Properties, Fate, and Behavior of Spilled Oil

Northwest Oil Spill Control Course
August 23, 2021

Tom Coolbaugh
Program/Facility Manager
Ohmsett Facility
tcoolbaugh@ohmsett.com
732-866-7285
www.ohmsett.com

Objective

To introduce the fundamentals of spilled oil characteristics, fate, and behavior

Topic Overview

Oil mass balance

- Oil properties
- Spreading
- Oil weathering

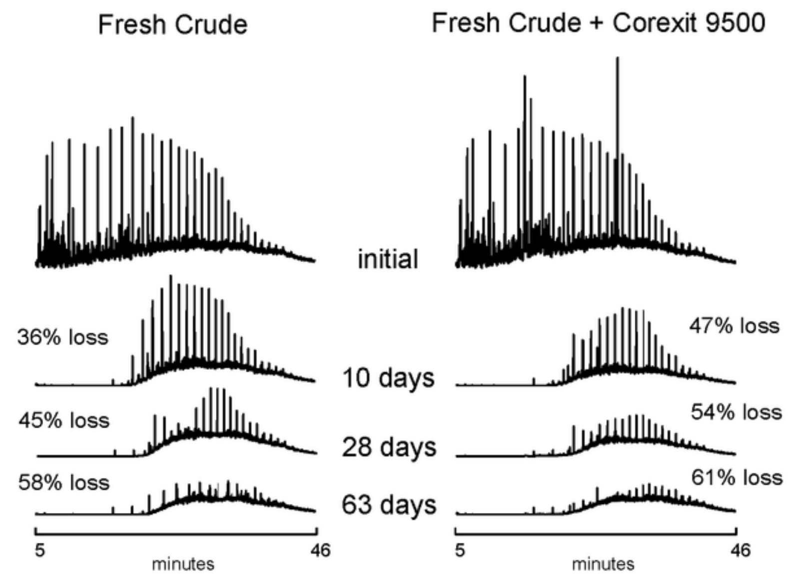
Oil transport

- Winds
- Currents
- Turbulence

Oil Properties

Crude oil is a mixture of complex organic and inorganic compounds

- Crude oil primarily consists of chains of carbon and hydrogen, known as hydrocarbons
- Inorganic compounds in crude oil include sulfur, lead, and numerous other components



Safety Data Sheet

1. Identification

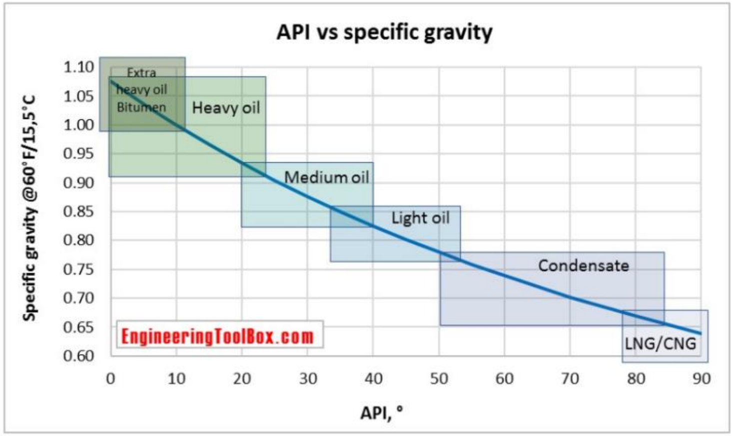
Product Name:	Crude Oil (Sweet)
Chemical Family:	Petroleum Hydrocarbon Mixture
Manufacturers Name:	Whiting Oil and Gas Corporation
Address:	1700 Broadway, Suite 2300 Denver, Colorado 80290
Product Use:	Feedstock for petroleum and petrochemical refining.
Phone Number for Information:	(303) 837-1661
Emergency Phone Number:	(800) 424-9300 (Chemtrec)

Crude oil is a complex mixture of paraffinic, cycloparaffinic and aromatic hydrocarbons covering carbon numbers ranging from C1 to over C60. It is amber to black in color. Crude oil contains small amounts of sulfur, nitrogen and oxygen compounds as well as trace amounts of heavy metals.

Density, Specific Gravity, and API Gravity

- Density is mass per unit volume (~1.03g/cm^3 for saltwater, i.e., 30 ppt salt)
- Specific gravity (SG) is the ratio of the mass of the material to the mass of freshwater, for the same volume and temperature
- API gravity is routinely used by the U.S petroleum industry

API Gravity = (141.5ºC/S.G.) - 131.5ºC

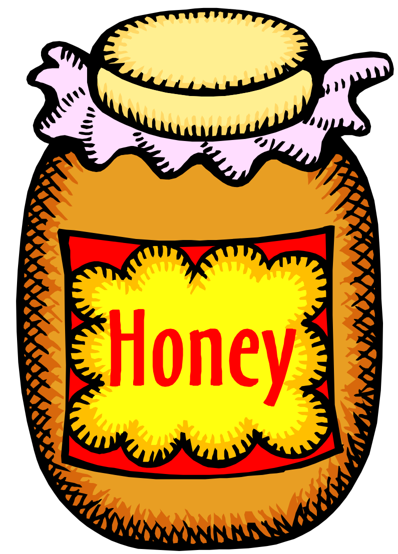


API Gravity: Heaviness compared to water

- Freshwater has an API gravity of 10.0
- Saltwater has an API gravity of 6.0
- Would you expect an oil with an API gravity of 25 to float or sink in saltwater?

Viscosity: “Flowability”

- Viscosity decreases with an increase in temperature - it also increases as the oil weathers
- Often expressed in “centistokes” (cSt) or “centipoise” (cP), in both cases, the higher the number, the higher the viscosity
- You can expect an order of magnitude change in the viscosity if the temperature change is about 40^{o}C (100^{o}F)



Viscosity Examples

Liquid	**Viscosity (cP)**
Water	1
Diesel fuel	10
Light machine oil or olive oil	100
Glycerin or castor oil	1,000
Honey	10,000
Molasses	100,000
Lard or shortening	1,000,000

Ohmsett

Viscosity Examples

- Remember, you can expect an order of magnitude change in the viscosity if the temperature change is about 40ºC (100ºF).
- For example, if an oil has a viscosity of 8,600 cSt at 50ºC, what is the viscosity at 10ºC?
- As it gets colder, oils become more viscous.
- When transported, oils are often heated.

