Coastal & Marine Environment

Oil Pollution (Spill)

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1. What is an oil spill?

- An *oil spill* is a release of a liquid petroleum hydrocarbon into the environment due to human activity, and is a form of pollution.
- The term often refers to marine oil spills, where oil is released into the ocean or coastal waters. Oil spills include releases of crude oil from tankers, offshore platforms, drilling rig sand wells, as well as spills of refined petroleum products (such as gasoline, diesel) and their by-products, and heavier fuels used by large ships such as bunker fuel, or the spill of any oily substance refuse or waste oil.
2. Oil spill facts

• Spills may take months or even years to cleanup.
• Oil also enters the marine environment from natural oil seeps.
• Most human-made oil pollution comes from land-based activities, but public attention and regulation has tended to focus most sharply on seagoing oil tankers.
3. Sources of oil pollution

Sources of oil input to the marine environment are often divided into natural, sea-based and land-based sources. In some classifications, the oil pollution is divided into four main categories of sources: 1. discharges through natural seeps, 2. discharges during the extraction of oil, 3. discharges during the transportation of oil, and 4. discharges during the consumption of oil (including both sea-based and land-based sources).
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3. Sources of oil pollution (Natural Seeps)

- Crude oil seeps naturally out of fissures in the ocean seabed. These seeps are natural springs where liquid and gaseous hydrocarbons leak out of the ground.
- Oil and gas seeps are fed by natural underground accumulations of oil and natural gas.
- Natural oil seeps are used in identifying potential petroleum reserves.
- Natural oil seeps contribute the highest amount of oil to the marine environment, accounting for 46% of the annual load to the world's oceans.
- Although they are entirely natural, these seeps significantly alter the nature of nearby marine environments.
3. Sources of oil pollution

**SEA-BASED**
- Operational discharges
- Accidental discharges
- Air pollution

- Accidental oil spills from tankers; commercial vessels; grounded and abandoned vessels; oil platforms; pipelines.
- Operational discharges of oil from all kinds of commercial vessels; oil platforms; pipelines.
- Emissions of nm VOCs and PAHs from tankers and from oil extraction.
- Other ship-related activities (dry docking).
- Other activities (dumping of oily waste, etc.)

Non-methane volatile organic compounds (nm VOCs), Polycyclic aromatic hydrocarbons (PAHs)
3. Sources of oil pollution (SEA-BASED)

- **OPERATIONAL DISCHARGES**: Discharges of oil from shipping, offshore extraction of oil, and transport of oil in pipelines is the result of either accidents or "normal", deliberate operational discharges. **Operational discharges are mostly deliberate and “routine”, and can to a very large extent be effectively controlled and avoided.** It is much a question combining available technical solutions within formation, education and a change of attitude among ship-owners, mariners, offshore platform and pipeline operators.
3. Sources of oil pollution (SEA-BASED)

- ACCIDENTAL DISCHARGES (oil spills) occur when vessels collide or come in distress at sea (engine breakdown, fire, explosion) and break open, or run around close to the shore, or when there is a blow out of an offshore oil well, or when a pipeline breaks.

Much can be done to avoid accidents, but there will always be unfortunate circumstances and situations that cause accidents to happen.
3. Sources of oil pollution (SEA-BASED)

- **SPILLS FROM SHIPS** Accidents involving oil tankers or offshore platforms or oil pipelines have caused many and sometimes very large oil spills. Such spills are the most obvious, visible and dramatic causes of acute oil pollution of the marine environment. However, the largest oil spill ever was caused by Iraq deliberately released about 240 million gallons (about 800,000 tones) of crude oil into the Persian Gulf during the 1991 Gulf War and burnt oil wells in Kuwait.

- **LEAKAGES FROM SUNKEN, GROUNDED OR ABANDONED SHIPS** is another potential (and often very real) source of oil to the marine environment. These can be merchant or military vessels. Sunken vessels means just that — ships that have sunk to the bottom of the sea, generally due to an accident but sometimes also as the result of a deliberate action to get rid of them, these abandoned vessels become potential sources of oil pollution, from either chronic leaks or a large release once oil storage areas fail.

