notice. The response resources (the booms, the skimmers) can be reached the accident area by the supply vessels within one hour and the resources can be deployed on the sea within one hour. It means the response process can begin at the latest in 3 hours under the ideal conditions.

As a result, Turkey should take more serious steps concerning with response operation and preparedness for eliminating oil pollution in emergency incidences. The officials and the response operation companies should also consider the following;

- Transparent coordination and communication should be between the organizations and officials.

- It is necessary to urgently assess the situations like the behavior of the oil on seawater, the shoreline area impacted by oil and response strategies to take early action to prevent oil pollution.

- The transfer operation of the remained oil in the ship and salvage operation of the ship should be conducted as soon as possible.

- The personnel involved in the response operation should be professional and trained.

- To avoid delays in collection and distributing sources of response, they must be properly checked to assess their suitability and performance.

- The PISCES II and the other software programs are important for the coordinators managed the response operation. The simulation program has the most advantage of documenting pollution/spill statistics, the stranded oil amount to the shoreline, the time to oil reach the coast, efficiency rate of the response equipment.

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