Pour Point

- The lowest temperature below which the liquid can not be poured (no movement observed)
- Similar to melting point
- Measurement can be highly variable (plus or minus 10^{0}F)

Pour Point

If the water temperature off Seattle is 48°F, which of these oils will likely form a thin, surface film (slick)?

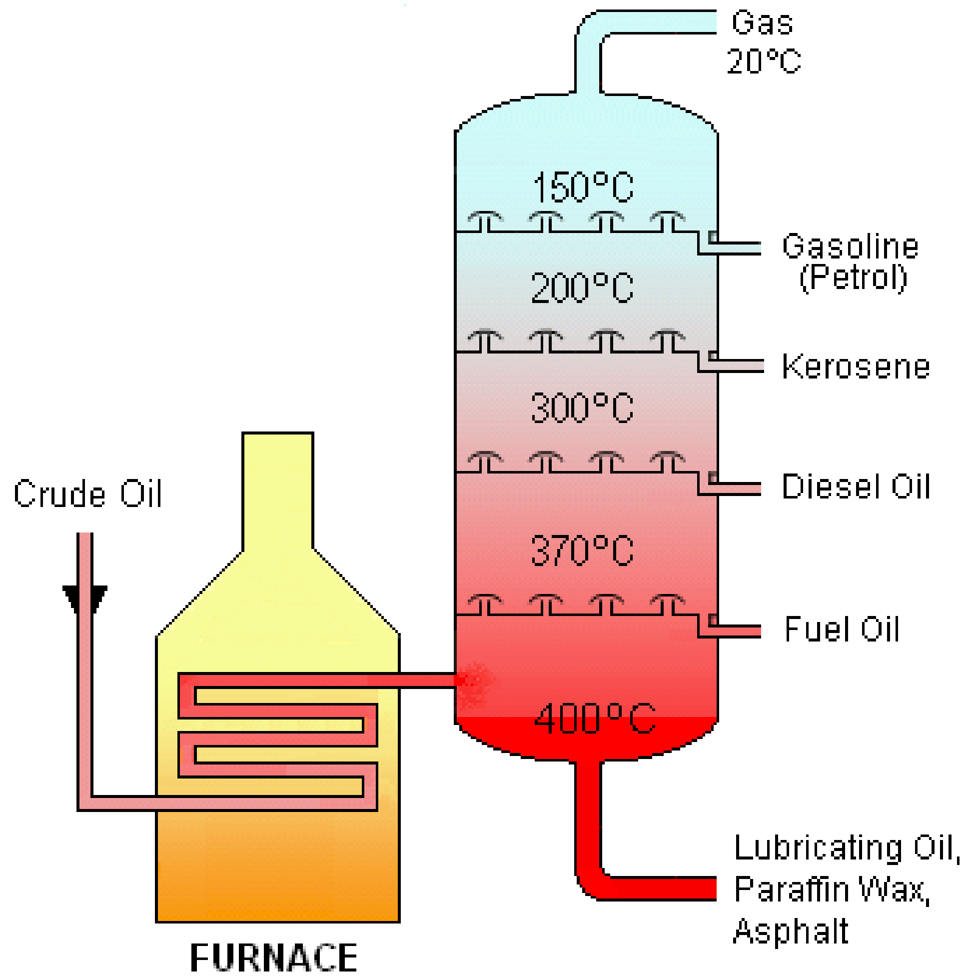
Product	API	Pour Point
• Diesel	34	5° F
• Prudhoe Bay	25	32° F
• Boscan (Venezuela)	10	50° F

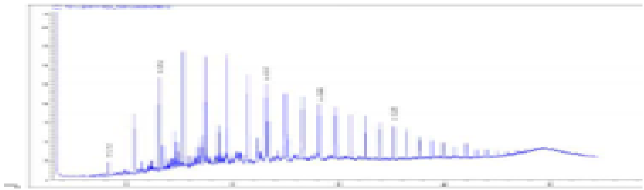
Marine Diesel

- **Recreational marine operators use off-highway 2D diesel and on-highway 2D (truck, tractor diesel and home heating oil)**
  - 2D fuel is used in warmer weather because it has a higher viscosity and pour point
- **Generally, off-highway diesel has a red-tint to identify that it has no highway taxes**
- **Commercial marine operations are primarily distillates, intermediate and residual oil**

Refining

- Crude oil is separated into fractions by fractional distillation
- Fractions at the top of the column have lower boiling points than those at the bottom
- Fractions are processed further in other refining units





QUIZ!

- Freshwater has an API gravity of __?
- For reference, oil pour point is 20^0F and the water temperature is 10^0F. Will spilled oil likely form a thin film?

What happens to oil when it is spilled?

- **Spreading**
- **Fate (Weathering)**
- **Behavior**
  - Currents
  - Wind
  - Turbulence

