PROBABILITY AND OIL SPILL TRAJECTORY ASSESSMENTS IN ASSET LIFE EXTENSION PROJECTS:

SESSION 10: SHIPPING RISK 2

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22 June 2022

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MAKING COMPLEX EASY

Outline

- Framing the Problem
- Probability Assessment
- Consequence Assessment
- Informing EIA, EIS, NEBA/SIMA, and OSRP

Setting the Stage

- Energy Transition
  - Climate and CO_2 focus
  - Transition to renewables
  - Decreasing oil production
  - But it takes time… decades?

- Aging Offshore Infrastructure
  - Many companies moving towards decommissioning
  - Some investing in Asset Life Extension

An aging oil drilling rig in the North Sea. Photo Credit: Erik Christensen

- Examples
  - North Sea: Equinor Statfjord Area & Troll East and West
  - Newfoundland: Suncor Terra Nova & Husky White Rose

Setting the Stage

- **Complex Global market**
  - **Increasing energy demand**
  - **Covid-19**
  - **Ukraine Crisis**
  - **Uncertainty**
  - **Many, many more**

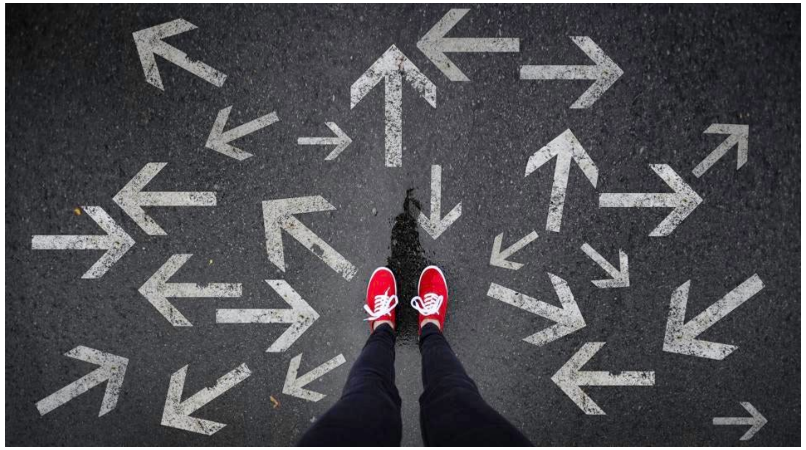


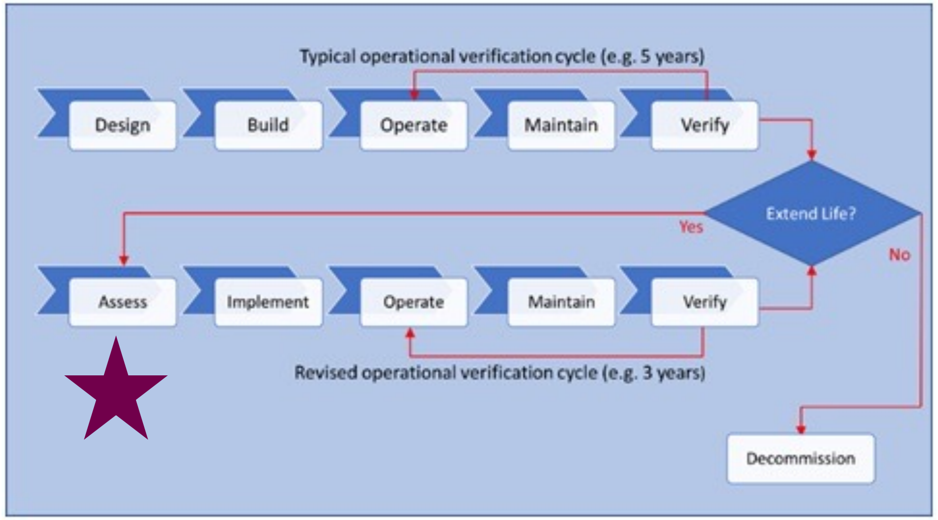
Photo Credit: Getty

Brent Crude Oil USD/Bbl over the last 10 years

Photo Credit: Trading Economics.com

Framing the Problem

- **Operator Assessment of Obsolescence**
  - **Life Expectancy**
  - **Cost of infrastructure**
    - **New vs. Existing**
  - **Regulatory Environment (and uncertainty)**



- **Assessment of Risk: Oil Spills**
  - **Likelihood, type, and volume of a releases**
  - **Environmental impact from releases**

RISK = PROBABILITY * CONSEQUENCE

Dr. Dagmar Schmidt Etkin

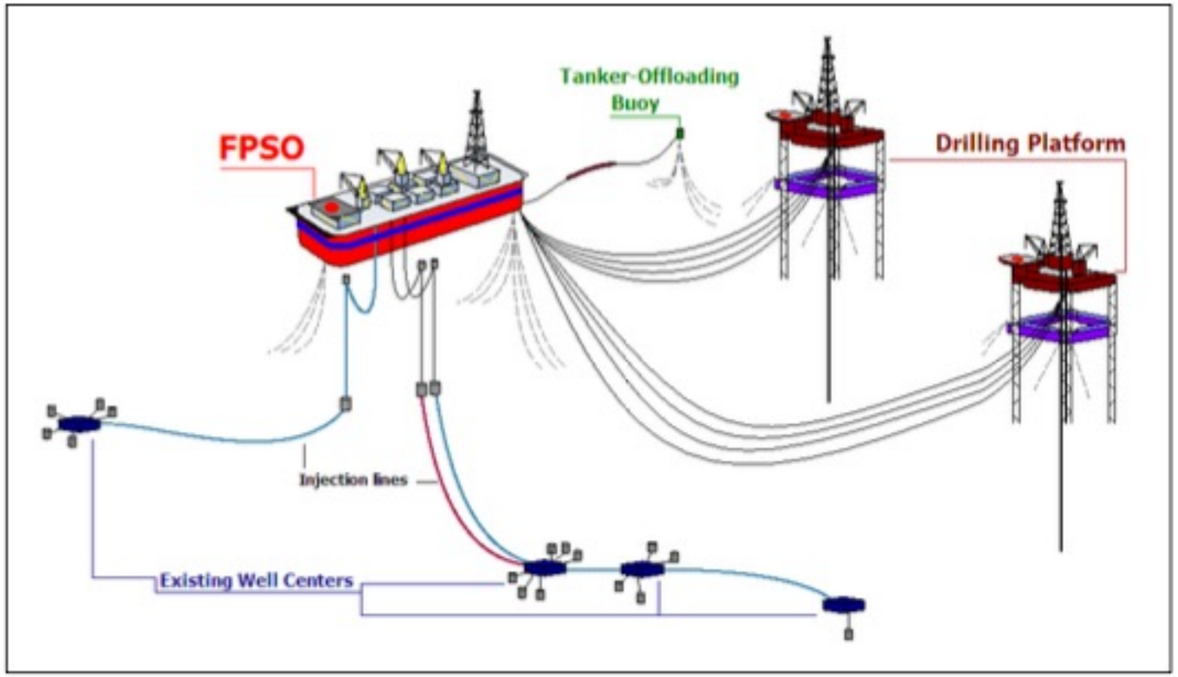
ENVIRONMENTAL RESEARCH CONSULTING

Impact →

Likelihood ↑	Negligible	Minor	Moderate	Significant	Severe
Very Likely	Low Med	Medium	Med Hi	High	High
Likely	Low	Low Med	Medium	Med Hi	High
Possible	Low	Low Med	Medium	Med Hi	Med Hi
Unlikely	Low	Low Med	Low Med	Medium	Med Hi
Very Unlikely	Low	Low	Low Med	Medium	Medium

