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OIL SPILLS RISK ANALYSIS: AN OVERVIEW

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INTRODUCTION

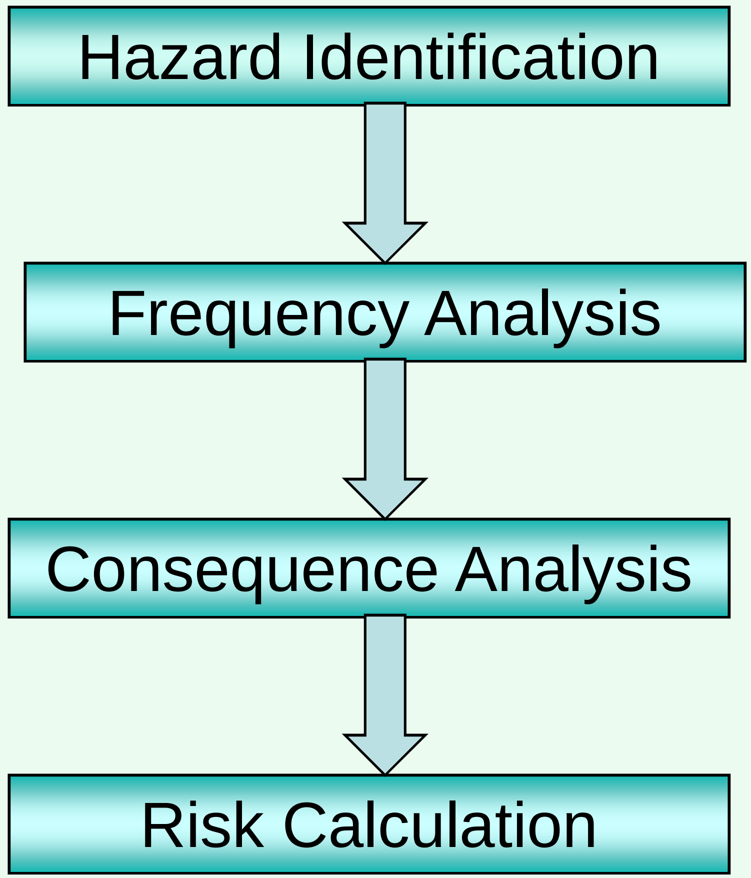
- Oil Spill: Release of large amount of oil into a water body leading to disastrous environmental effects.
- Oil spills can occur due to various reasons such as
  - Equipment breakdown in an oil tanker which causes leakage of oil into the sea
  - When countries are at war, one country may decide to dump gallons of oil into the other country's oceans.
  - Illegal dumping of crude and waste oil into ocean
  - Natural disasters (like hurricanes) may cause an oil spill, too by causing an oil tanker to flip over, pouring oil out.

MAJOR OIL SPILL INCIDENTS

Year	Place	Tanker	spill (in tons)
1983	The Persian Gulf	Nowruz Oil Field	100,000
1983	South Africa	Castillo De Belluer	160,000
1988	The Monongahela River	Storage Tank	2,400
1989	Prince William Sound, Alaska	Exxon Valdez	37,620
1993	Off The Shetland Islands	Braer	85,000
1996	Off SW Wales	Sea Empress	72, 000
2001	Galapagos Islands	Jessica	600

RISK ANALYSIS: GENERAL OVERVIEW

Stages of Risk Analysis



1. Hazard Identification: Identification and generation of a comprehensive and representative set of events which can realistically cause a spill. Diagrammatically, this can be represented by a spill event tree etc. Usually these events are

- Collision: the striking together of two vessels whilst underway;
- Grounding: a vessel touches the sea bottom, either powered or drifting;
- Contact: a vessel strikes an external object other than another vessel or sea bottom;
- Cargo transfer failure: a cargo spill occurs while conducting ship/shore or ship/ship loading or unloading;
- Fire/explosion: occurs onboard vessel but not due to above;
- Structural failure: the hull cracks;
- Sinking: a vessel sinks due to breach in watertight integrity or adverse loading.

2. Frequency Analysis i.e. Assessment of oil release probability. Mostly, this is estimated by combination of component probabilities derived on basis of reliability data (if available) and statistical analysis of historical data. Other sources of frequency analysis are

   – Data and Statistics
   – Expert Advice
   – Historical Records
   – Ground Truthing
   – Consultation
   – Individual Experience

3. Consequence Analysis: The effects of oil spill are analysed in terms of following scenarios
   - Environmental
   - Ecological
   - Habitat
   - Fisheries
   - Tourism
   - Aquaculture
   - Cultural
   - Economic

- The analysis of oil spills requires evaluation of spill size distribution. The basic approach to spill size estimation is through the use of log normal distribution assumption

4. Risk Calculation: Broadly risk can be represented as
   – Probability of occurrence and exposure expressed as a percent chance
   – Risk Units which quantify both the occurrence of oil spill and consequence associated with it.

