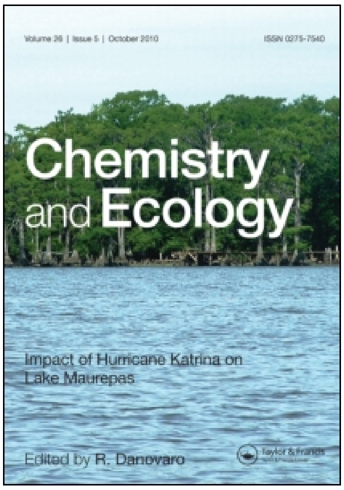

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QUANTITATIVE POLLUTION SPILL RISK ASSESSMENT: USING A GIS-BASED SYSTEM

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Federal and State agencies have recently advocated risk-based analysis as a mechanism for advancing regulatory reform and safety determination in marine systems. The present investigation promotes this objective through the development of risk-based environmental planning strategies for oil spill contingency plans. This alternative approach to contingency planning departs from conventional methodology by employing quantitative risk assessment methods to identify hazardous oil spill zones and sensitive environmental areas, R_o and R_e, respectively. The product of this conversion is referenced on a single "Risk" layer within a Geographic Information System (GIS) framework allowing coastal managers to evaluate natural resource data with associated elements of oil spill risk. As a new tool for coastal pollution management, risk-based environmental planning strategies have shown potential for evolving more efficient oil spill contingency plans.

Keywords: Environmental Sensitivity Index (ESI); Geographic Information Systems (GIS); oil spill contingency plan; Quantitative Risk Assessment (QRA)

INTRODUCTION

Increasing petroleum imports and accompanying vessel traffic within the coastal zone are exposing near shore ecosystems to greater risk from oil spills and associated resource degradation. Consequently, Area Contingency Plans (ACP's) have come under scrutiny in recent

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years to affirm the adequacy of emergency preparedness programmes. Resulting evaluations have suggested that while the contingency planning process has undergone positive changes since the implementation of the Oil Pollution Act of 1990 (OPA, 1990) (Slade, 1991; Holt and Johnson, 1995), further refinements are still necessary to provide the most efficient means in planning for, and responding to, spilled hazardous substances in the coastal zone (*e.g.*, US Coast Guard, 1996).

Risk Assessment

Unlike the detailed quantitative risk assessments required by the Federal Government for industrial ocean drilling licensees, ACPs are not necessarily mandated to employ Quantitative Risk Assessment (QRA) when generating environmental planning strategies. At present, planning elements which influence the location of manpower, equipment, spill drills, and protection strategies, are rarely quantitative (Iakovou *et al.*, 1996). Consequently, oil spill planning strategies are developed using general knowledge of shipping volumes and spill incidents, relying primarily on local emergency planning committees to supply area information.

In conducting contingency plan evaluations, consistent with Oil Pollution Act (OPA), 1990, Title VII, §5(A), the United States Coast Guard (1994a) recommended the design and implementation of a generic system for risk assessment which would form the basis for contingency plan formulation. A standardized approach to this planning element would allow for a quantitative comparison of risk between different port settings irrespective of port size, volume traffic, and other specific items (US Coast Guard, 1994b).

Project objectives included designing a standardized environmental risk assessment component to append existing oil spill risk analyses. The new methodology for estimating oil spill and environmental risk was evaluated in terms of serving as a constituent part for the evolving generic system for risk assessment.

Geographic Information Systems (GIS)

GIS technology has been embraced rapidly by the oil spill community. The Florida Marine Spill Analysis System uses GIS as the backbone of its analytical capabilities, as do the two most prominent oil spill information systems: Gulf-Wide Information Systems (G-WIS) and the Oil Spill Information Management System (OSIMS). The advantage of GIS over traditional mapping methods is obvious, GIS having more flexibility for modification and updating, as well as allowing multi-layers of map data to be presented as appropriate for any needs.