Probability Assessment

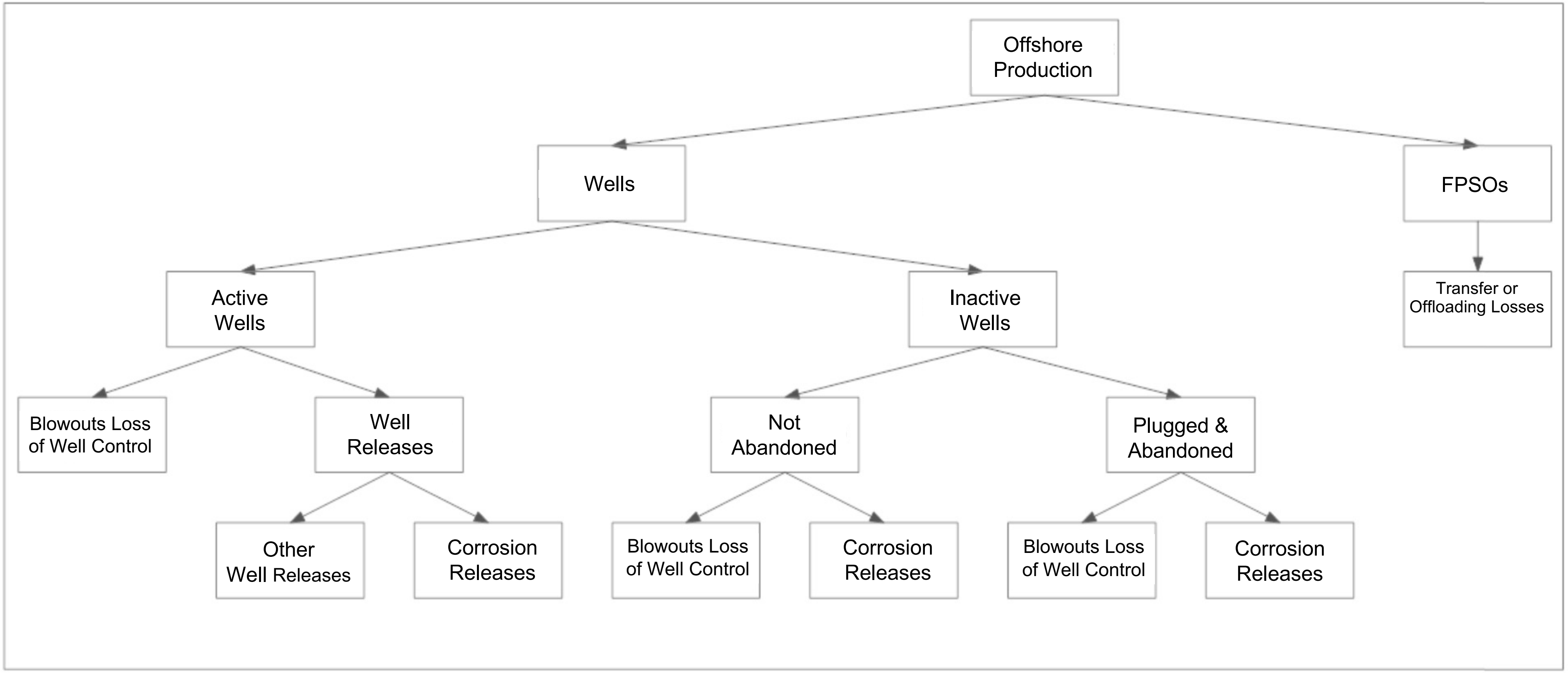
- Types of Releases
  - Blowout:
    - Loss of well control
  - Well Release:
    - Drill pipe, tubing, flow lines
  - Corrosion-related discharge:
    - episodic or chronic



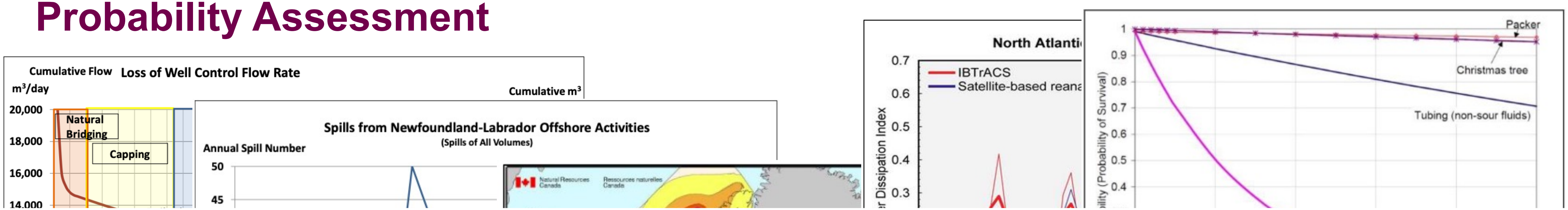
Scenario ID	Spill Event	Spill Rate	Release Duration	Total Volume
SSB-26	Subsurface blowout	Declining from 20,000 m^3/day to 12,935 m^3/day as per Figure 1	26 days	368,776 m^3 2,319,532 bbl
SSB-115	Subsurface blowout	Declining from 20,000 m^3/day to 8,210 m^3/day as per Figure 1	115 days	1,283,040 m^3 8,070,078 bbl
BS-55	Batch spill: Loss from offloading hose (valve to valve)	55 m^3 instantaneous release	Instantaneous	55 m^3 346 bbl
BS-120	Batch spill: Loss from production riser (FPSO)	120 m^3 instantaneous release	Instantaneous	120 m^3 755 bbl