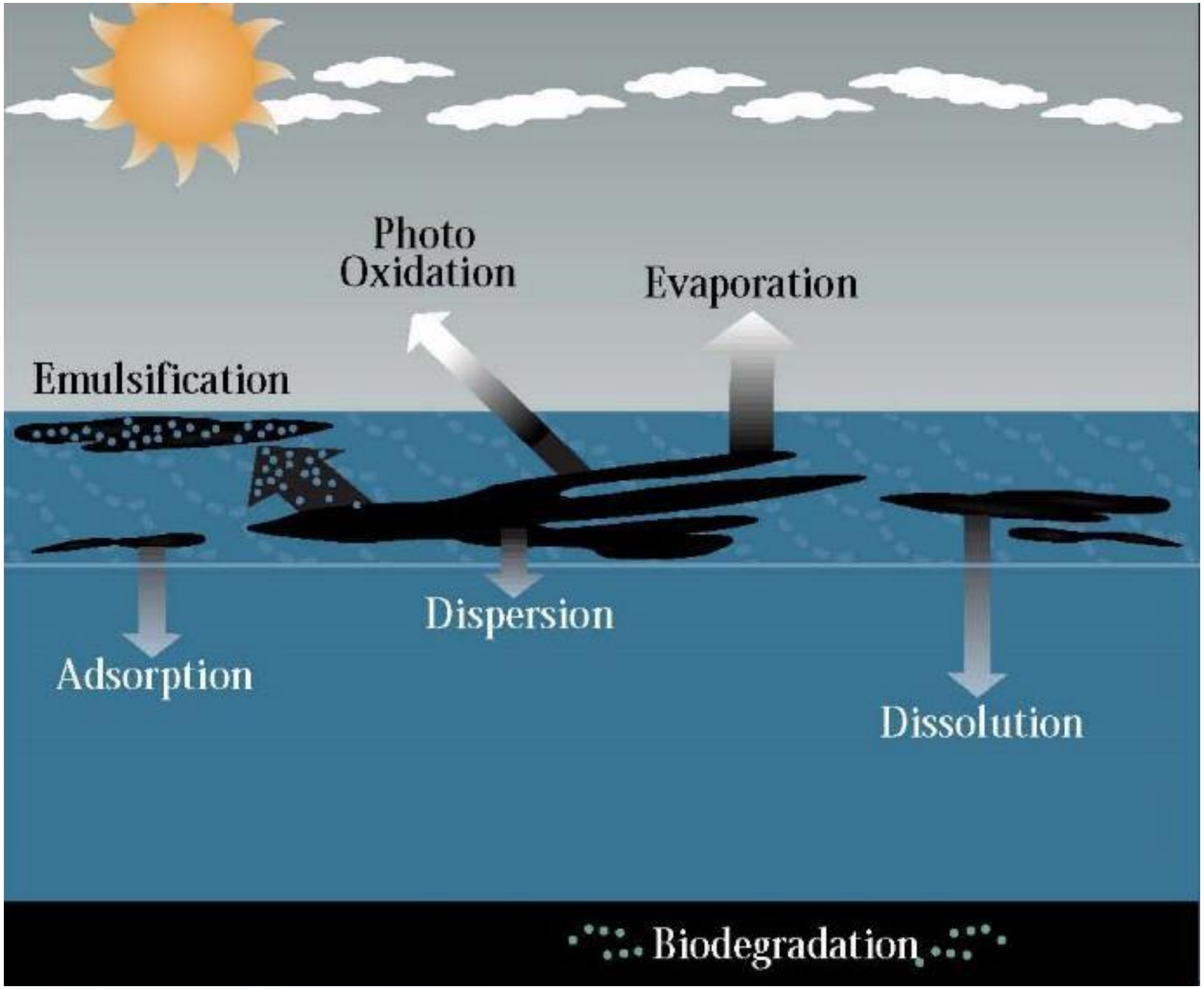
- **Spreading occurs in the first few minutes to hours of the spill**

- **90% of the oil may be in 10% of the slick**

Oil Fate (Weathering)

- Oil changes its chemical and physical properties almost immediately when spilled in the water.
- This is due to oil spreading, evaporation, dispersion, emulsification, dissolution, oxidation, oil-particle interaction and biodegradation.
- Eventually, the amount of oil in the slick decreases overtime.

Oil Weathering Processes

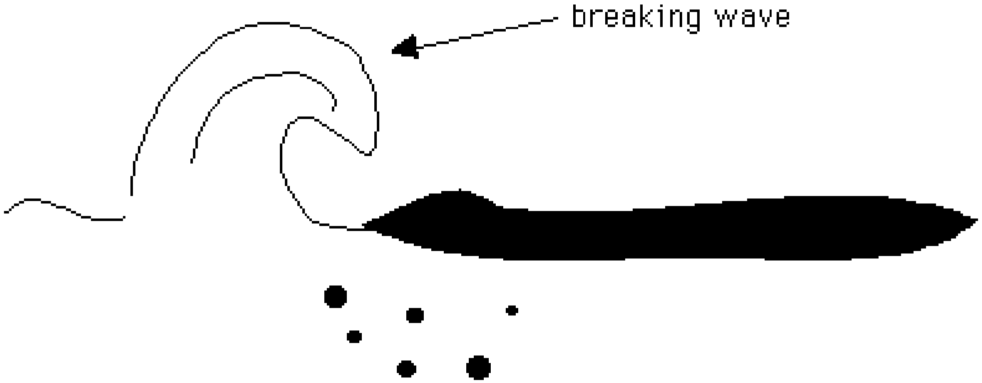


Evaporation

- Major mechanism for removing oil
- Changes the physical properties of the remaining oil
- Depends on oil properties, water temperature and wind speed
- Alaska North Slope crude (10 knot wind, 100 bbl) ~30% evaporation
- Gasoline ~99% evaporation

Dispersion

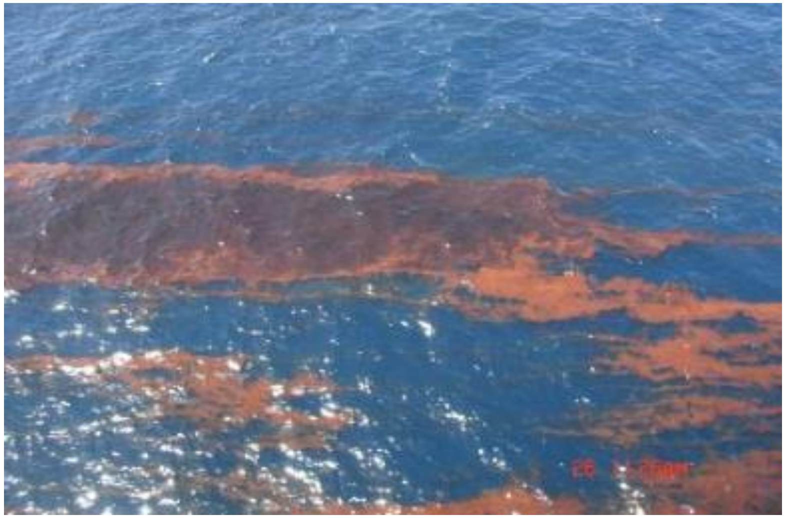
- **Other major removal mechanism**
- **Increase viscosity decrease in dispersion**
- **Droplets 50 to 70um in diameter are not likely to resurface due to turbulence (about the thickness of a human hair)**