- **SPILLS FROM OFFSHORE DRILLING**
  - If an influx of pressurized oil or gas does occur during drilling, well control is maintained through the rig's blowout prevention system (BOP). This is a set of hydraulically operated valves and other closure devices (rams) which seal off the well, and route the wellbore fluids to specialized pressure controlling equipment. Trained personnel operating this highly reliable equipment minimize the possibility of a blowout, or an uncontrolled flow of fluids from a well".
  - However, it does not always work. the most typical causes of blowouts "include equipment failure, personnel mistakes, and extreme natural impacts (seismic activity, ice fields, hurricanes, and so on). Their main hazard is connected with the spills and blowouts of oil, gas, and numerous other chemical substances and compounds. The environmental consequences of accidental episodes are especially severe, sometimes dramatic, when they happen near the shore, in shallow waters, or in areas with slow water circulation.
3. Sources of oil pollution (SEA-BASED)

- **FROM SHIPS** Ship-related operational discharges of oil include the discharge of bilge (Lower part of boat) water from machinery spaces, fuel oil sludge, and oily ballast water from fuel tanks. Also other commercial vessels than tankers contribute operational discharges of oil from machinery spaces to the sea. Cargo-related operational discharges from tankers include the discharge of tank-washing residues and oily ballast water.

- **FROM OFFSHORE DRILLING**: Operational discharges in the offshore exploration for and extraction of oil and natural gas include operational wastes, such as drilling fluids/drilling muds, produced formation waters and formation cuttings, and machinery space discharges.

- **FROM OFFSHORE PIPELINES**: There is no certain figure of how many miles of offshore pipelines there is in the world today. One estimation, published in the 2002 U.S. National Research Council (NRC) report, is 82,748 miles (about 52,000 kilometres) of pipelines. Operational discharges from offshore oil pipelines usually consist of chemical discharges during construction, hydrostatic testing, commissioning, pigging, and maintenance of the pipeline systems. Pipeline discharges usually contain corrosion and scale inhibitors, biocides, oxygen scavengers, and other agents. However, pipelines can also continuously leak oil in small quantities, although the line is intact. (When a pipeline breaks, however, the spill will be an acute one, like any other accidental oil spill.)
Chapter 2: Offshore Drilling

Accident

On shore
3. Sources of oil pollution (LAND-BASED)

- Discharges of untreated or insufficiently treated **municipal sewage** and storm water (urban runoff).
- Discharges with rivers.
- Discharges of untreated or insufficiently treated **wastewater from coastal industries**.
- **Accidental or operational discharges** of oil from coastal refineries, oil storage facilities, oil terminals, and reception facilities.
- **Emissions of gaseous** hydrocarbons from oil-handling onshore facilities (terminals, refineries, filling stations) and from vehicles exhausts (traffic).
3. Sources of oil pollution (LAND-BASED)

- Oil discharged with **untreated or insufficiently treated municipal sewage and storm water** — urban runoff — comes from cars, machinery, spills at filling stations and garages, flushed-out residues of lubricants, etc. The storm water contains waterborne and airborne pollutants; everything that is flushed onto or falls down upon the hard surface will become constituents of the contaminated storm water: car exhausts, particles from worn tyres, small spills of oil from engines of different vehicles, small oil spills from garages, workshops, residues of oils and lubricants that we want to get rid of.

- Oil also enters the marine environment with **untreated or insufficiently treated waste water or storm water from various coastal facilities**: coastal industries, coastal refineries, coastal oil storage facilities, oil terminals, and reception facilities. Untreated storm water from ports, refineries, oil storage facilities, oil terminals etc. especially oil terminals, has a high oil content that originates from valves, pumps, loading ramps for vehicles, quays, etc.

- People pour untreated waste water and residues directly into **rivers** and the rivers bring the pollution, including the oil, to the sea.

- Consequently, a lot of oil goes literally down the drain from our towns and cities into the sea — either through a municipal sewage treatment plant, where it will harm the treatment process, or more or less untreated. When streets, roofs, handling areas in ports, and other hard surfaces are washed by rain and snow, the resulting waste water (storm water) is flushed into the general sewer system or into storm drains along roadsides. If the sewage treatment is adequate, the storm water and municipal sewage will both be treated. If no treatment plant exists, or treatment facilities are inadequate, the sewage, including the storm water, will be discharged into the sea more or less uncleaned.
3. Sources of oil pollution (AIR-BASED)

- **Volatile organic compounds** (VOCs) are a mixture of propane, butane and several other gases given off through the vaporization of crude oil and refined products, such as petrol. VOCs are usually divided into non-methane (nmVOCs) and methane. As soon as petroleum is handled in the open air, vapours escape unless something is done to contain them. These hydrocarbons in gaseous form can be emitted into the atmosphere from platforms (extraction of oil), tankers (transportation of oil), terminals (loading and unloading of oil), filling stations (petrol tanking) refineries (processing of oil), pipelines (leakages of oils and gas), and aircraft (refueling and fuel dumping). Hydrocarbon vapours can be recovered and "recycled" as liquid fuel. They are collected and condensed when petroleum products are being loaded and unloaded at terminals, refineries and petrol stations.