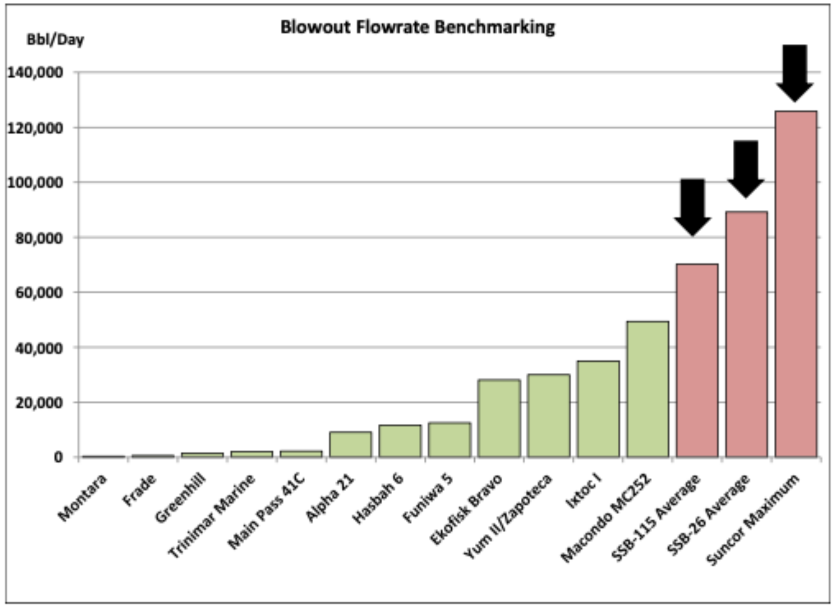
Probability Assessment

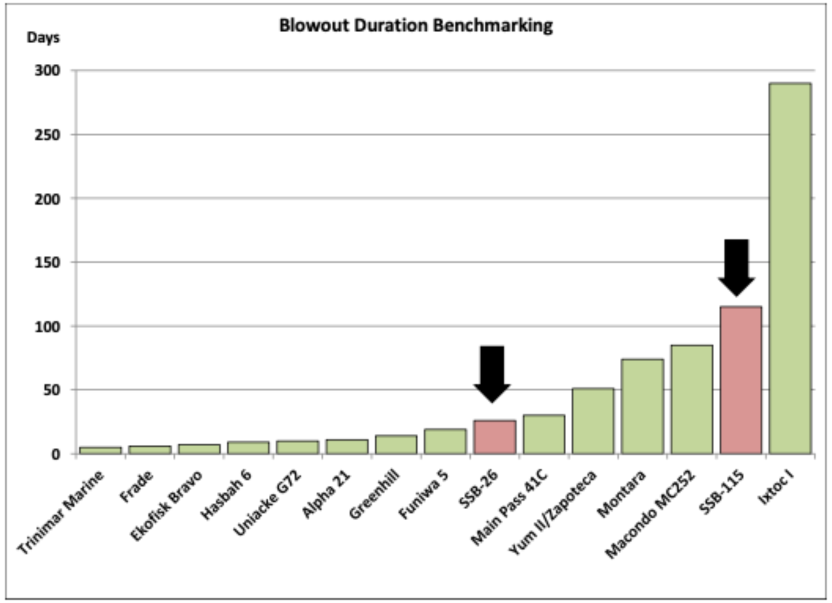
- **Basic Types of Spills Assessed**

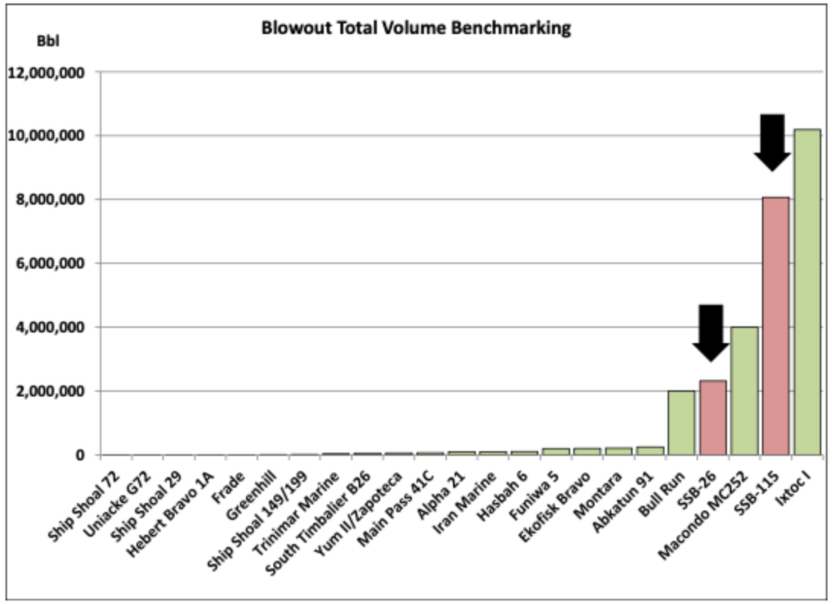


Probability Assessment









Benchmarking release rates, duration, and total volume to real world releases

Probability Assessment

- **Likelihood Outputs**
  - **Blowout probability with and without new wells**
  - **Mean frequency of well releases**
  - **Probability of:**
    - **well blowout by volume category**
    - **well releases by volume category**
    - **corrosion leading to spillage**
    - **batch spillage**
  - **Summary of expected volume by percentile**
  - **Probable return periods**

Table 6: Mean Frequencies of Subsurface Blowouts for Project during Production

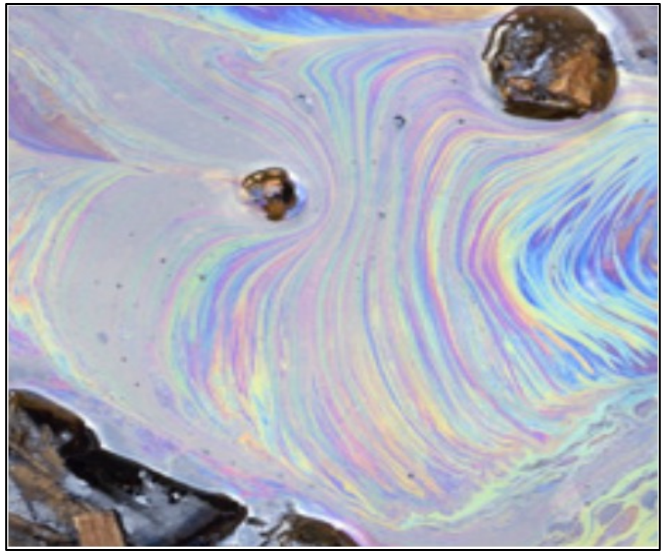
Year	Probability of Blowout (Expected Frequencies in Time Period)									
	Number of Wells Without Future Well C09SWS				Blowout Probability in Specified Year	Number of Wells With Future Well C09SWS				Blowout Probability in Specified Year
	Total Wells		Wells Without Gas-Lift			Total Wells		Wells Without Gas-Lift[8]		
	Active	Inactive	Active	Inactive		Active	Inactive	Active	Inactive	
2019	17	0	14	0	0.00235	18	0	15	0	0.00252
2020	17	0	14	0	0.00235	18	0	15	0	0.00252
2021	17	0	14	0	0.00235	18	0	15	0	0.00252
2022	17	0	14	0	0.00235	18	0	15	0	0.00252
2023	17	0	14	0	0.00235	18	0	15	0	0.00252
2024	17	0	14	0	0.00235	18	0	15	0	0.00252
2025	17	0	14	0	0.00235	18	0	15	0	0.00252
2026	17	0	14	0	0.00235	18	0	15	0	0.00252
2027	16	1	13	1	0.00219	17	1	14	1	0.00236
2028	16	1	13	1	0.00219	17	1	14	1	0.00236
2029	16	1	13	1	0.00219	17	1	14	1	0.00236
2030	16	1	13	1	0.00219	17	1	14	1	0.00236
2031	14	3	11	3	0.00186	15	3	12	3	0.00203
2032	14	3								
2033	0	17								
2034	0	17								
2035	0	17								
2036	0	17								
2037	0	17								
After[9]	0	17								

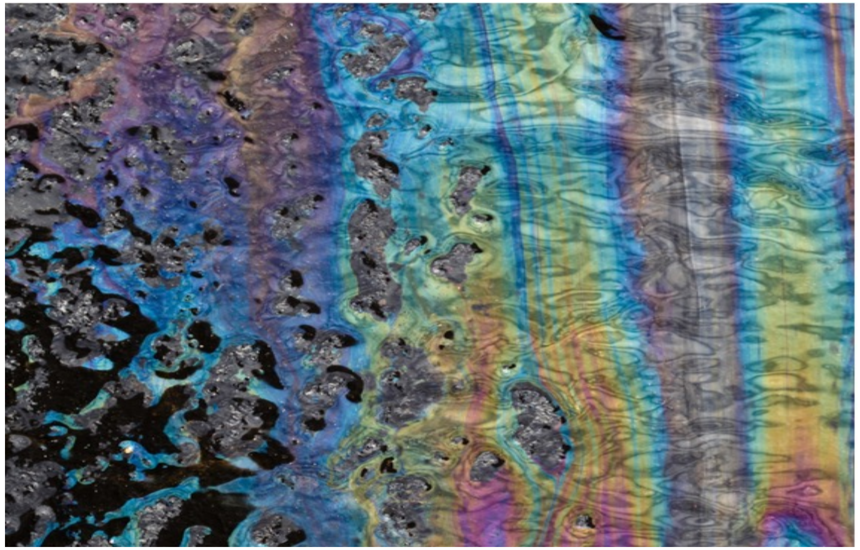
Table 14: Probabilities and Return Periods

Modeled Scenario	Spill Event	Total Volume		Probability (With 17 Wells)		Probability (With 18 Wells)	
		m^3	bbl	Per Year	TNALE Production Lifetime	Per Year	TNALE Production Lifetime
SSB-26	Subsurface blowout	368,776	2,319,532	0.000009	0.000121 110,000 years	0.0000091	0.000128 110,000 years
SSB-115	Subsurface blowout	1,283,040	8,070,078	0.000004	0.000061 250,000 years	0.0000046	0.0000642 250,000 years
BS-55	Batch spill: Loss from offloading hose	55	346	0.13	1.8 7.7 years	0.13	1.8 7.7 years
BS-120	Batch spill: Loss from FPSO production riser	120	755	0.000022	0.00031 45,000 years	0.000024	0.00033 45,000 years

Modeling Environmental Consequences Following a Release of Oil

- **Questions Addressed:**
  - **Trajectory** – Where will released oil move in the environment?
  - **Fate** – How will oil behave and weather in the environment?
  - **Effects** – What biological / socio-economic resources may be affected?