Ohmsett

Emulsification

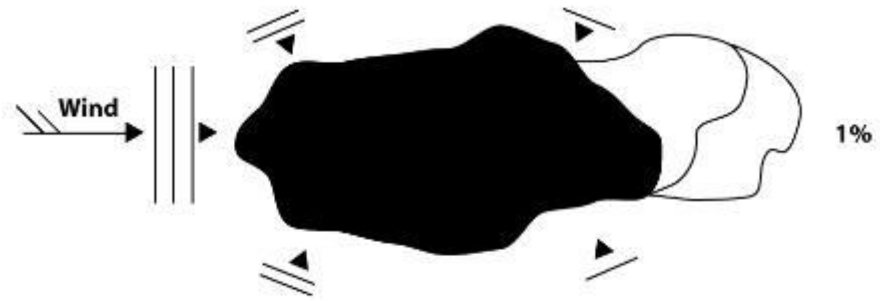
- **Oils with high wax and asphaltene content are more likely to emulsify (asphaltene + wax) >5%**
- **Oil must "weather" a certain amount before forming a stable emulsion**
- **There are "stable" and "non-stable" emulsions**
  - If energy is removed from a stable emulsion, it generally stays as an emulsion
  - Not true with non-stable emulsions
- **Emulsions can be 70% to 90% water**

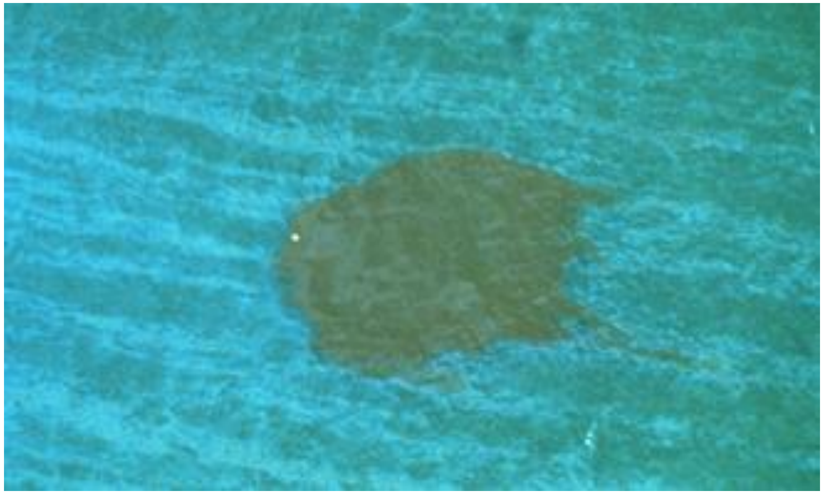


As oil weathers…

- Density increases slightly but oil likely remains buoyant
- Viscosity can increase by orders of magnitude
- Oil film may form crust (skinning), physical barrier

"Weathered oil - pancake"





- Oil is no longer fresh and continues to break down, creating "pancakes"

Eventually the oil forms tarballs…

...that are difficult to track by air and boat

Ohmsett

Oil Weathering: Timeline

- **Evaporation** (less than 5 days)
- **Dispersion** (less than 5 days)
- **Dissolution** (less than 5 days)
- **Emulsification** (can be delayed for days, but the emulsification process can be rapid)
- **Sedimentation** (depends on conditions)
- **Photo-oxidation** (begins immediately)
- **Biodegradation** (microbes are first responders)

Transport: All the factors that “move” oil around

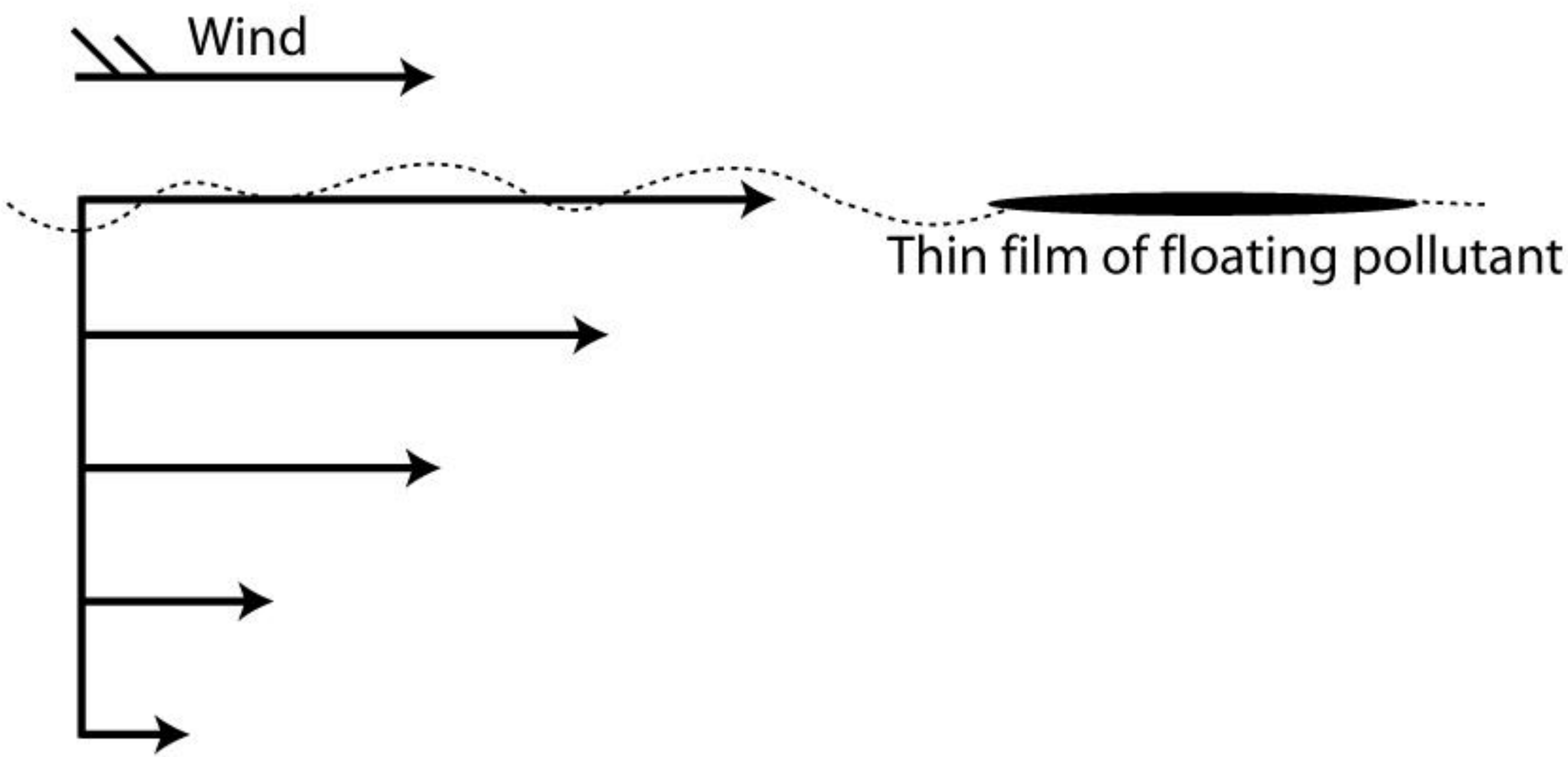
- Advection: movement of a mass or fluid
- Winds, currents, and turbulence are advection mechanisms that can transport oil great distances