Sensitivity Indices

Since the *Ixtoc I* well blow-out in 1979, environmental sensitivity maps have played an integral role in protecting coastal resources from spilled oil. Gundlach and Hayes (1978) were the first to propose a classification system (*i.e.*, Environmental Sensitivity Index (ESI)) based on the environment's susceptibility to oil. Area planning committees now use sensitivity rankings to determine protection priorities, develop protection strategies and in identifying clean-up strategies (Pavia *et al.*, 1995). The National Oceanic and Atmospheric Administration (NOAA) maintains a national database housing all ESI rankings for coastal states. With the help of industry and the federal Government, NOAA periodically updates and distributes this information provides computer information.

METHODS

To complete the investigation, three subtasks were identified: 1) database acquisition, 2) ESI condensation and 3) risk assessment.

1. Database Acquisition

Oil spill databases were obtained from the South Florida Oil Spill Research Center (SFOSRC) at the University of Miami. The U.S. Coast Guard Marine Safety Information System (MSIS) database, housing technical data on oil spills (spill incident name, latitude/longitude, volume of lost product) occurring in the Gulf of Mexico, was obtained and edited to reflect information pertaining to the study area: Tampa Bay, Florida.

Natural resource and habitat coverages for Tampa Bay were provided by the Florida Department of Environmental Protection, Florida Marine Research Institute (FMRI) and the U.S. Coast Guard. ArcInfo® coverages: base map, ESI, manatee, seagrass and oil spill coverages were imported into GIS software ArcView® and edited to reflect the spatial distribution of natural resources in Tampa Bay.

2. ESI Condensation

To make this product usable and more efficient than conventional indices, the 10 ESI shorelines were condensed and grouped into five new categories (Tab. I): High priority, high-medium priority, medium priority, medium-low priority, and low priority shorelines, or ecotypes. In cases where ESI shorelines were denoted by two numbers (*i.e.*, 10E/6 or 3/8), the ecotype was placed into the highest priority condensed group reflecting the higher of the split designations. This was done to afford the shoreline the greatest level of protection. The original ESI coverage for Tampa Bay was then reconfigured to display the new ESI conversions.

For project objectives, sensitivity indices were expanded from the traditional shoreline rankings to habitat coverages imported for the study. Rankings were based on both sensitivity to oiling and the magnitude of the resources.

TABLE I ESI shoreline condensation procedure for new ESI classification

ESI Shoreline designation	*Shoreline "ecotype"*	*New ESI Category*
10E	sheltered mangroves and marshes	5
10A	exposed mangroves and marshes	5
9	sheltered tidal flats	5
8	sheltered rocks/sea walls/vegetated banks	4
7	exposed tidal flats	4
6	gravel beaches/riprap	3
5	mixed sand and gravel beaches	3
4	coarse grained sand beaches	2
3	fine sand beaches	2
2	exposed rocky platforms	1
1	exposed vertical rocky shores/sea walls	1

3. Risk Assessment

Risk to natural resources from oil spills was determined by calculating two independent risk values R_o and R_c. Historical oil spill frequency and volume data were evaluated using Equation (1):

$$R_o = \text{Laf}^*\text{Lav},$$

where Laf = log oil spill $[(\text{freq}/5)/n_f]$ and Lav = log oil spill (vol/n_v) were used to determine oil spill risk R_o (n_f is frequency, n_v is number) (Fig. 1 and Tab. II). The magnitude of R_o is then determined the circumference of oil spill risk zones; increasing the zone radii $1.6{\cdot}10^3$ m for every four risk values. Environmental risk values (R_e) were computed by quantifying the natural resources that fall within oil spill risk zones: Equation (2) is a summary of the method for determining R_e:

$$R_e = \text{Lal} + \text{Las} + \text{Lam},$$

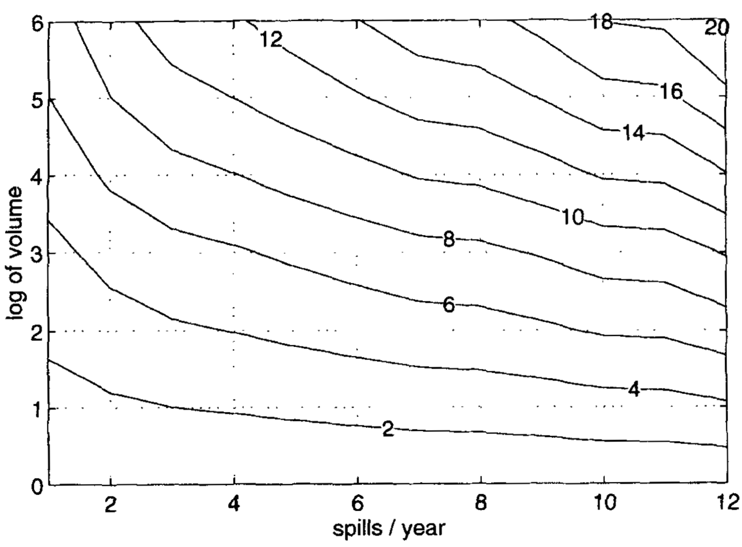

FIGURE 1 Risk values as a function of oil spill frequency and volume. The graph expresses the relationship between oil spill frequency and volume data as risk contours. The magnitude of the oil spill risk value, R_o determines the circumference of the risk zone.

TABLE II Oil spill frequency (Laf) and volume data (Lav) adjusted to yield risk value R_o

Lat/Long	*Frequency*	*Laf*	*Volume (gal)*	*Lav*	*Oil spill risk value, R_o*
27.95, 82.43	63	3.1	78000	5.415	16.787
27.91, 82.43	57	3.057	50570	5.228	15.982
27.91, 82.41	22	1.865	291000	6.163	11.494
27.90, 82.41	58	3.064	1080	3.431	10.513
27.90, 82.43	28	1.97	24260	4.907	9.667
27.86, 82.53	21	1.778	30210	5.003	8.895
27.91, 82.58	16	1.66	35000	5.067	8.411
27.93, 82.45	21	1.778	9210	4.362	7.755
27.75, 82.62	31	2.093	310	2.792	5.844
27.71, 82.71	28	1.97	280	2.748	5.414

where Lal = $\log[\Sigma(\text{ESI}1l\ldots5l/nl_1\ldots l_5)]$ (Tab. III), Las = $\log[(\text{sea}\%{}^*0.25)/n_s]$ and Lam = $\log[(\text{man}^*0.5/5)/n_m] + 1$. To complete the risk assessment, R_o and R_c were evaluated within the context of ACP environmental planning strategies.

RESULTS AND DISCUSSION

As an alternative methodology for developing contingency plan elements, risk-based environmental planning strategies differ from ACP Area Response Plan Maps by quantitatively identifying oil spill risk zones and natural resources (Figs. 2 and 3). This method has proven

TABLE III ESI classification of shoreline segment lengths with associated Lal value

Lat/Long	*ESI segment length(ft):*	*ESI1*	*ESI2*	*ESI3*	*ESI4*	*ESI5*	*Lal*
27.95, 82.43		0	0	8987	13217	16265	5.413
27.91, 82.43		1257	534	0	16143	8673	5.227
27.91, 82.41		0	476	9194	8976	6543	5.153
27.90, 82.41		0	0	221	3752	10824	5.106
27.90, 82.43		1674	0	14574	8514	2732	5.083
27.86, 82.53		0	790	1891	1794	9973	5.068
27.91, 82.58		0	657	2905	3898	8466	5.062
27.93, 82.45		0	2373	2702	19840	0	5.057
27.75, 82.62		910	0	0	10244	4045	4.962
27.71, 82.71		0	0	11783	0	3217	4.874