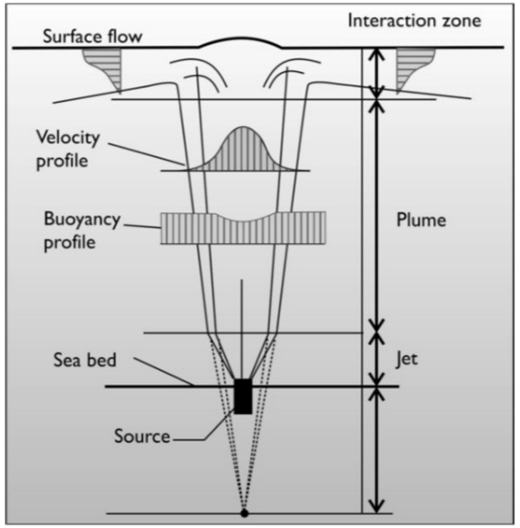


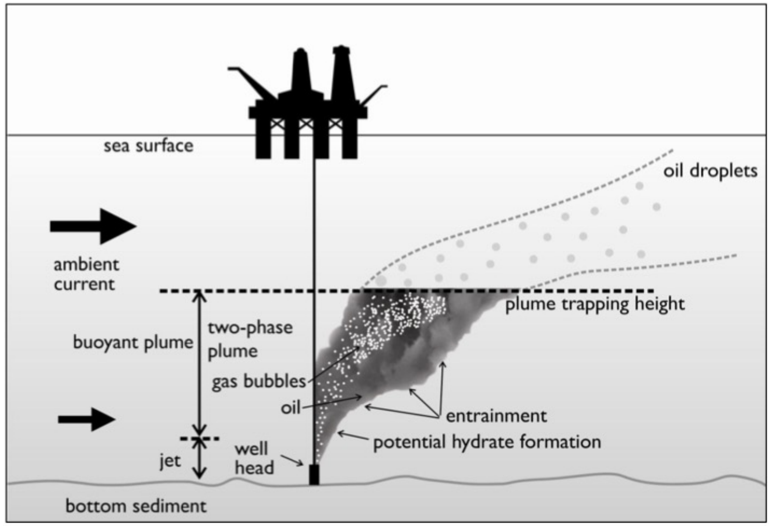


Modeling Approach

OILMAPDeep

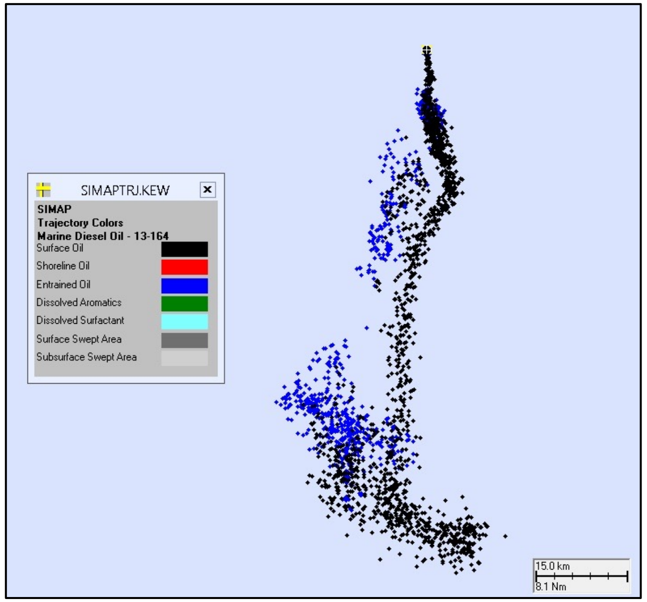
- Near-field Analysis
  - Used to characterize the plume dynamics and droplet size distribution of spilled oil in the region immediately surrounding the modelled blowout.





SIMAP

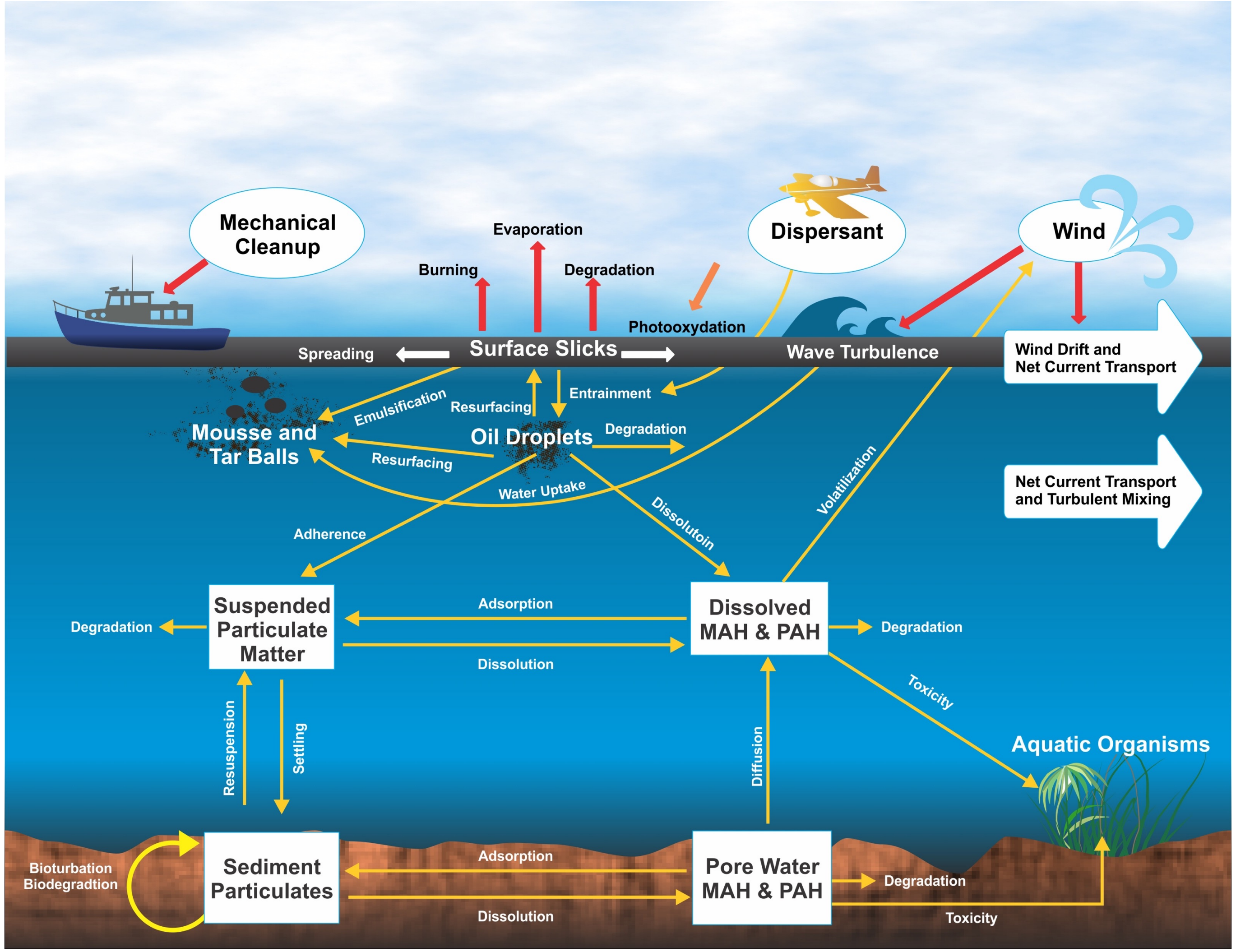
- Far-field Analysis
  - Used to characterizes the trajectory (movement) and fate (behavior) of spilled oil in 3D to determine the potential effects of a spill. Oil is treated as many individual parcels called Lagrangian Elements (LE).