26 1:17PM

Wind and Current

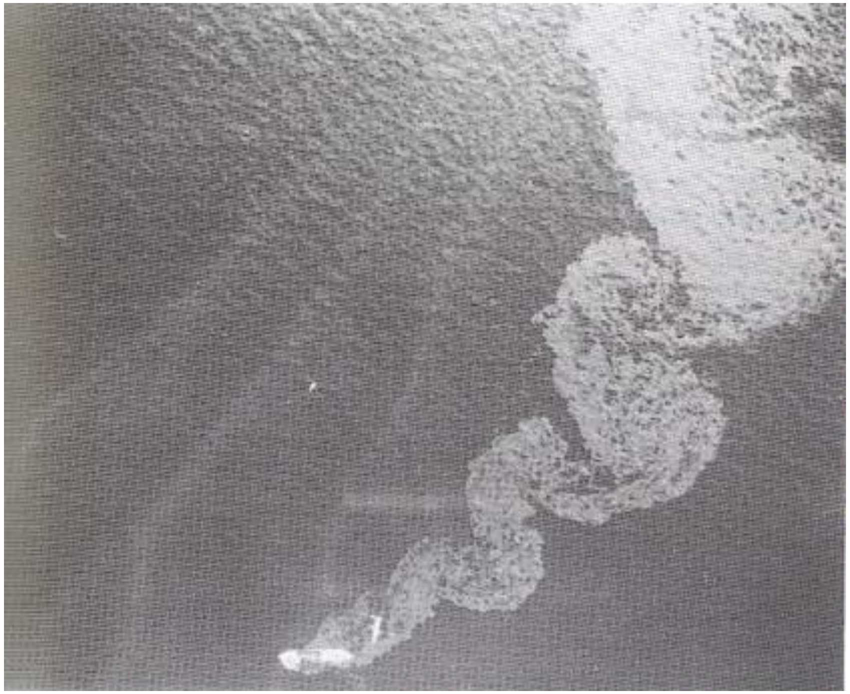
- Oil typically moves at 1 to 6% of the wind speed
- Most modelers use 3% of the wind speed
- In open water, the angle between the surface current and wind is generally 10° or more
- Wind direction predictions are typically not this accurate and few modelers include a rotation angle

Wind and Current

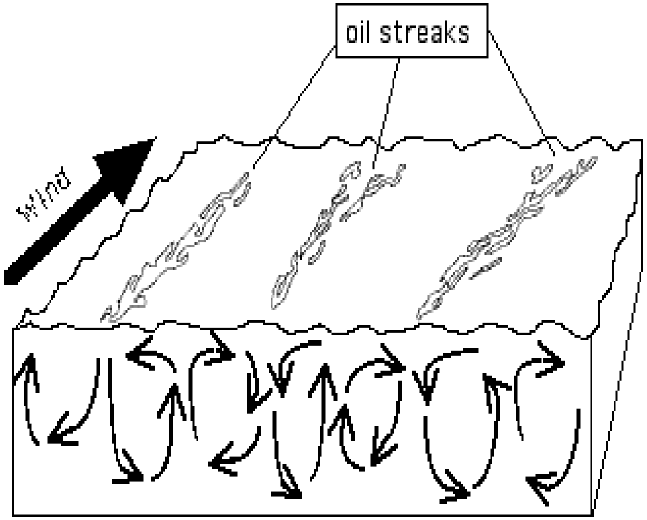


What processes interact with a “slick”?

Turbulence



Langmuir Circulation




SCIENCE

SURFACE MOTION OF WATER INDUCED BY WIND

Langmuir, I., Surface Motion of Water Induced by Wind, *Science,* 87: 119-123, 1938