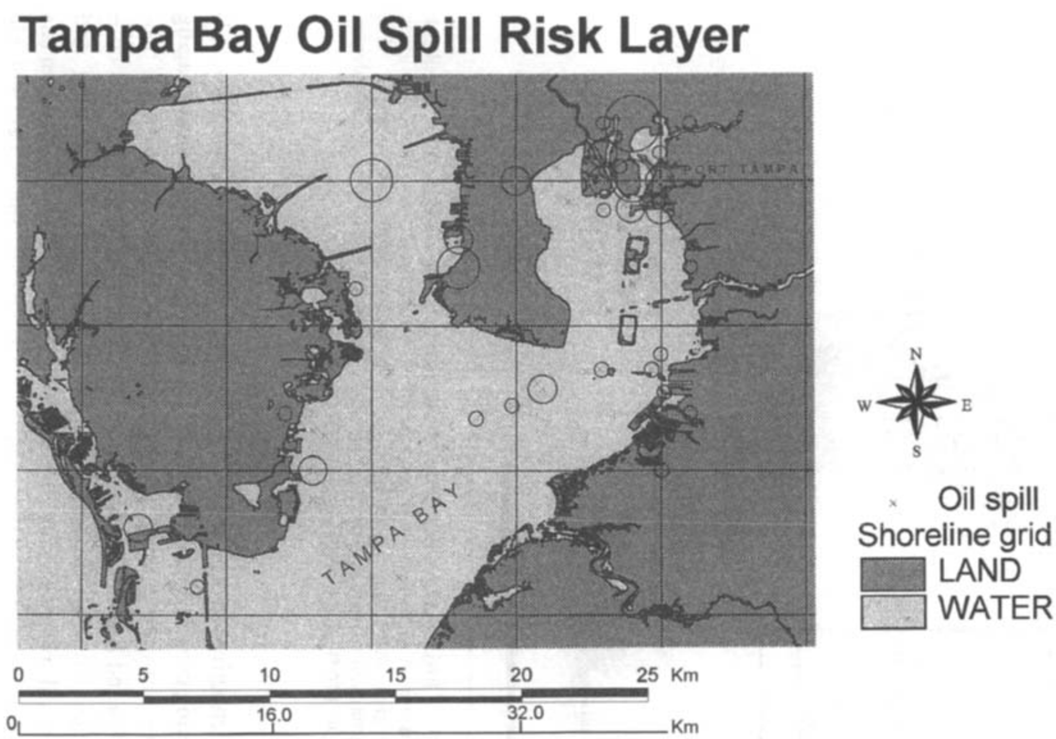

FIGURE 2 Tampa Bay oil spill risk layer. The Tampa Bay basemap is overlaid with a layer of oil spill risk allowing managers to plan spill response tactics for areas most likely to receive oil contamination.

Risk - Based Planning Map

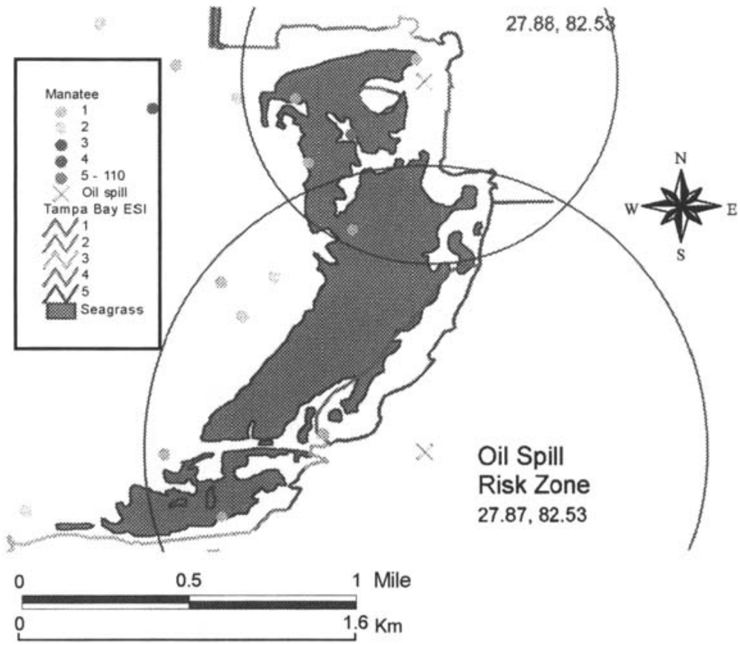

FIGURE 3 Risk-based planning map. Risk-based planning maps identify oil spill risk zones and the natural resources within zone limits. Natural resources in the oil spill risk zone are quantified using Equation (2). to yield environmental risk values, R_e. The planning maps allow managers to set protection priorities, determine protection strategies, and identify pre-staging area for response equipment.