Each point is an individual LE moving on its own. The trajectory and fate, including the chemical and physical parameters of each particle, are tracked individually for each LE throughout the model domain over time.

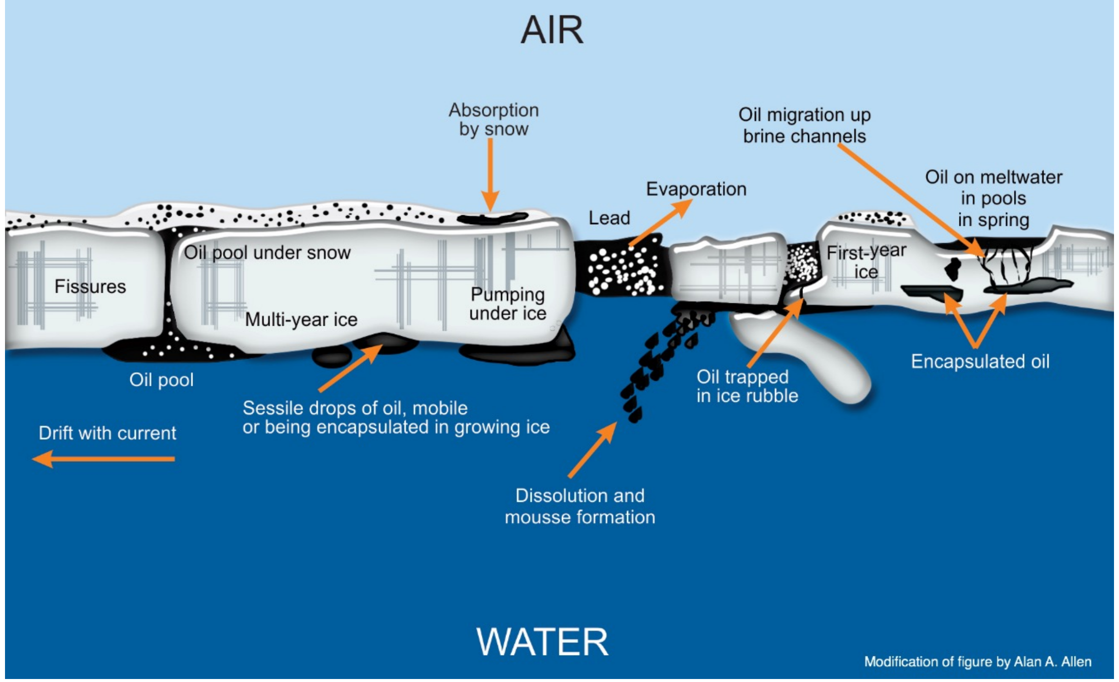
Simulating Oil in the Environment

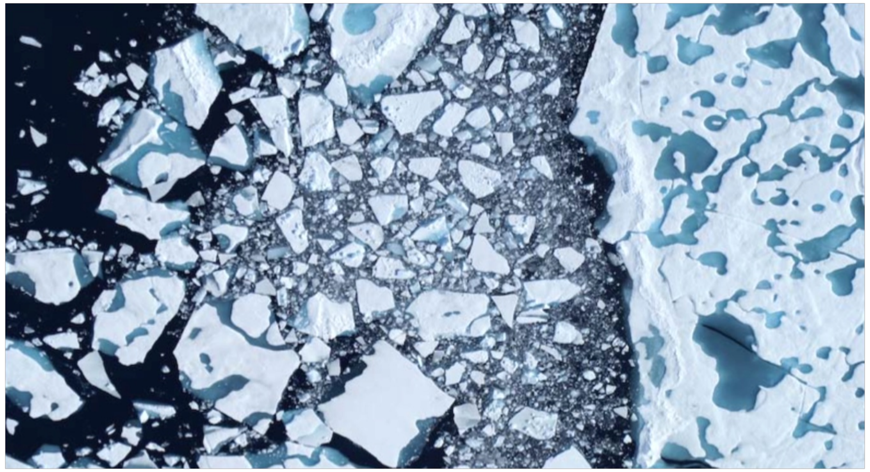
- **SIMAP**
  - Transport
  - Oil spreading
  - Evaporation
  - Dissolution
  - Entrainment
  - Emulsification
  - Degradation
  - Horizontal and Vertical Dispersion
  - Volatilization from the water column
  - Adherence of droplets to suspended sediments
  - Sedimentation
  - Emergency Response



Oil Fate Processes in Ice

- ***Advection*** – oil moves with ice at high coverage, modified at intermediate coverage, no effect at low ice coverage
- ***Evaporation*** – reduced rate due to shielding from wind, reduced wave energy
- ***Entrainment*** – reduced due to reduced wave energy
- ***Spreading*** – slowed by cold, presence of ice, herding effects