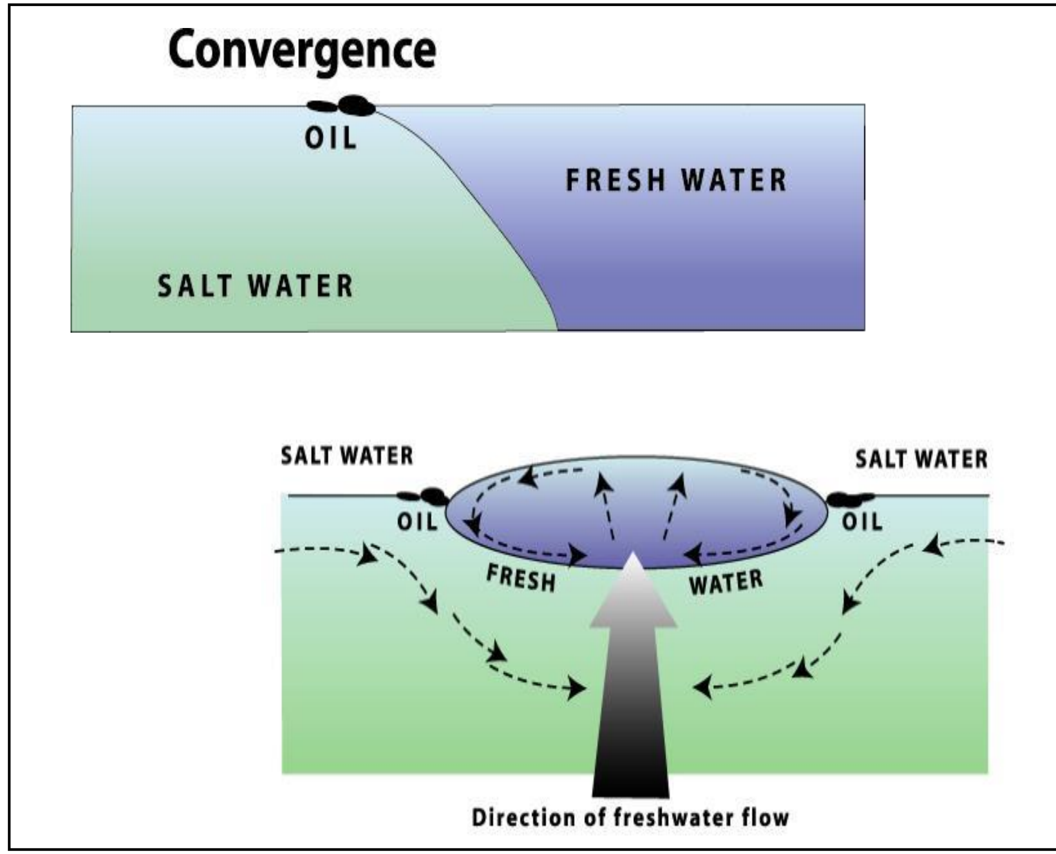
Over time, the slick fragments into smaller and smaller pieces

Surface oil can persist over large distances and concentrate in convergence zones

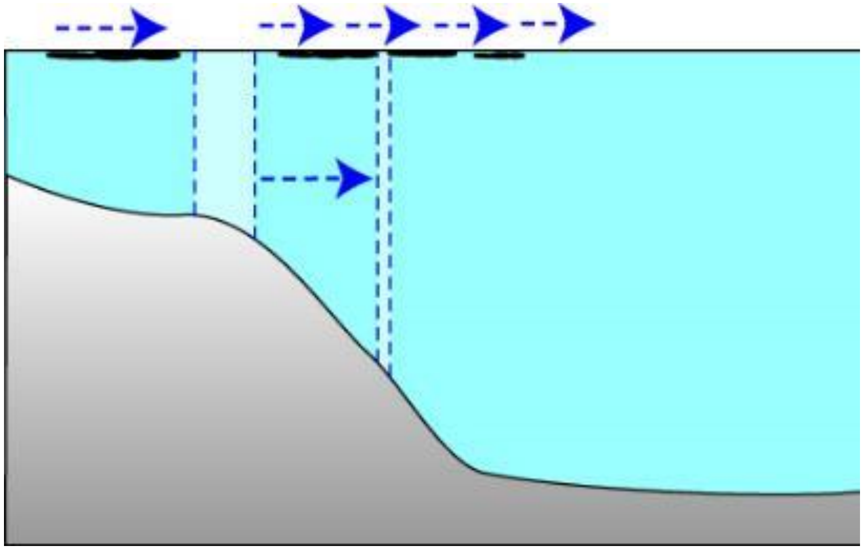
- **Animals may concentrate and feed in convergence zones**

