Decision Support and Communication for Oil Spills in the Coastal Zone – An Integrated Web and GIS approach for the Norwegian Coast

Geir Morten Skeie[1], Odd Willy Brude[1], Frode Engen[2], Kjell Are Moe[1], & Ole Hansen[3]

[1]Alpha Environmental Consultants, [2]Norwegian Clean Seas Association for Operating Companies (NOFO), [3]Norwegian Coastal Administration

Abstract

When an oil spill occurs in coastal waters, the situation can rapidly develop and increase in complexity. Depending on the characteristics of the spill, oil slicks spread and travel in different directions as a result of local winds and tidal currents. Each individual slick may require specific response measures, based on the resources at risk. If oil reaches the shoreline, the coastal characteristics will determine restoration and protection priorities, including cleanup strategies.

The Norwegian coastline presents a particular challenge because it has a length of more than 82,000 km; a high degree of complexity and diversity, and over 20,000 sites of environmental priority, the Norwegian coastline presents a particular challenge. To meet this challenge, a computer-based system has been developed and implemented integrating GIS (Geographical Information Systems) and web components. This system is based on high resolution sea charts, as well as detailed national data sets on vulnerable coastal

locations. A special user-interface has also been developed and tailored specifically for the needs of oil spill command-centers.

Based on input from a range of sources, digital maps present the estimated oil slick formations and track the movement of the spilled oil. Sensitive sites and shoreline characteristics are also depicted on the maps, which serve as a quick reference for oil spill responders. From this critical information, priorities can be made, response efforts identified and marked on the map. This information is then distributed to the relevant parts of the oil spill response organization and to the general public, as appropriate.

The computer-based system is implemented by Norwegian operators and is a core tool for large scale training drills and spill response exercises. Norwegian authorities have also recently applied the system in evaluations of a series of ship incidents.

This paper focuses on the functionality of the user-interface component of the system, and discusses issues that may be applicable for oil spill operations in all coastal waters.

Background

Mainland Norway is located between latitude 58° N and 71° N and longitude 5° to 31° E. Norway is among the world's main producers of oil and gas, with a production of 157 262 000 tons of oil and 68 881 000 000 Sm^3 of natural gas in 2002 (Anon., 2003). A total of 49 offshore fields are currently in production on the Norwegian continental shelf.

This includes 37 production platforms, 3 production ships, 79 sub sea installations, 7,877 km of oil and gas pipelines, and more than 1,500 development wells.

Biological resources are abundant along the Norwegian coastline and the adjacent shelf areas. The coastal and marine environments contain ecological resources with a national as well as an international importance. The management and protection of these resources is a major issue of concern for Norwegian authorities as well as for the operators on the Norwegian continental shelf. In addition, Norwegian authorities are concerned with protecting the interests of commercial fisheries. Commercial fisheries are one of the most important industries in Norway. The development of aquaculture of Atlantic salmon during the last decade has placed Norway among the world's leading suppliers of farmed fish and shellfish.

Oil spill contingency and emergency response planning have emerged as important issues of concern in Norway as a consequence of the potential threat that an accidental marine pollution event poses to the vulnerable marine environment. This has initiated the development of a series of national guidelines and standards related to acute oil spills have been developed, Background research included Particularly Sensitive Areas (PSA) and petroleum activity (Moe *et al.*, 1999a), a model for prioritization of environmental resources (Anon., 1996), guidelines for environmental monitoring during and after oil spills (Moe *et al.*, 1999b), as well as guidelines for cleanup operations after an oil spill (Carroll *et al.*, 1999; Langfeldt & Køgeler, 1999). Another result of the emphasis placed on planning and emergency response has been the early development of digital databases

and decision support systems. By 1994, sensitive resources along the entire Norwegian coastline were documented in a national database (Skeie *et al*., 1995). In the past few years, a number of other web and GIS based projects related to acute oil spills and emergency response have been implemented (e.g. Skeie *et al*., 1999, 2000; Rødal et al., 2003).

However, several gaps in the coverage of information related to the coastline have been revealed from the projects described above. These gaps are comprised of the following subsets: a) Data (high resolution coastline, coastal characteristics, bathymetry, b) Operationalization (moving from qualitative guidelines to quantitative analyses) and c) Interfacing (integrating data sets and approaches in a structure suitable for decision support).

Availability and quality of data

A systematic review of all available data formed the initial phase of our work. This review concluded that the most relevant data were as follows:

Coastline and bathymetry

The Norwegian Mapping Authority has the overall responsibility for maintaining digital data for the Norwegian coastline and the Norwegian economic zone. The data are commercially available in two different formats, with only a limited geographical overlap. Maps of the southern part of Norway are presented predominantly in the IMO

S57 format, while the remaining areas of the country are presented in a proprietary NSKV format only.