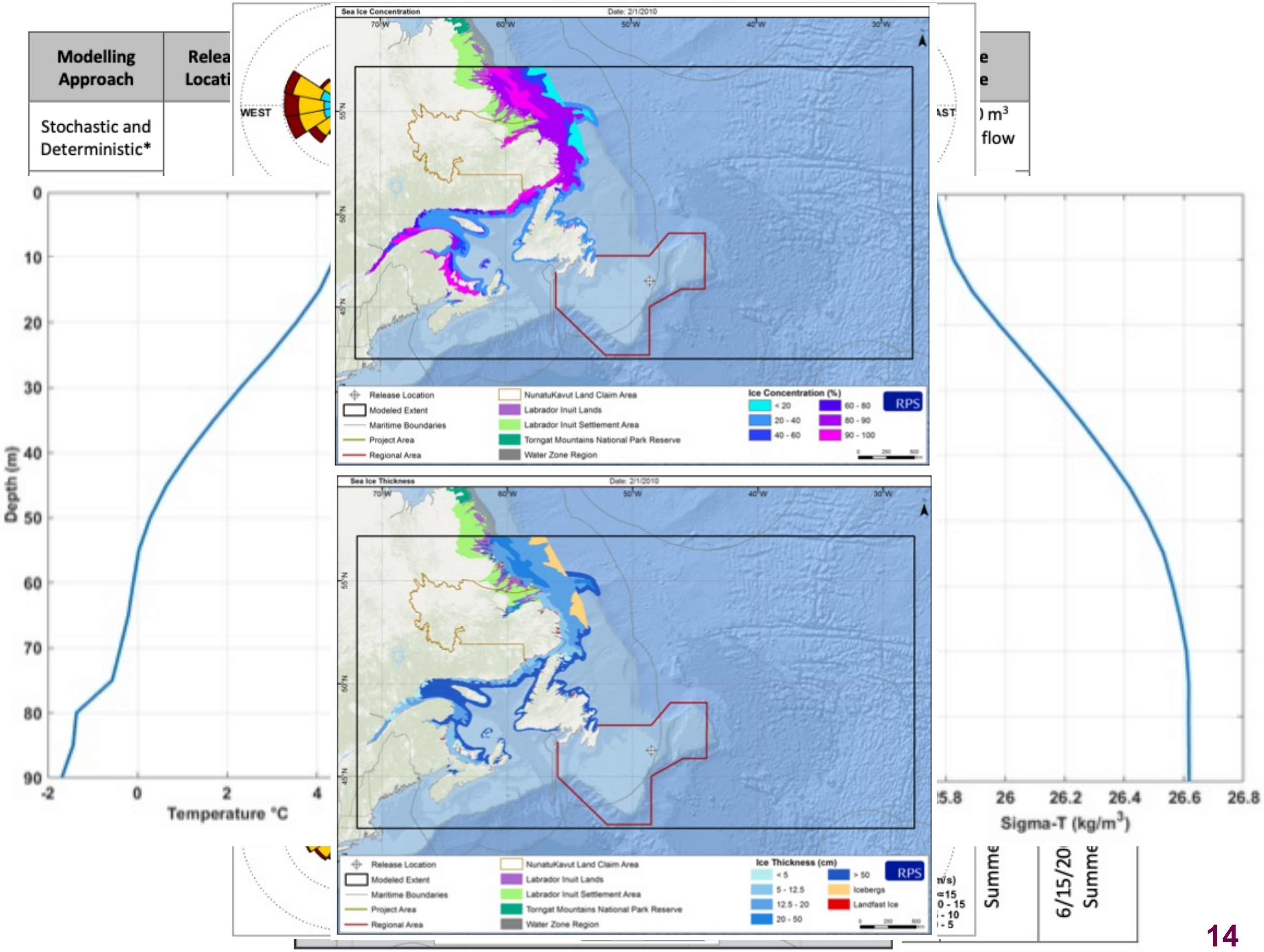




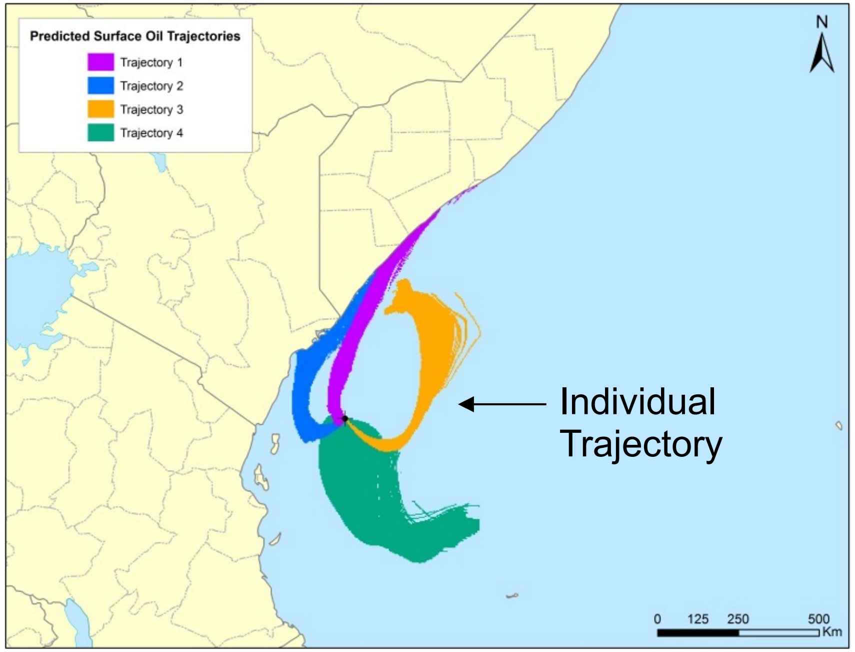
Relatively Ice Free (0-30%) | Partial Ice Cover (30-80%) | Complete Ice Cover (80-100%)

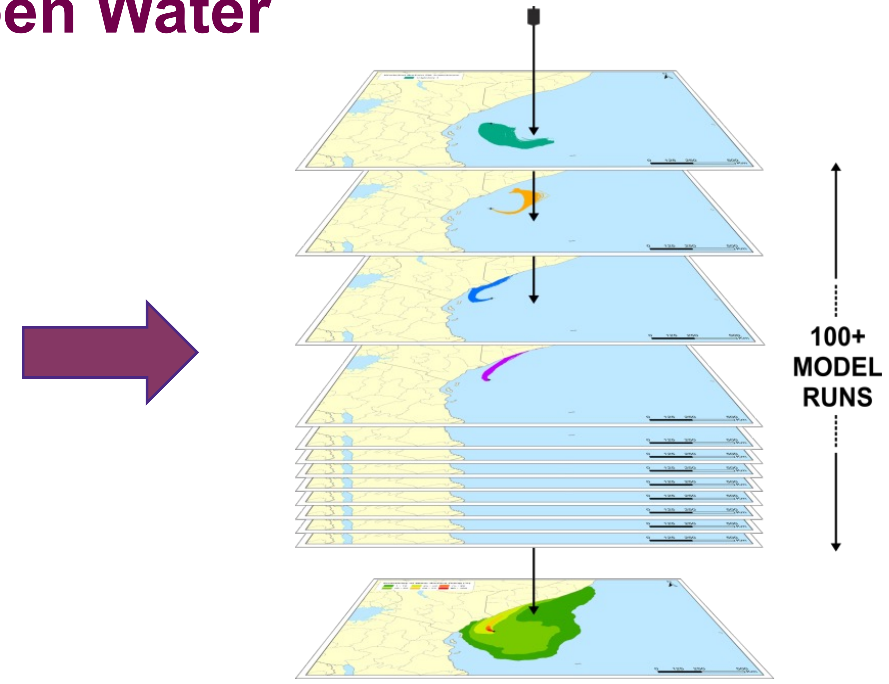
SIMAP Model Inputs

- Release Location
- Date, Time, and Model Duration
- Fuel/oil type and characteristics
- Amount released and release duration
- Geographic data
  - Shoreline data
  - Habitat data
  - Depth
- Environmental Conditions
  - Winds & Currents
  - Temperature & Salinity
  - Ice



Stochastic Modeling – in Lakes and Open Water



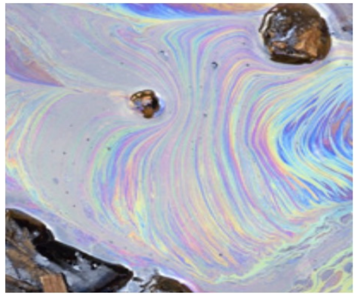
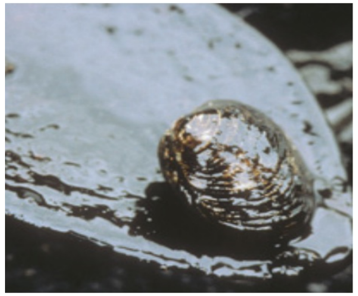
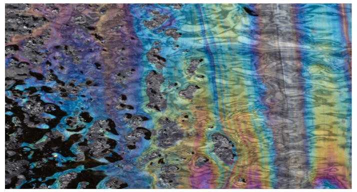


- Multiple 3D deterministic model trajectories (>100) are run for one release scenario to characterize the consequences of spills under various environmental conditions (i.e., variable currents, winds, ice, etc.)
- Long term wind and currents records (5-10 years)
- Randomly selected start dates
- **Statistical analysis** of all trajectories generates maps of overall **oiling probability** and **minimum travel time**
- Areas and volumes affected over prescribed minimum cut-off values or thresholds are then evaluated
- Individual representative trajectories are identified and examined in more detail (e.g., 95th percentile "worst cases")
- Results may be separated and analyzed based upon specific timeframes (e.g., months, seasons, ice cover, etc.)