- **Polycyclic aromatic hydrocarbons** (PAHs) include around a hundred of the petroleum hydrocarbons and are natural constituents of oil. When fossil fuels are burnt, especially on a small scale when combustion is often incomplete, PAH compounds form and escape to the atmosphere or to water. PAHs occur both in gaseous form and bound to particles (soot). Large amounts of PAHs are emitted from recreational vessels due to inadequate fuel combustion in two-stroke (outboard) engines.
3. Sources of oil pollution (AIR-BASED)

- **FROM SHIPS AND BOATS**

  **Tankers:** When crude oil is unloaded from a tanker, the cargo tanks will contain a mixture of gases, including VOCs. When the tank is filled again with crude oil, the gases are vented to the open air. However, with new technology the VOCs can be condensed and recovered and used as tanker fuel (instead of the much "dirtier" bunker fuel). In other words, when an oil tanker is making a delivery, vapours that escape will be captured and go back into the tanker. On board a tanker, emissions of VOCs can be controlled by allowing a slight overpressure in the tanks.

- **Pleasure craft:** Two-stroke petrol outboard engines are popular and common in pleasure craft (recreational vessels, leisure craft). It is a compact, simple engine which requires little maintenance. In relation to its weight, the two-stroke outboard engine generates much power. It is reliable in operation and comparatively cheap. From an environmental point of view, however, these engines are bad news. They are extremely fuel-consuming due to low thermal efficiency and cause high emissions of uncombusted hydrocarbons (PAHs) and carbon monoxide. The PAHs virtually "disappear" into the water stirred up by the propeller and get dissolved in the water, i.e., transformed from air pollutants to water pollutants. Considerable damage is caused by these hydrocarbon compounds to water-living organisms (to which they are toxic), especially in shallow coastal areas which serve as marine "nurseries".
3. Sources of oil pollution (AIR-BASED)

**FROM OFFSHORE DRILLING**
Activities that cause air pollution (VOCs, methane, carbon dioxide, and nitrogen oxides) from offshore installations include gas venting on shuttle tanks when oil is loaded onto these tanks for transport, as well as gas flaring, gas turbine exhausts, diesel or fuel exhausts, well testing and diffuse emissions from the platform and drilling place. About two-thirds of the air pollutants are VOCs and they mainly derive from the offshore storing and loading of crude oil. About 70 per cent of the VOCs can be recovered (see above).

**FROM TERMINALS AND REFINERIES**
Crude oil is transported to an oil terminal — a land-based facility which receives and stores crude oil and other products from offshore oil production — by ship or pipeline. In port, at the terminal, it is technically possible to recover hydrocarbon vapours.

**FROM AIRCRAFT**
Human activities causing atmospheric deposition of hydrocarbons on the sea include military and commercial jets that occasionally jettison excess fuel over the ocean.
Chapter 2

Gaza area 130 sq miles

Mousse: قشدة
Cling: يتشبث
Slick: بقعة زلقة

4. Environmental effects

- When oil is spilled or leaked into water ways and the ocean, it spreads very quickly with the help of *wind and currents*. A single gallon of oil can create an oil slick up to a couple of acres in size! The BP oil slick had spread over **580 square miles** in just three days.

- When oil starts mixing in water, it can change composition and becomes what's known as "mousse". This is a sticky substance that clings even more to whatever it comes in contact with. Many marine animals don't know to avoid a slick and some fish may even be attracted to it as it can resemble food.
4. Environmental effects

- Some of the many effects on animals coming into contact with crude oil include:
  - Hypothermia and drowning of birds as the oil breaks down the insulating capabilities of feathers, makes them heavier and compromises flying ability
  - Hypothermia in some seal pups as the oil destroys insulating fur
  - If oil is ingested, it can either poison the animal outright, make them extremely sick or create a level of toxins in their system that then causes poisoning further up the food chain. Birds and other animals often ingest oil when trying to clean themselves. Shellfish and corals are particularly at risk in these scenarios as they cannot escape from an oil slick.
  - Damage to the airways of birds and animals.
  - Damage to animal immune systems
  - Interruption of breeding and fouling of breeding grounds
  - Thinner bird and turtle egg shells and also damage to fish larvae, causing deformities
  - Damage to sea grass beds and other shelter/feeding areas
  - Tainting of algae, which perform a vital role in waterway ecosystems
4. Environmental effects