- Quantification of spill consequences involves determination of spread and evaporation of oil slick, interaction with rough seas and their eventual break up followed by determination of trajectory of oil slicks and probable shoreline impact.

- the quantified results are displayed in terms of risk profiles viz., event or fault tree or Hazard Maps or Graphs depicting percent chance of exposure or Risk Units.

Determination of Spread of Oil Spill

Spill Analysis Models

Modeling of oil spills (trajectory simulation) is feasible if extensive information of variables such as meteorology, marine currents, oil chemistry, ship structure etc are available.

Statistical Analysis of Past Incidents

Statistical analysis is useful in absence of requisite model inputs. Oil spill estimation is based on previous incidents

CASE STUDIES

Crete, Greece*

METHODOLOGY OVERVIEW

- Hazard identification: oil pollution caused by heavy marine traffic and ship wreckage
- Frequency Analysis: based on available data for oil spill incidents in the area of Crete covering the period 1995-1999
- Consequence Analysis: a general relational rating system of high, medium and low was used to identify the probability of the threat occurring. Scenarios covered: tourists, fisheries and environmental
- Risk Calculations: Representation in terms of Risk Units

* : Kassomenos, 2003

Background of the Analysis

- Crete is one of the majors Mediterranean islands, located in the South Aegean Sea.
- Crete has about 600000 habitants, but more than 5 million tourists visit the island during an entire year.
- The areas of Cretan Sea are characterized by heavy marine traffic.
- The frequent navigation of tankers through this area enhances the possibility of marine pollution by oil-based waste from the ships as well as from possible shipwrecks.

- Crete consists of 4 prefectures (administrative areas), specifically from west to the east, prefectures of Hania, Rethymnon, Ieraklion and Sitia.
- There are 5 significant cities located in the north of Crete and one in the South.
- The capital *Heraklion* with about 150000 people, *Chania* with about 80000, *Rethymnon* with about 30000 and *Ag. Nikolaos* and *Sitia*.
- The city of Ierapetra is located in the Southeast part of the island, with about 15000 habitants. The last three cities are located in the Prefecture of Lasithi.


CRETAN SEA
Archaeological Sites
Towns and Cities
Chania
Rethymnon
Samaria
Heraklion
Knossos
Ag Nikolaos
Sitia
Zakros
Gournia
Ierapetra
Gortys
Phaestos
Libyan Sea

Map of Crete

Risk Analysis Methodology

- Cretan Sea is characterized by winds blowing from the Northern sector, throughout the year. Southern winds, that potentially could transport pollutants towards the area of the southern coast of Crete, represent less than 15% of the days.
- Use of general relational rating system of high, medium and low to identify the probability of the threat occurring.
- The planning process should identify and measure the probability of all potential risks and the impact on the ecosystem or human/financial activity if that threat occurred.

- As per priorities of significance of a particular threat , the impacts were rated as follows:
  - 0 = No impact in the financial activity of the population or no ecological disaster in the protected areas.
  - 1 = Noticeable impact
  - 2 = Damage
  - 3 = Major damage
- To measure the potential risks, a weighted point rating system was developed.
- Each level of probability was assigned points as follows: High risk, points 10, Medium risk, points 5 and Low risk, one point.

- The points assigned to each risk level are introduced in such a way to separate the three different risk levels, quantify the risks and discriminate the results.
- To obtain a weighted risk rating, probability points was multiplied by the highest impact rating for each activity.
- Based on this rating method, threats that pose the greatest risk (e.g., 15 points and above) can be identified.
- The following infrastructure, in the region of Crete was identified as vulnerable to oil-spills:
  - Protected areas and locations of special natural beauty
  - Zones of Fishing and Pisciculture
  - Tourist zones - Tourist Installations and beaches

- The combined Risk Units for each month and area were calculated according to the following formula:

$$RU_{ij} = á_i \times b_j \times (c_k + d_m + e_n)$$

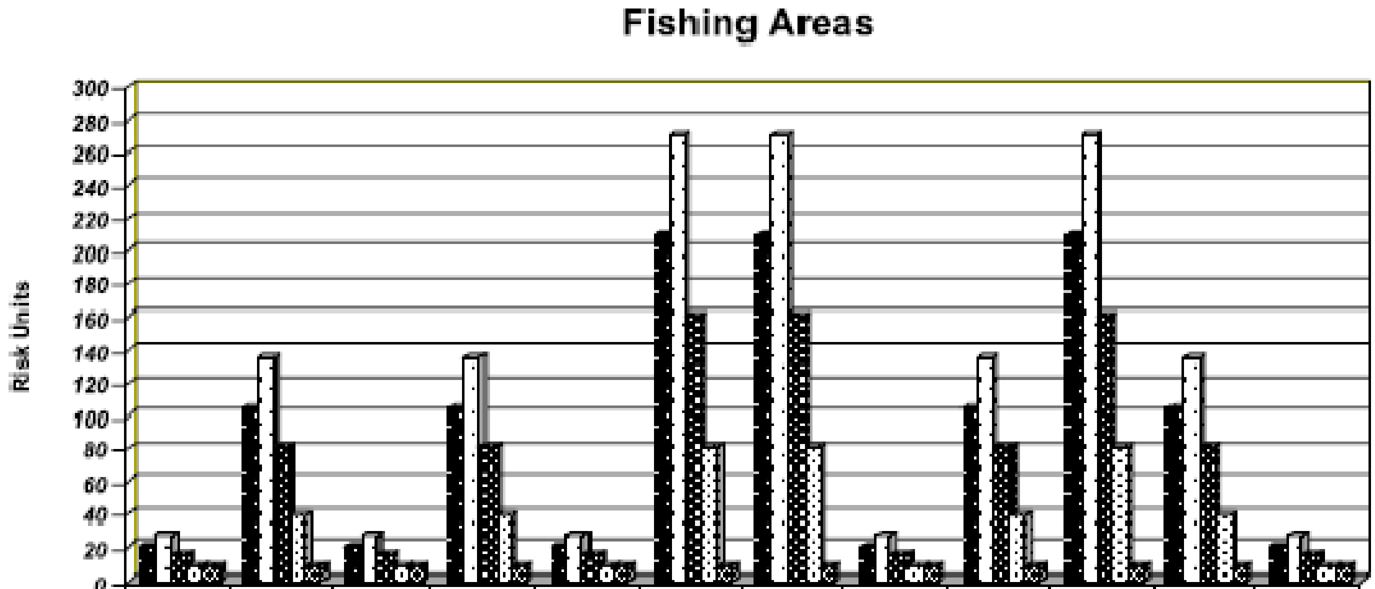
  – RU : Risk Units
  – i month i=1,...,12, j: area (Heraklion, Chania, Sitia, Agios Nikolaos, Rethymnon, South Crete) j=1,...,5
  – a_i month factor, a_i =1,5,10 ; b_j area factor, b_j =1,2,3
  – c_k prevailing wind flow (Northern, Southern) C_k =1,2, k=1,2
  – d_m Kind of disaster (fishing area, tourist installation, protected area), d_m=1,2,3, m=1,2,3
  – e_n possibility of early fighting, e_n = 1,2,3,4,5, ; n=1,...,5

- When the combined Risk Units (RU) are less than 80, then the risk is considered to be low, when RU is between 80 and 150 the risk is moderate and for more than 150 risk units the risk is high.

- This threshold was chosen, for the high risk, because it represents the beginning of the upper half of the scale.

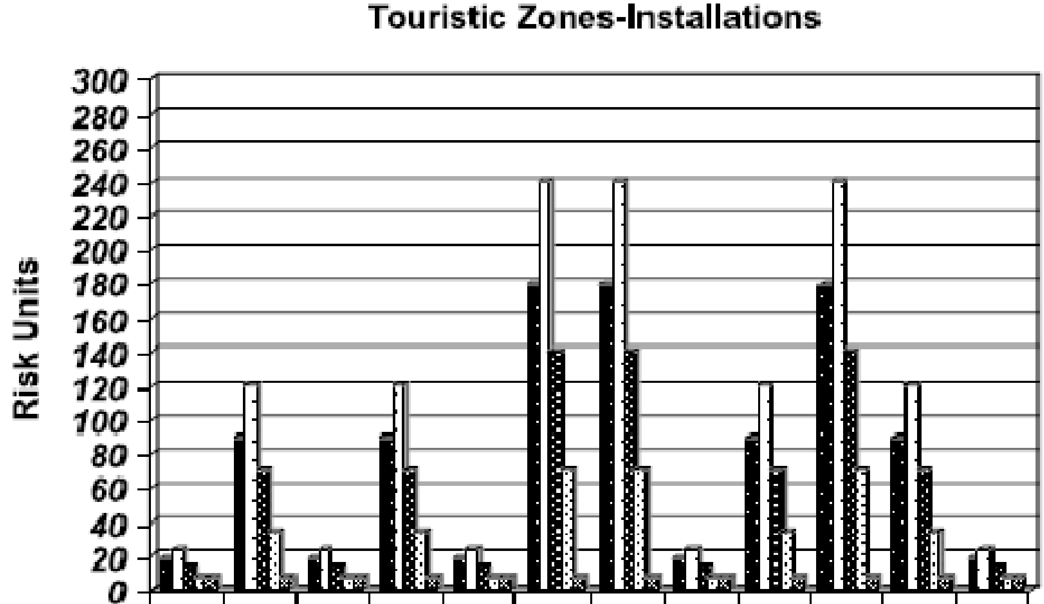
Results from Crete Oil Spill Risk Analysis

- The regions of Chania, and Heraklion present high risks, increasing during the summer period with northern winds.
- The area of the Prefecture of Rethymno (Agios Nikolaos and Sitia) presents low risk than, nevertheless, increases during the summer period with northern winds.
- The areas of Southern Crete presented low risk and thus seems to be less vulnerable to oil spill risks.