Ohmsett

Convergence zones

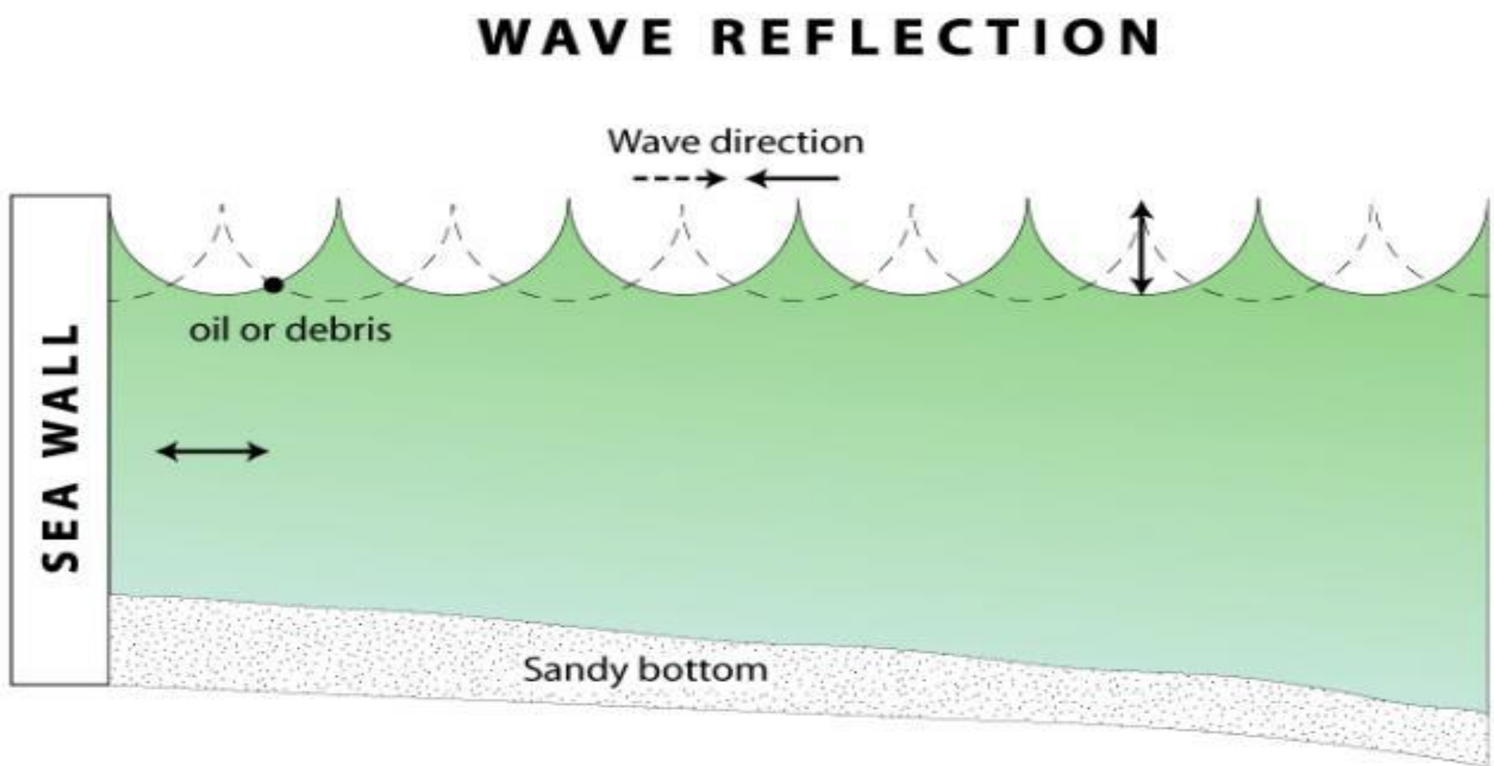


Bathymetry and Convergences



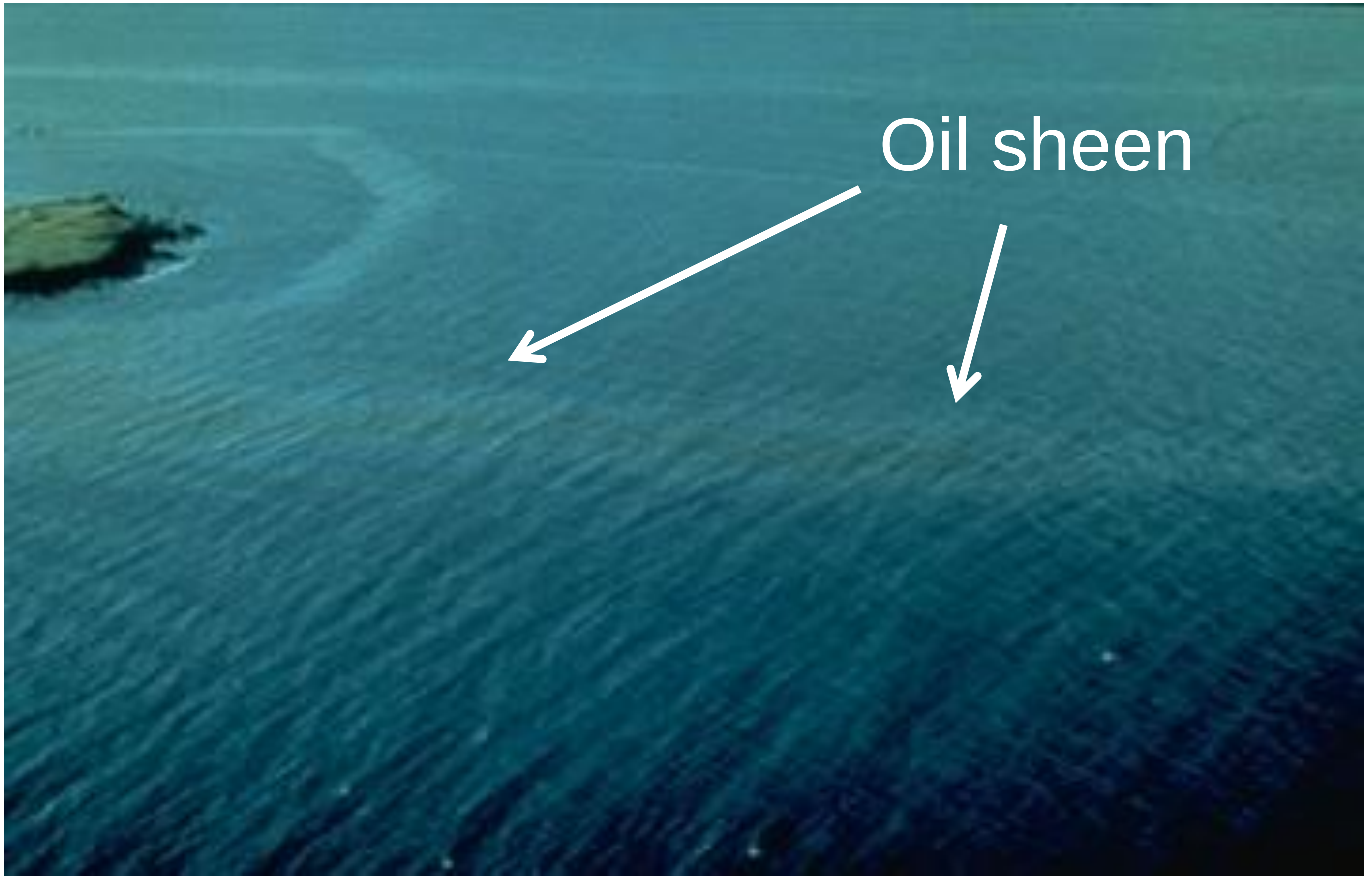
Surface convergence

Wave Reflection



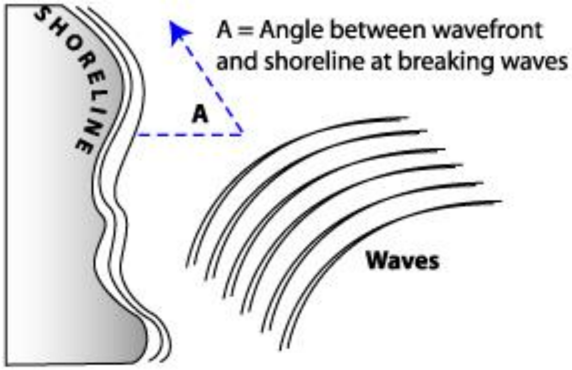
Wave reflection from a vertical wall
(Modified from Bascom, 1980)