Thresholds of Concern

Threshold Type	Cutoff Threshold	Rationale/Comments (Socio-economic, Response, Ecological)	Visual Appearance	References
Oil Floating on Water Surface	* 0.04 g/m^2	**Socio-economic:** A conservative threshold used in several risk assessments to determine effects on socioeconomic resources (e.g. fishing may be prohibited when sheens are visible on the sea surface). Socio-economic resources and uses that would be affected by floating oil include commercial, recreational and subsistence fishing; aquaculture; recreational boating, port concerns such as shipping, recreation, transportation, and military uses; energy production (e.g., power plant intakes, wind farms, offshore oil and gas); water supply intakes; and aesthetics.	Fresh oil at this minimum thickness corresponds to a slick being barely visible or scattered sheen (colorless or silvery/grey), scattered tarballs, or widely scattered patches of thicker oil.	French McCay et al., 2011; French McCay et al., 2012; French McCay, 2016; Lewis, 2007, Bonn Agreement
	10 g/m^2	**Ecological:** Mortality of birds on water has been observed at and above this threshold. Sublethal effects on marine mammals, sea turtles, and floating Sargassum communities are of concern.	Fresh oil at this thickness corresponds to a slick being a dark brown or metallic sheen.	French et al., 1996; French McCay, 2009 (based on review of Engelhardt, 1983, Clark, 1984, Geraci and St. Aubin 1988, and Jenssen 1994 on oil effects on aquatic birds and marine mammals); French McCay et al., 2011; French McCay et al., 2012; French McCay, 2016
Shoreline Oil	* 1.0 g/m^2	**Socio-economic/Response:** A conservative threshold used in several risk assessments. This is a threshold for potential effects on socio-economic resource uses, as this amount of oil may trigger the need for shoreline cleanup on amenity beaches, and affect shoreline recreation and tourism. Socio-economic resources and uses that would be affected by shoreline oil include recreational beach and shore use, wildlife viewing, nearshore recreational boating, tribal lands and subsistence uses, public parks and protected areas, tourism, coastal dependent businesses, and aesthetics.	May appear as a coat, patches or scattered tar balls, stain	French-McCay et al., 2011; French McCay et al., 2012; French McCay, 2016
	100 g/m^2	**Ecological:** This is a screening threshold for potential ecological effects on shoreline flora and fauna, based upon a synthesis of the literature showing that shoreline life has been affected by this degree of oiling. Sublethal effects on epifaunal intertidal invertebrates on hard substrates and on sediments have been observed where oiling exceeds this threshold. Assumed lethal effects threshold for birds on the shoreline.	May appear as black opaque oil.	French et al., 1996; French McCay, 2009; French McCay et al., 2011; French McCay et al., 2012; French McCay, 2016
In Water Concentration	* 1.0 ppb (µg/L) of dissolved PAHs; corresponds to ~100 ppb (µg/L) of whole oil (THC) in the water column (soluble PAHs are approximately 1% of the total mass of fresh oil)	Water column effects for both **ecological** and **socioeconomic** (e.g., seafood) resources may occur at concentrations exceeding 1 ppb dissolved PAH or 100 ppb whole oil; this threshold is typically used as a screening threshold for potential effects on sensitive organisms.	N/A	Trudel et al. 1989; French-McCay 2004; French McCay 2002; French McCay et al. 2012

*Thresholds used in supporting stochastic results figures. For comparison, a bacterium is 1-10 µm in size, a strand of spider web silk is 3-8 µm, and paper is 70-80 µm thick. Oil averaging 1 g/m^2 is roughly equivalent to 1 µm.


SIMAP Model Outputs

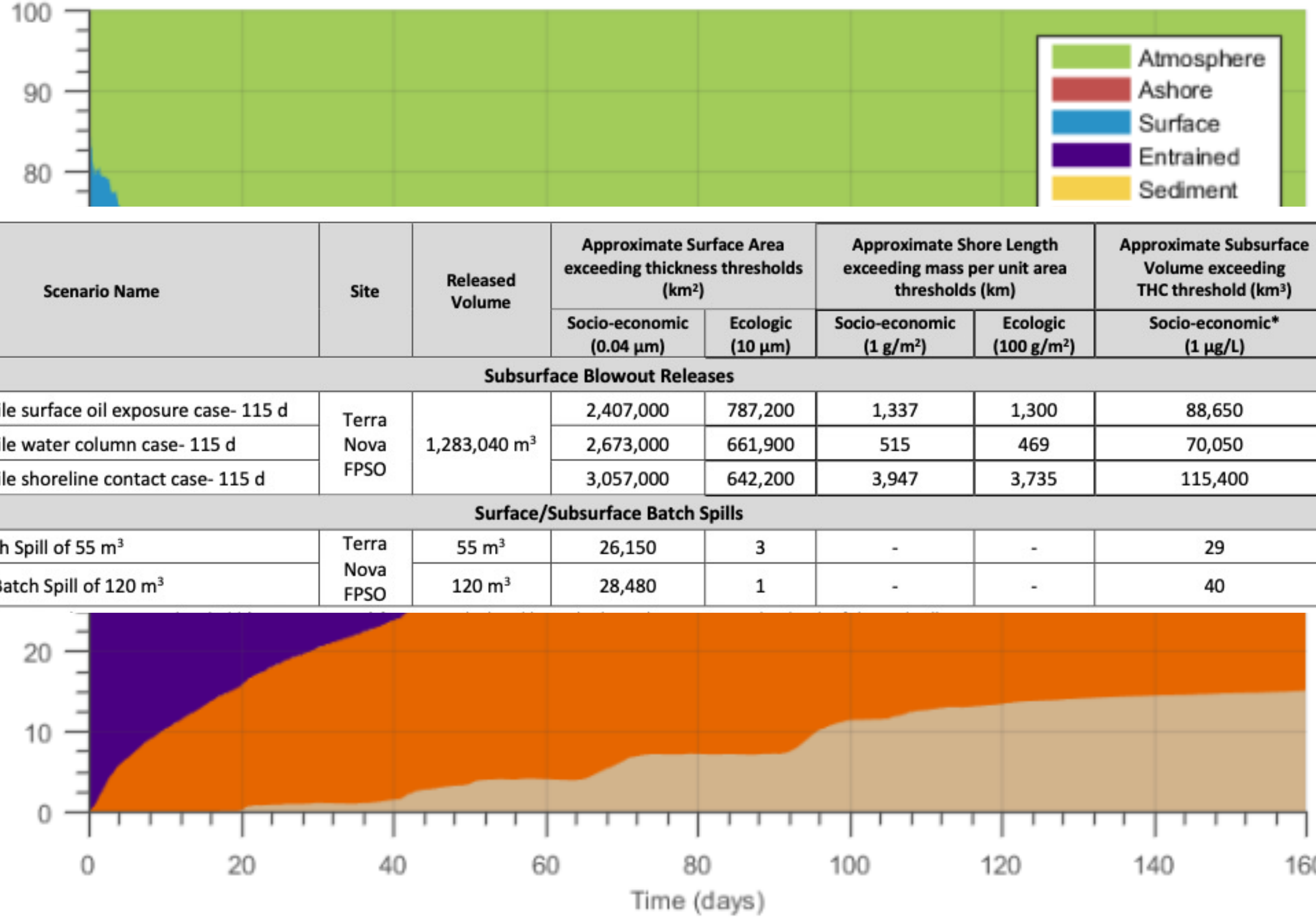
- **Stochastic Outputs (Consequence)**
  - **Probability and Minimum time of socioeconomic and ecological threshold exceedances for surface, shoreline, and water column environmental compartments.**
  - **Read together: "There is X% probability that oil is predicted to exceed the identified threshold at a specific location, and this exceedance could occur in as little as Y days."**
  - **Threshold exceedance stats.**