Shoreline habitats

Large parts of the Norwegian coastline habitat were classified with regard to geophysical characteristics such as substrate and beach morphology in the 1980s (e.g. Klokk *et al.*, 1982). This work was based on 1:50,000 land maps, and the results presented as a series of scaled down paper maps. Data for use in shoreline habitat classification also included geological maps, available from the Geological Survey of Norway (NGU), as well as aerial photographs available from the offices of the County Governor.

Shoreline sensitivity

In the year 2000, Norwegian authorities established a set of guidelines for use in prioritizing shorelines during an oil spill response operation. These guidelines identified sensitive shoreline locations in order to establish protection priorities and identify cleanup strategies. In terms of environmental sensitivity, the presence of vulnerable resources was considered an important element. Digital data sets on the presence of these resources are available from several of the County Governors, and are also available on a nationwide basis in the Marine Resources Data Base (see Skeie et al., 1995).

Wave exposure of shoreline

An important aspect in decisions regarding protection and cleanup strategies are the degree of wave exposure. This aspect has implication on residence time of oil (i.e. self-

cleaning) and also safety of personnel and equipment involved in cleanup operations. At the beginning of this project, such data were not available.

Data quality

All decision support systems require high quality data for high quality decisions. In the development and maintenance of this system, data quality has been a key issue. Different data types were systematically reviewed in terms of their temporal variation and sensitivity for decision making. From this review, three main groups were identified:

- Shoreline characteristics. During field training and exercises, photographic documentation of is collected and the GIS data sets verified. If discrepancies are observed, the data base is updated and photographic documentation included in the system, for interactive display from the digital maps.

- Changes in infrastructure. New roads, harbour structures and landfills are ongoing activities. It is the intention to annually update this information, which is held by the NCA, one of the users of the system.

- Sensitive environmental resources. These resources show significant seasonal variations in presence and sensitivity. As overlap between such resources is one of the components in shoreline sensitivity, conservative approach has been selected, in that any presence at any time of the year is considered an overlap. These data are updated on an annual basis.

While the first two groups are data forming an integral part of the system, the third group comprises external data, which may come from a wide range of data sources. As a result,

automatic routines for performing overlap analyses with shoreline data are provided for the end user of the system, allowing additional updates whenever needed.

Design

The overall design of the system was developed in a series of meetings with a project work group involving various types of users, such as operators and Norwegian authorities. From these discussions, an overall system design was established, incorporating the following main components:

- GIS data sets in ArcView shapefile format

- Textual information in HTML format

- GIS functionality through an ArcView Extension

- Web functionality through Microsoft FrontPage

- Status tracking via an integrated GIS and Web interface.

A core task of the work group was to evolve quantitative relations from qualitative recommendations and guidelines, thus enabling GIS and web functionality in terms of prioritizing shorelines and selecting cleanup methods.

Data compilation

Coastline and bathymetry

Mapping data were purchased from The Norwegian Mapping Authority, in the S57 format as well as the proprietary NSKV format. Based on documentation of the

proprietary format, a series of algorithms was developed to convert the proprietary format to ArcView shapefiles. To include all related attribute information, different algorithms were required for the three basic formats (Polygon, Line and Point) and for various data subsets.

The second step in the data compilation phase involved the splicing of thematic data to achieve complete geographical coverage. This step required extensive efforts due to the need to standardize two different systems for nomenclature and subdivisions. The third step in the process of compiling these data types included two extensive GIS calculations. The first calculation established a national grid on bathymetry based on all 400,000 individual depth measurements, using ArcView Spatial Analyst. The resulting grid was then converted to polygons, to allow use of the data set in standard ArcView applications. The second calculation used a set of buffer functions to establish a polygon theme of all areas where the distance to the shoreline was less than 200m or where water depth was less than 20m, indicating areas where the use of chemical dispersants are not recommended.

Shoreline habitats

The basis for the initial work on establishing a digital data set on shoreline habitats was formed by using existing paper maps, a revised classification scheme, and the high resolution coastline maps from the data compilation formed. Initially, this work began in the Northern counties of Norway, as a joint effort between several research institutions. The coverage progressed southwards, and detailed aerial photographs were applied in

several counties where these were required for a successful classification. A complete national coverage of shoreline habitats was achieved in mid-2003. During this process, a discrepancy was unveiled involving differences in the location of the coastline in the data sets from the two branches of the Mapping Authority dealing respectively with land maps and charts. It is our understanding that this discrepancy has been addressed and adjusted in favor of the charts.