- Even once the oil appears to have dissipated, it can still lurk beneath the surface of beaches and the seabed, severely affecting marine organisms that burrow, such as crabs, for literally decades. These burrowing creatures are also food for other animals, so the cycle of poisoning continues for many years.
- There's really no aspect of a marine and coastal environment that is not in some way adversely affected by an oil spill. The closer the spill occurs to the shoreline, the more pronounced the damage will be due to coastal zones being home to more concentrated and diverse populations of marine, bird and animal life than far out to sea.
5. Methods of clean up

- Biological
- Chemical
- Physical (or Mechanical)
Biological methods

In nature, many microorganisms such as bacteria and fungi break down oil into a harmless substance. Biological agents are chemicals or organisms that speed up the rate of the biological breakdown of oil. These microorganisms and agents are being researched and have the potential to provide clean-up in sensitive areas such as shorelines and wetlands without further harming the environment.

Photo by NOAA
Special chemicals such as soaps are called dispersants and can be used to break up or dissolve oil. Also, gelling agents are used to react with oil to form a rubbery solid which can then be removed from the water. Another chemical method is simply burning the oil off of the surface. However, because burning and special chemicals might hurt the environment and living organisms, these methods are not the best choice along coastlines or populated areas.
Physical mechanical methods

These methods involve physically removing the oil from the water. Typical examples of this include using large vacuums, skimmers, and substances to soak up or absorb oil. These are often used along with the large booms that keep the oil in one place.
Booms are commonly first used to hold oil in one place so that it is easier to clean. Once the spread of oil is controlled, environmental scientists can choose from three major methods for oil clean-up: Biological, Chemical, and Physical/Mechanical.

**Response Equipments**

**BOOMS**

**Skimmer**

**Vacuum**
6. Case study
Gulf of Mexico oil spill

• The *Deep water Horizon oil spill* is an oil spill in the Gulf of Mexico which flowed for three months in 2010. The impact of the spill continues even after the well was capped. It is the largest accidental marine oil spill in the history of the petroleum industry. The spill stemmed from a sea-floor oil gusher that resulted from the April 20, 2010 explosion of *Deep water Horizon*. The explosion killed 11 men working on the platform and injured 17 others. On July 15, the leak was stopped by capping the gushing well head, after it had released about 4.9 million barrels (780 $\times$ $10^3$ m$^3$), or 205.8 million gallons of crude oil. It was estimated that 53,000 barrels per day (8,400 m$^3$/d) were escaping from the well just before it was capped. It is believed that the daily flow rate diminished overtime, starting at about 62,000 barrels per day (9,900 m$^3$/d) and decreasing as the reservoir of hydrocarbons feeding the gusher was gradually depleted. On September 19, the relief well process was successfully completed.
6. Gulf of Mexico oil spill

- The spill caused extensive damage to marine and wild life habitats as well as the Gulf's fishing and tourism industries. In late November 2010, 4,200 square miles (11,000 km²) of the Gulf were reclosed to shrimping after tar balls were found in shrimpers‘ nets. The total amount of Louisiana shoreline impacted by oil grew from 287 miles (462 km) in July to 320 miles (510 km) in late November 2010. In January 2011, an oil spill commissioner reported that tar balls continue to wash up, oil sheen trails are seen in the wake of fishing boats, wetlands marsh grass remains fouled and dying, and that crude oil lies offshore in deep water and in fine silts and sands onshore. A research team found oil on the bottom of the seafloor in late February 2011 that did not seem to be degrading.
6. Gulf of Mexico oil spill

• Skimmer ships, floating containment booms, anchored barriers, sand-filled barricades along shorelines, and dispersants were used in an attempt to protect hundreds of miles of beaches, wetlands and estuaries from the spreading oil. Scientists have also reported immense underwater plumes of dissolved oil not visible at the surface as well as an 80-square-mile (210 km²) "kill zone" surrounding the blown well.
Proper disposal of used oil

- Put your used oil in a clean plastic container with a tight lid. Do not mix it with any thing else – paint gasoline, solvents, anti-freeze, etc. – that will make it unsuitable for recycling. Take your used oil to a recycling center that collects used oil, a service station, quick lube, or any location that accepts used oil.