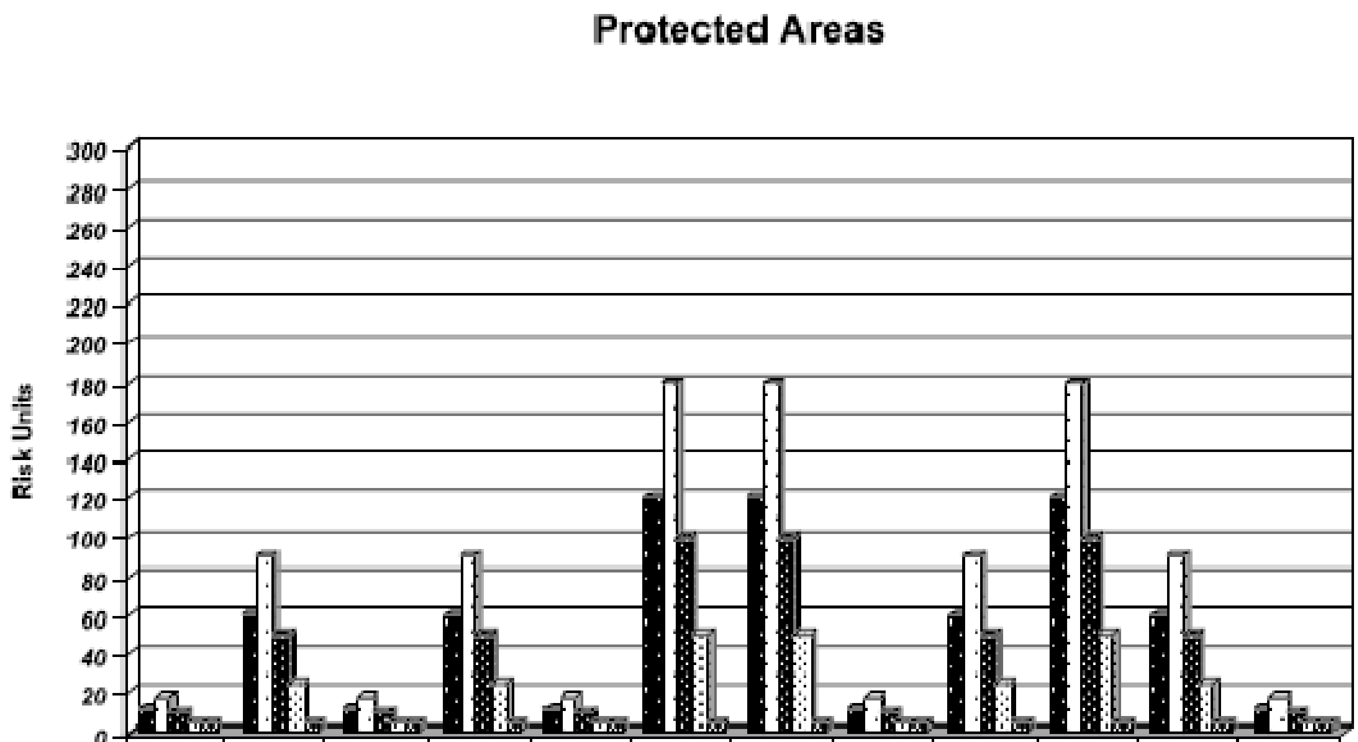
	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	OCT	NOV	DEC
Heraklion	21	105	21	105	21	210	210	21	105	210	105	21
Chania	27	135	27	135	27	270	270	27	135	270	135	27
Sitia	16	80	16	80	16	160	160	16	80	160	80	16
Ag Nik-Reth	8	40	8	40	8	80	80	8	40	80	40	8
South Crete	8	8	8	8	8	8	8	8	8	8	8	8

Risk Combination for Fishing areas and pisciculture installations in Crete. Numbers are in risk units



	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	OCT	NOV	DEC
Heraklion	18	90	18	90	18	180	180	18	90	180	90	18
Chania	24	120	24	120	24	240	240	24	120	240	120	24
Sitia	14	70	14	70	14	140	140	14	70	140	70	14
Ag Nik-Reth	7	35	7	35	7	70	70	7	35	70	35	7
South Crete	7	7	7	7	7	7	7	7	7	7	7	7

Risk Combination for Tourist zones, and Tourist installations in Crete. Numbers are in risk units



	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	OCT	NOV	DEC
Heraklion	12	60	12	60	12	120	120	12	60	120	60	12
Chania	18	90	18	90	18	180	180	18	90	180	90	18
Sitia	10	50	10	50	10	100	100	10	50	100	50	10
Ag Nik-Reth	5	25	5	25	5	50	50	5	25	50	25	5
South Crete	5	5	5	5	5	5	5	5	5	5	5	5

Risk Combination for Protected areas and sites of special natural beauty. Numbers are in risk units