Stochastic Scenario Parameters		Areas Exceeding Threshold (km^2)		
Component and Threshold	Probability Contour or Bin	Annual Results	Winter (ice cover)	Summer (ice-free)
Surface Oil > 0.04 µm, on average	1%	3,498,000	3,562,000	3,307,000
	10%	2,796,000	2,893,000	2,698,000
	90%	1,490,000	1,499,000	1,520,000
Water Column Dissolved Hydrocarbons > 1 µg/L at some depth within the water column	1%	254,300	274,200	244,000
	10%	199,800	212,900	188,100
	90%	72,930	78,000	71,710
Shoreline Contact with Oil > 1 g/m^2, on average		Lengths Exceeding Threshold (km)		
	1 - 5%	2,596	2,054	1,737
	5 - 15%	2,334	1,939	1,861
	15 – 25%	671	510	698
	25 – 50%	211	358	138

Scenario	Release Location	Scenario Timeframe	Average Probability of Shoreline Oil Contact (%)	Maximum Probability of Shoreline Oil Contact (%)	Minimum Time to Shore (days)	Maximum Time to Shore (days)
115-day release	Terra Nova	Annual	8	33	6	155
		Winter	9	37	6	160
		Summer	8	31	17	160

SIMAP Model Outputs

- **Deterministic Outputs (Consequence)**
  - For each representative deterministic simulation provide:
  - Cumulative
    - surface oil thickness
    - In-water concentration
    - Shoreline & Sediment oil
  - Mass Balance
  - Areas, lengths, and volumes exceeding thresholds



Scenario Name	Site	Released Volume	Approximate Surface Area exceeding thickness thresholds (km²)		Approximate Shore Length exceeding mass per unit area thresholds (km)		Approximate Subsurface Volume exceeding THC threshold (km³)
			Socio-economic (0.04 µm)	Ecologic (10 µm)	Socio-economic (1 g/m²)	Ecologic (100 g/m²)	Socio-economic* (1 µg/L)
Subsurface Blowout Releases							
95th percentile surface oil exposure case- 115 d	Terra Nova FPSO	1,283,040 m³	2,407,000	787,200	1,337	1,300	88,650
95th percentile water column case- 115 d			2,673,000	661,900	515	469	70,050
95th percentile shoreline contact case- 115 d			3,057,000	642,200	3,947	3,735	115,400
Surface/Subsurface Batch Spills							
Surface Batch Spill of 55 m³	Terra Nova FPSO	55 m³	26,150	3	-	-	29
Subsurface Batch Spill of 120 m³		120 m³	28,480	1	-	-	40

Modeling Wrap Up

- **OILMAPDeep & SIMAP** can be used to predict subsurface blowouts, as well as in-water, and surface releases
  - where oil would move,
  - how long it will take to get there,
  - how much would be anticipated, with
  - site-specific and season-specific accuracy.

- **Modeling** is being requested more frequently by regulators and stakeholders with more detailed EIS's being required, ALE's, and COSRP's (planning and preparedness).

- **Model results** can be used to communicate the range of potential effects following a release to aid in the decision-making processes, planning, preparedness, and environmental assessment. They can also inform oil spill response plans, exercises & drills for hypothetical or real-world releases with and without response options.

Assertions / Conclusions

- **Energy Transition** is underway but progressing slowly. Dependence on hydrocarbons will continue for decades.
- **Asset Life Extension Projects** may reduce costs to maintain production capacity and circumvent more time-consuming regulatory hurdles around new infrastructure.
- Using **Historical** release data, **Project-Specific** data, and **Site-Specific** geographic and environmental characteristics allows for a robust approximation of the range of likelihood and potential for impacts.
- **More modeling** is being requested more frequently by regulators, stakeholders, & industry for use in EIA, EIS, NEBA/SIMA, OSRP, and more.
- **Considered Together,** PROBABILITY and CONSEQUENCE assessments inform operators and regulators about the **RISK** of new or continued operations to help them make informed decisions around **Asset Life Extension**.

THANK YOU

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RPS Overview: Science and Technology

- Global science and technology solutions company. Through consulting, environmental modeling, and application development, RPS helps a diverse range of clients solve their issues of concern.
- Environmental scientists, software developers and engineers, based in Rhode Island.
- Since 1979 and in over 100 countries, provide services and custom solutions and modeling to sectors including energy, environment, construction, defense, security, emergency management, transportation, and shipping.
- Scientists and engineers within RPS are developers and users of OILMAP, SIMAP, OILMAPLand, CHEMMAP, SARMAP, MUDMAP, OceansMap, etc.

OFFICE LOCATIONS

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AUSTRALIA
Adelaide
Brisbane
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Ipswich
Mackay
Margaret River
Melbourne
Newcastle
Perth
Port Douglas
Sunshine Coast
Sydney
Townsville
Whitsundays
Wollongong

NEW ZEALAND
Wellington

INDONESIA
Jakarta

MALAYSIA
Kuala Lumpur

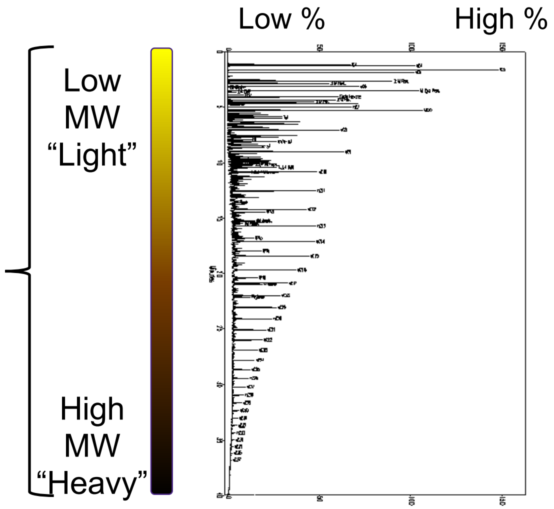
PAPUA NEW GUINEA
Port Moresby

Chemical Parameters of Oil

Oil is a combination of
10's-100's of thousands
of chemical compounds
(e.g. hydrocarbons)

***Each* oil has a *different* composition**

Example Composition of a Light Crude Oil



***Each* line is a *different* chemical**

***Each* chemical has *different* properties**

*Simplify each oil by grouping like-compounds (**pseudo-component approach**):*

Characteristic	**Volatile and Highly Soluble**	**Semi-volatile and Soluble**	**Low Volatility and Slightly Soluble**	**Residual (non-volatile and very low solubility)**
Distillation cut	1	2	3	4
Boiling Point (^{o}C)	< 180	180 - 265	265 - 380	>380
Molecular Weight	50 - 125	125 - 168	152 - 215	> 215
$\text{Log}(K_{ow})$	2.1-3.7	3.7-4.4	3.9-5.6	>5.6
Aliphatic pseudo-components: Number of Carbons	volatile aliphatics: C4 – C10	semi-volatile aliphatics: C10 – C15	low-volatility aliphatics: C15 – C20	non-volatile aliphatics: > C20
Aromatic pseudo-component name: included compounds	MAHs: BTEX, MAHs to C3-benzenes	2 ring PAHs: C4-benzenes, naphthalene, C1-, C2-naphthalenes	3 ring PAHs: C3-, C4-naphthalenes, 3-4 ring PAHs with $\log(K_{ow}) < 5.6$	>4 ring aromatics: PAHs with $\log(K_{ow}) > 5.6$ (**very low solubility**)

Biological Exposure Assessment

- **Smothering / Coating** (floating and shoreline oil)
  - Thermal Regulation (birds and mammals)
  - Mechanical (smothering, prevention of uptake and depuration, interference with motility, etc.)
  - Adsorption of toxic compounds (via skin or gut)
- **Toxicity** (dissolved hydrocarbons)
  - Requires uptake into tissues
  - Dissolved components
  - Acute and chronic
- **Mechanical Interference** (subsurface oil droplets)
  - Clogging of feeding appendages and gills
  - Impeding movements
- **Behavioral Interference** (floating and shoreline oil)
  - Avoidance (leave area or shut down)
  - Attraction (more exposure)