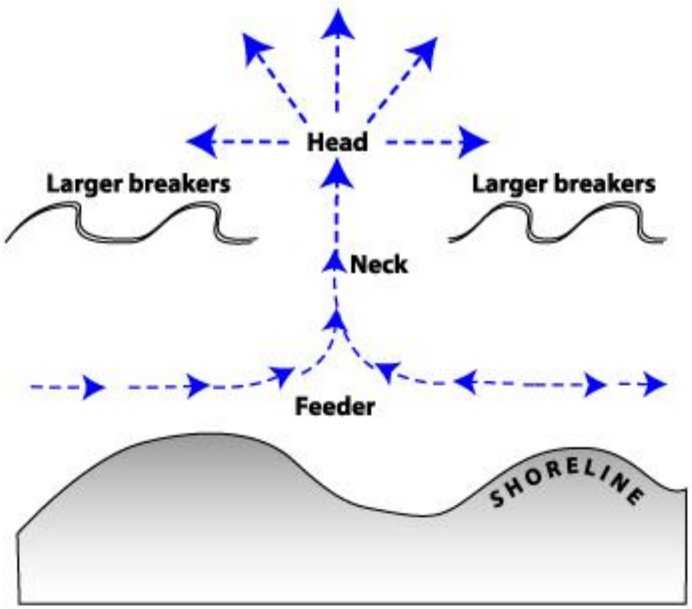
Wave Reflection



Rip Currents

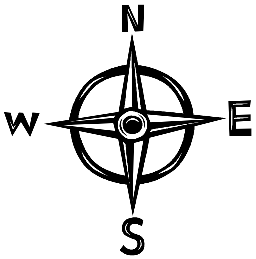
- **Longshore currents**
  - ~0.3 to 1.0 m/s
  - ~1.5 m/s approaching neck (difficult to walk)
- **Important mechanism for transporting oil in nearshore areas beyond breakers and offshore**



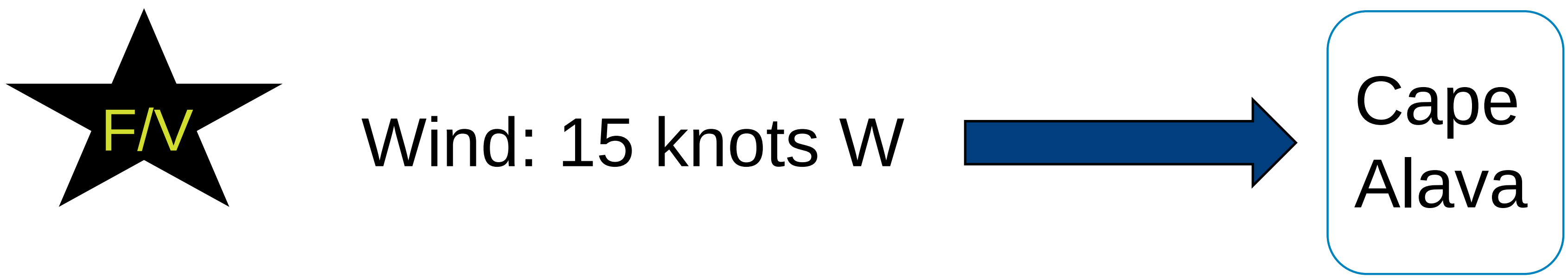


Rip Currents

Tying it all together



- **We've discussed how oil acts when it is spilled on water.**
  - Now let's wrap up with a basic example of the fate of oil…



- **Situation: A F/V has spilled 1000 barrels of diesel 10 nautical miles offshore Cape Alava. The wind is 15 knots from the W – assume that is the transport mechanism**
- **Would you expect to see a shoreline impact?**

NOAA's Automated Data Inquiry for Oil Spills (ADIOS)

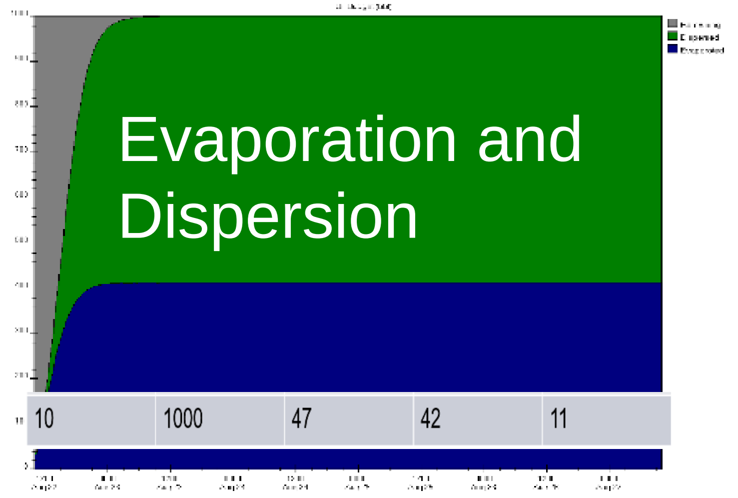
Hours into spill	Released bbl	Evaporated percent	Dispersed percent	Remaining percent
2	1000	9	2	89
3	1000	17	4	79
4	1000	25	8	68
5	1000	31	13	56
6	1000	36	19	44
7	1000	40	26	33
8	1000	43	33	24
9	1000	45	38	17
10	1000	47	42	11

Back to the scenario…

- 1000 barrels of diesel spilled 10 nautical miles (nm) offshore. The wind is 15 knots from the W.
- Would you expect to see a shoreline impact?
  - 15 knots * 3% = 0.45 kts
  - The diesel is moving at 0.45 kts and has 10 nm to go
  - Time = Distance/Speed
  - 10 nm/0.45 kts = 22.2 hours to reach shore

How quickly will the diesel evaporate and disperse?

Remember @ 10 hours, 89% was no longer on the water surface



Conclusion

- Oil changes its physical characteristics over time
- Winds, currents and turbulence affect the behavior and movement of an oil spill
- As a spill progresses, oil is not a cohesive slick rather it is distributed over a wide area
- Because oil usually floats on the surface, it can re-coalesce in areas of surface convergence
- In general, the quicker a spill response can be initiated, the more positive (or less negative) the outcome