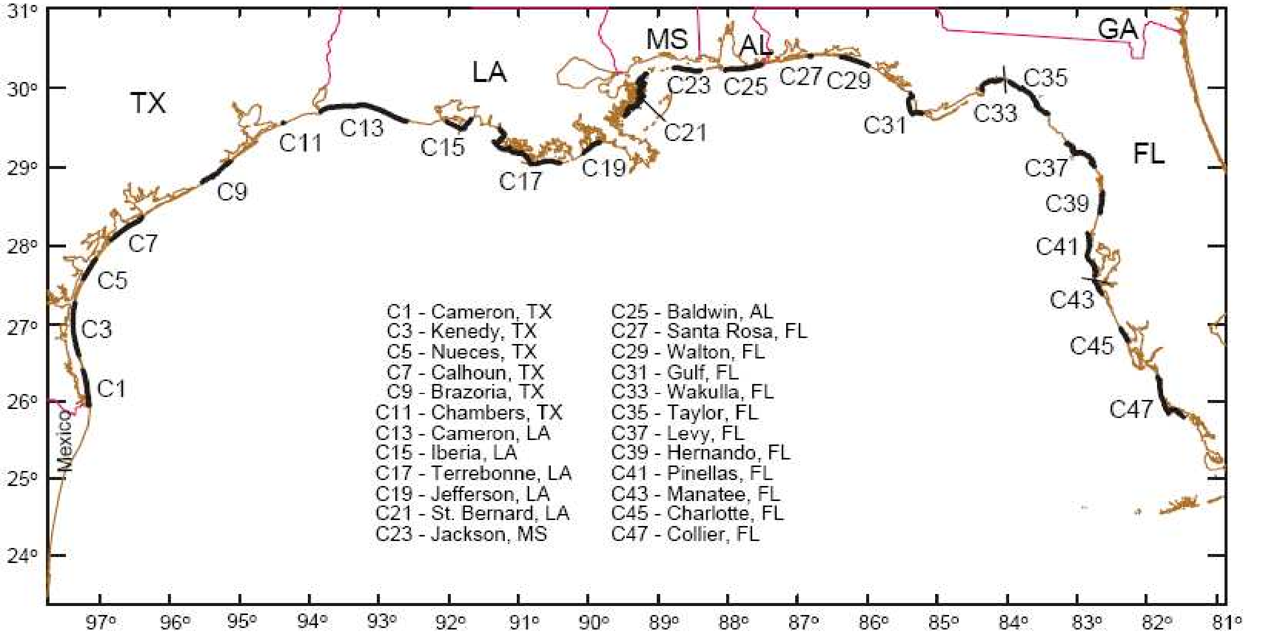
Gulf of Mexico (GoM)*

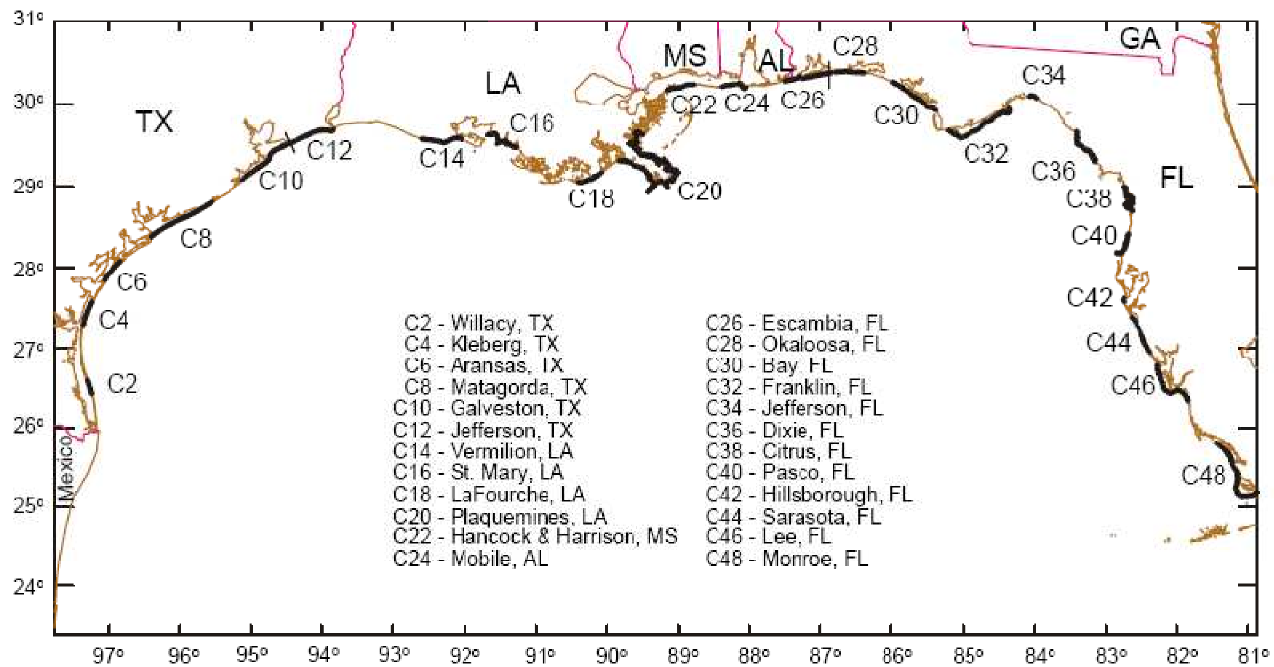
METHODOLOGY OVERVIEW

- Hazard identification: activities associated with offshore oil exploration, production, and transportation resulting from oil lease sales
- Frequency Analysis: deliberately initiated hypothetical oil spills uniformly in space and time
- Consequence Analysis: oil spill trajectory simulations through the OSRA Model #
- Risk Calculations: expressed as percent chance that an oil spill starting within a particular launch area will contact a segment under study

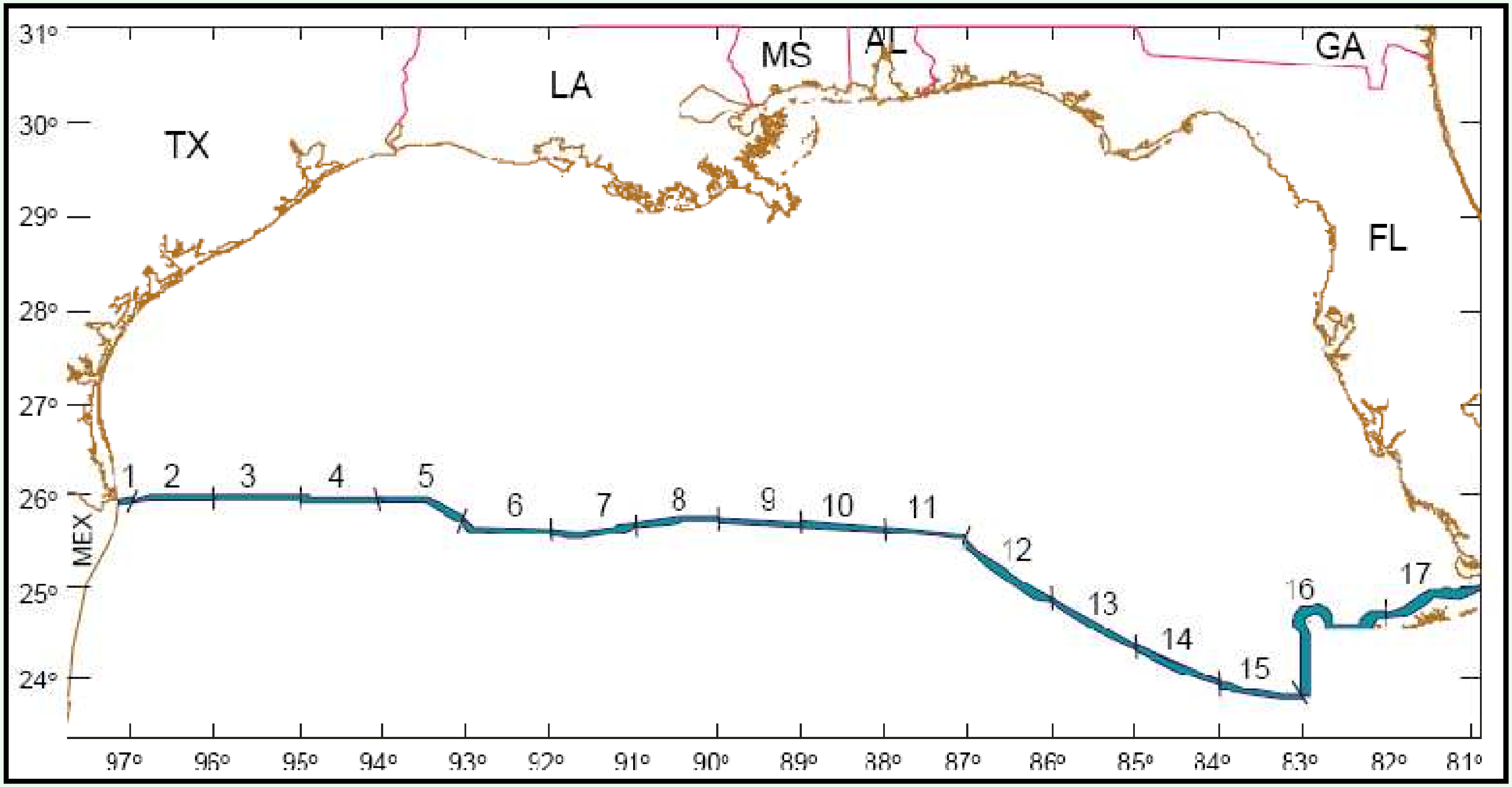
*:Minerals Management Service, U.S. Department of the Interior, 2007
#: developed by Smith et al. (1982) & enhanced by MMS (LaBelle & Anderson, 1985; Ji et al., 2003-04)

- The Minerals Management Service (MMS) has conducted a formal oil-spill risk analysis (OSRA) to provide spill statistics that can be used in contingency planning for U.S. Outer Continental Shelf (OCS) lands in the Gulf of Mexico
- The study area is the Walker Ridge Planning Area that encompasses a portion of the offshore waters within the Gulf of Mexico and is approximately 140 to 160 nautical miles offshore.
- The OSRA Model, simulates oil-spill transport using realistic data fields of winds and ocean currents in the GOM.