- **Illegal Disposal Practices**
  Pouring used oil down a drain. Pouring used oil into a storm sewer. Tossing used oil on your driveway, street or the ground. Disposing of oil in lakes, streams or wetlands. Spreading oil to suppress dust or kill weeds Burning oil outdoors.
7. Oil spill modeling

Governing equations

1. Momentum Equations

\[
\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} - f_v = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \varepsilon_h \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) + \left( \varepsilon_v \frac{\partial^2 u}{\partial z^2} \right)
\]

\[
\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} + f_u = -\frac{1}{\rho} \frac{\partial p}{\partial y} + \varepsilon_h \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) + \left( \varepsilon_v \frac{\partial^2 v}{\partial z^2} \right)
\]

\[
0 = -\frac{1}{\rho} \frac{\partial p}{\partial z} - g
\]

2. Continuity Equation

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0
\]

\[
\frac{\partial \eta}{\partial t} = -\frac{\partial}{\partial x} \int_{-h}^{u} udz - \frac{\partial}{\partial y} \int_{-h}^{v} vdz
\]
7. Oil spill modeling

Governing equations

3. Surface boundary conditions

Wind shear stresses

\[
\frac{\tau_{sx}}{\rho_{water}} = \varepsilon_v \frac{\partial u}{\partial z} = \frac{\rho_{air}}{\rho_{water}} c_s W_x \sqrt{W_x^2 + W_y^2}
\]

\[
\frac{\tau_{sy}}{\rho_{water}} = \varepsilon_v \frac{\partial v}{\partial z} = \frac{\rho_{air}}{\rho_{water}} c_s W_y \sqrt{W_x^2 + W_y^2}
\]

Sea temperature

\[
K_s \frac{\partial T}{\partial z} = Q_T
\]
7. Oil spill modeling

Governing equations

4. Spill advection-diffusion equation

\[
\frac{\partial C}{\partial t} = -u \frac{\partial C}{\partial x} - v \frac{\partial C}{\partial y} - w \frac{\partial C}{\partial z} + \varepsilon_h \left( \frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} \right) + \varepsilon_v \left( \frac{\partial^2 C}{\partial z^2} \right) + \omega C + \sum S_m
\]

in which

- \( u, v, w \) are the water velocity components in \( x, y \) and \( z \) directions;
- \( C \) is the oil droplet concentration;
- \( \varepsilon_h \) and \( \varepsilon_v \) are the mixing coefficients in horizontal and vertical directions;
- \( \omega \) is the buoyant velocity of oil droplet.
- \( \sum S_m \) is the effective source term.

\[
\omega = \frac{1}{18} \frac{\rho_w - \rho_o}{\rho_w} g \frac{d^2}{\nu}
\]

where \( \rho_w \) and \( \rho_o \) are the mass densities of water and oil, respectively;

- \( \nu \) is the kinematic molecular viscosity;
- \( d \) is the particle size of oil droplet.

In the surface layer, \( \sum S_m \) can be expressed as:

\[
\sum S_m = -S_e - S_d + E_m
\]

where \( S_e \) and \( S_d \) are the rates of evaporation and dissolution/unit area of surface oil; \( E_m \) is the effect on the distribution of surface oil due to emulsification.
GNOME (General NOAA Operational Modeling Environment) is the oil spill trajectory model used by OR&R Emergency Response Division (ERD) responders during an oil spill. ERD trajectory modelers use GNOME in Diagnostic Mode to set up custom scenarios quickly. In Standard Mode, anyone can use GNOME (with a Location File) to:

- predict how wind, currents, and other processes might move and spread oil spilled on the water.
- learn how predicted oil trajectories are affected by inexactness in current and wind observations and forecasts.
- see how spilled oil is predicted to change chemically and physically ("weather") during the time that it remains on the water surface.

To use GNOME, you describe a spill scenario by entering information into the program; GNOME then creates and displays an oil spill "movie" showing the predicted trajectory of the oil spilled in your scenario. Along with GNOME, most users also will want to download the Location Files for their regions of interest. Location Files contain prepackaged tide and current data and make it easier to work with GNOME.
Coastal & Marine Environment

GNOME NOAA Model

Go to NOAA website / GNOME page [click here]

Wind speed and direction

Oil spill location
Chapter 2

Coastal & Marine Environment

After 1 day

90km
After 3 days

200km
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Anonymous lecture on oil pollution – unit 4
http://www.epa.gov
http://www.noaa.gov