to be effective in (1) evolving resource protection priorities, (2) developing protection strategies, (3) identifying appropriate pre-staging areas for response equipment, (4) promoting integration with the proposed United States generic system for port risk assessment and contemporary oil spill information systems, and (5) maintaining and updating oil spill risk values in a database format. The investigation has shown that standardized risk value assignments (R_o and R_e) are a viable alternative to qualitative oil spill assessment methodologies.

As a finding separate from project objectives, base map and natural resource coverages were found to be inconsistent when viewed simultaneously. Reasons for this may have arisen from temporal variations in coverage production dates or from coverage reference to tidal marks. This observation identifies a common concern when using GIS to analyze spatial data, but did not affect the outcome of this investigation.

The Tampa Bay Area Contingency Plan for Oil and Hazardous Substance and Pollution Response divides environmental planning and response issues into three sections, each of which are covered by an Area Subcommittee to follow through the sections below. The Scientific Support Subcommittee supplies information regarding the following tasks:

1. identification and mapping of economic and environmentally sensitive areas,
2. identification of response strategies in sensitive areas,
3. priority of sensitive areas for protection,
4. development of site-specific response strategies, including the possibility of pre-staging response equipment in the vicinity,
5. appropriate countermeasures for offshore and inshore areas (MSO Tampa Bay, 1996).

The Preparedness Subcommittee incorporates the scientific data into the overall contingency planning process for Tampa Bay. This includes, but is not limited to, developing strategies for response to oil spills and preparing spill drills and exercises.

Risk-based Planning

This investigation sought also to determine the usefulness of risk-based environmental planning for tasks charged to the Scientific Support and Preparedness Subcommittees. In the present Tampa plan, there is no quantitative method for defining oil spill risk zones or environmental risk within oil spill zones.

Because of limited resources to protect sensitive areas, planning committees can benefit from the incorporation of criteria other than sensitivity to oiling as a method for priority significant economic and environmental regions; the criteria are at risk. The question of how to plan for environmental contingencies between two or many equally sensitive areas is thus solved by incorporating a GIS risk layer on to habitat coverages. Risk-based planning addresses this strategy by allowing planners to:

- Priority for resource protection. Risk-based planning allows environmental managers to identify oil spill protection priorities. When two regions are of equal environmental or economic importance, oil spill risk defines protection priority. When two regions are of equal oil spill risk, environmental and/or economic sensitivity defines protection priority. In this manner, a quantitative assessment of oil spill and environmental risk provides an objective rationale for resource priority. Although not included in the present study, provisions will be made to incorporate U. S. Army Corps of Engineers petroleum transport data into the risk assessment framework.
- Develop protection strategies. Quantitative evaluations of sensitive resources within oil spill risk zones will permit planners to develop environmental protection strategies catered to the specific needs of each identifiable risk zone. The GIS framework permits managers to query risk zones for the amount and kind of petroleum spilled in the area. In this manner, managers can estimate and plan for the equipment needed to protect and clean natural resources within defined risk zones.
- Designate pre-staging areas. Based on analysis of oil spill and environmental risk, planners can identify the area most likely to be impacted from an oil spill and pre-stage the response equipment accordingly.
- Update information. The GIS database framework supplies the user with a simple means for entering new data pertaining to oil spills as the information becomes available. In this manner, as oil spill and environmental risk zones change, ACP elements such as resource priority and planning strategies can be amended as needed.

CONCLUSION

The present investigation provides a setting in which quantitative risk and environmental sensitivity are combined within a GIS framework. Risk-based planning strategies therefore allow contingency planners to view natural resource data with associated elements of oil spill and environmental risk. This alternative methodology has increased the efficiency and applicability of contingency planning.

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