Location of Gulf of Mexico Counties/Parishes (not to scale)



Locations of the U.S./Mexico international boundary segments in the Gulf of Mexico

- At about 11 km intervals in the north-south direction and about 10 km intervals in the east-west direction, the OSRA model launched a hypothetical oil spill every 1.0 day. At this resolution, there were 15 total launch points in space, and hypothetical spills were launched from each spatial grid point over two time periods, 9 years and 7 years.
- The environmental resources considered in this analysis include the counties and parishes along the coast of the Gulf of Mexico.
- The hypothetical oil-spill launch area for this analysis is between 140 and 160 nautical miles from the coast.

- The model calculates the movement of hypothetical spills by successively integrating time sequences of two spatially gridded input fields: the surface ocean currents and the sea-level winds, both of which were generated by other computer models using many observations of relevant physical parameters. In this fashion, the OSRA Model generates time sequences of hypothetical oil-spill locations–essentially, oil-spill trajectories.
- At each successive time step, the OSRA Model compares the location of the hypothetical spills against the geographic boundaries of shoreline and designated offshore environmental resources.

- The model counts the occurrences of oil-spill contact to these areas during the time periods that the habitat is known to be used by the resource.

- Finally, the count of occurrence of oil spill contact is used to compute frequencies and consequently probabilities of oil-spill contact for designated oil-spill travel times (e.g., 3, 10, or 30 days).

- Two separate model runs were used to calculate the trajectories for this statistical report.
  - 9-year (1986-1994) simulation performed by Dynalysis of Princeton (Herring, et al., 1999)
  - 7-year period, 1993-1999, performed by Princeton University (Oey, et al.,2004) for and the results were saved at 1-hour intervals.
- The statistics for the contacts by the trajectories forced by the two model runs were combined for the average probabilities.
- The ocean model simulations were extensively skill-assessed with many observations from the GoM (Herring et al., 1999; Oey, et al., 2005) and a good determination of the model's veracity was made.

Results from GoM Oil Spill Risk Analysis

- As one might expect, the environmental resource locations closest to the spill sites had the greatest risk of contact.
- Due to the climatology of the wind, the spring season had the higher average probabilities of contact (the highest being 8 percent), and the fall season had the lowest (none greater than 0.5 percent).
- With increased travel time, the complex patterns of wind and ocean currents produce eddy-like motions of the oil spills and multiple opportunities for a spill to make contact with any given environmental resource.

Table Probabilities (expressed as percent chance) that an oil spill starting within a particular launch area in the Walker Ridge Planning Area will contact a county/parish land segment within 30 days

County/Parish	Annual	Winter	Spring	Summer	Fall
C7	n	n	1	n	n
C8	1	2	2	n	n
C9	1	1	2	n	n
C10	2	2	6	1	n
C12	1	n	3	n	n
C13	2	1	8	n	n
C14	1	n	4	n	n
C15	n	n	2	n	n
C17	1	n	5	n	n
C18	1	n	2	n	n
C19	n	n	1	n	n
C20	1	n	5	1	n

Notes: ** = Greater than 99.5 percent; n = less than 0.5 percent.
Rows with all values less than 0.5 percent are not shown.

Location of county/parish land segments

C7 (Calhoun, TX) C8 (Matagorda, TX) C9 (Brazoria, TX)
C10 (Galveston, TX) C12 (Jefferson, TX) C13 (Cameron, LA)
C14 (Vermilion, LA) C15 (Iberia, LA) C17 (Terrebonne, LA)
C18 (LaFourche, LA) C19 (Jefferson, LA) C20 (Plaquemines, LA)

Table Probabilities (expressed as percent chance) that an oil spill starting within a particular launch area in the Walker Ridge Planning Area will contact an international boundary sea segment within 3, 10 and 30 days

International Boundary Sea Segment	Number of Days		
	3	10	30
1	n	n	n
2	n	n	n
3	n	n	2
4	n	n	4
5	n	1	9
6	n	4	17
7	2	13	26
8	6	16	23
9	1	7	12
10	n	2	5
11	n	n	1
12	n	n	1
13	n	n	1
14	n	n	n
15	n	n	n
16	n	n	n
17	n	n	n

Note: ** = Greater than 99.5 percent; n = Less than 0.5 percent.

Remote Sensing & GIS :Tool in Risk Assessment*

- Provide a real time and low cost system for detecting oil spill, and assess spillage risk.

- The System is made of three sub-systems, that is, (i) Detection and Monitoring, (ii) spatial database, and (iii) Prediction.

- Oil spill data, access and protection information will be placed in GIS database and interfacing it with a relational database for rapid access, retrieval and query.

*: Shattri B: Remote Sensing and GIS Application In Oil Spills Risk Assessment, GIS Development.net,1998

- The remotely sensed data as spatial data input is used to derive valuable information about marine water pollution, especially on oil spillage.

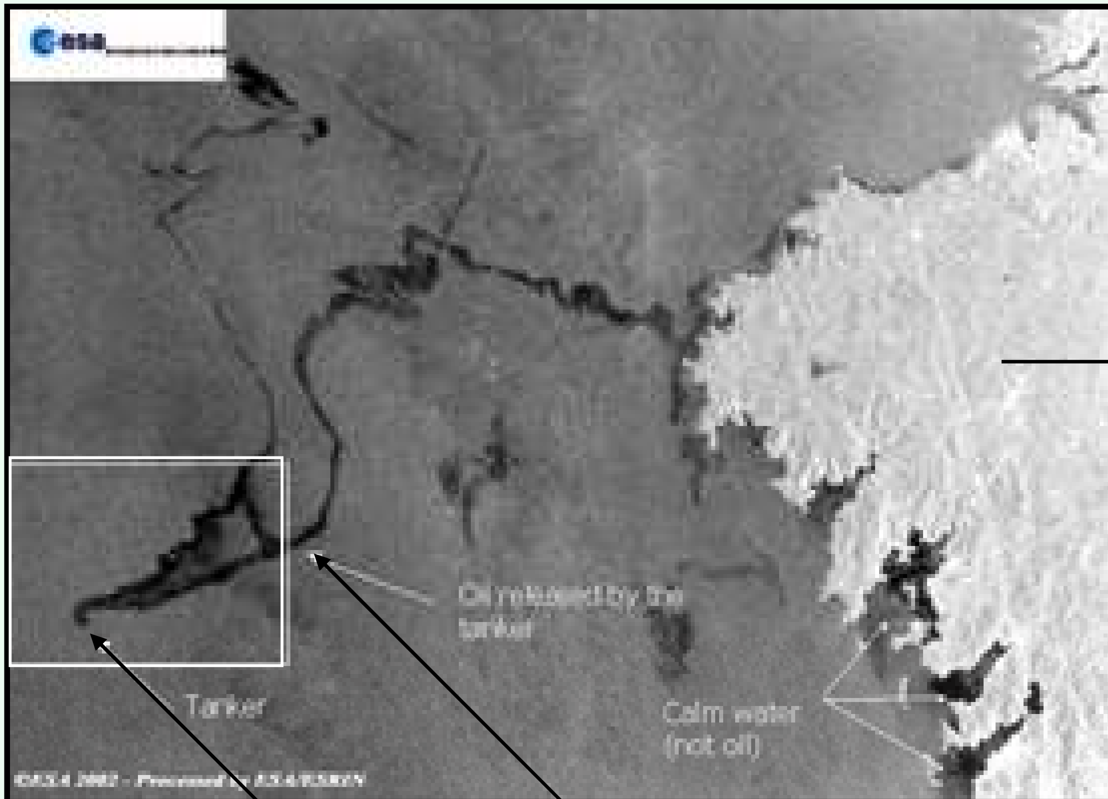
- The remotely sensed data including LANDSAT TM, SPOT Panchromatic and MSS (Multi Spectra Scanner), and air-borne images are integrated in the GIS based oil spill risk management system in order to detect, assess the risk and handle the oil spills problem in an alert situation.

- Various information can be retrieved from this system such as location of oil spills, quantity of oil spills, their distribution in the affected area; for example location of the areas of heaviest contamination, the length of shoreline affected by the oil slick.

- An oil slick movement model incorporated into this system in favor of predicting the oil slick movement direction and duration to reach the shoreline. Wind, wave and current are the main parameters for this model.

- The GIS based system can be used to establish the appropriate response and locate the dense areas in a slick and local surveillance, to permit clean-up vessels to detect the oil to be cleared in rapid circumstances.

- This risk management system will allow new opportunities for assessment, multiple resource planning, permit viewing of the state's natural resources in ways out therefore realized, improve the decision-making process, and provide a baseline for future assessments.



<u>Satellite Imaging of an Oil Spill by a Tanker</u>

Image Source: Optical Society of America, 2002

CONCLUSIONS

- A schematic risk assessment is required for proper analysis of threat of oil spills in marine environments.
- Both past data and model results can be used for risk estimation and are used as per background conditions for various regions.
- Risk analysis can be carried out in different ways but should achieve the ultimate objective of threat representation so that prevention strategies can be formulated.

Thanks