Shoreline sensitivity

In cooperation with the relevant authorities, each shoreline habitat was attributed an initial sensitivity on a scale from 1 to 3, based on a combination of shoreline habitat and degree of wave exposure (Table 1).

The model developed by Norwegian authorities for prioritizing vulnerable resources was made operational in 1999, to allow standardized evaluation of different data sets on a month–to–month basis (Skeie *et al.*, 1999). This model also allows calculation of maximum annual priority, i.e. the highest priority value achieved by a given area in any month of the year. An ArcView script was developed to calculate overlap between individual shoreline segments and areas of designated priority, assigning the segment a value from 1 to 3, depending on the priority of the area.

The shoreline sensitivity priority model developed during the project contains four different levels, where the fourth also takes into account degree of contamination. The priority model is now integrated in the computer-based system.

Wave exposure of shoreline

To quantify wave exposure along the coastline with an appropriate spatial resolution, a total of 78 000 calculation points were evenly distributed along the digital coastline. Data on historical wind on adjacent meteorological stations were acquired from the Norwegian Meteorological Institute, and wave exposure calculated according to a model first presented by Baardseth (1970), and further modified by others, see Kvist & Lein (1999).

The model is based on wind statistics, i.e. observations on wind direction and force, and the number of open sectors, Sn, referring to open water encompassing the site, i.e. sectors not comprising land contours within a given radius. For each location, calculations are made for three distance intervals within 36 circle sectors, and an exposure values is assigned. By interpolating exposure values from adjacent locations, exposure values were subsequently calculated for all shoreline segments.

System Architecture and User Interface

Based on the overall design, the detailed design of the computer-based system has evolved throughout the project, according to feedback from users, lessons learned, and an increasing demand for functionality specifically designed for various areas of use.

The current architecture of the system is depicted in Fig.1. The information is organized in databases, some of which are geo-referenced. Access to this information is given through either a web or a GIS interface. The system is installed on computers, usually laptops, which are set up as personal web servers using MS Internet Information Server.

When used in an oil spill response operation, access to the Web interface is provided through a dedicated intranet, and access may also be provided to other parts of the response organization through extranet or the internet.

In the following, selected highlights are given for the web and the GIS interface, respectively.

The Web interface

Through the web interface, access is given to all textual information, as well as databases and data sets.

The main parts of the textual information include the priority model, description of a range of cleanup methods (Fig. 2), and the user manual for the web as well as the GIS interface. An important aspect of the web interface is the presentation of results from field verifications, where digital data sets are checked versus "the real world" (Fig 3). Results are documented through geo-referenced digital photographs, and any discrepancies are addressed in updated digital data sets.

The web interface also provides access to information from databases. In an oil spill response operation, the situation is continuously followed and logged through the GIS interface. As this information is essential also for other parts of the oil spill responders, it is made available through database queries from the web. The databases include:

- Situation maps, showing the location of oil spills, oil spill response resources and sensitive biological resources (Fig. 4). These maps are sorted according to time stamp and location, and may be downloaded to local disks or distributed to relevant parties via email.

- Oil spill response resources, showing name and type of resource, number of units, mobilization time, amount of oil recovered, and demobilization time. Changes in the location made through the GIS interface are reflected on-line.

- Oil slicks, which are individually labeled and tracked throughout the event until either successfully removed from the sea surface or stranded.

- Monitoring data, allowing presentation of results from monitoring studies carried out according to national guidelines.

During an oil spill response operation, a "Status page" is available to all computers linked through the intranet or extranet. This page provides the latest information on key parameters such as; total oil spilled number of oil slicks still on the sea, total oil recovered, number of units active in oil spill operations, as well as the number of situation maps prepared. During an oil spill response operation, the standard queries present current status on all parameters, e.g. last location of any given oil slick. However, all information is stored in the system, allowing subsequent analyses of the entire incident and full and complete documentation.

The GIS interface

Through the GIS interface, all standard ArcView functionalities are made available. In addition a number of routines have been tailored to specific users of the system.

All spatial information relevant to the oil spill response operation is entered and updated through the GIS interface. This includes oil slick formations, location of response equipment, and stations for monitoring studies. The GIS interface also provides access to a series of functions for queries, analysis and visualization of relevant information. Selected examples are given below.

- Protection and cleanup priority, where the shoreline may be interactively classified according to shoreline type, degree of wave exposure, and three different levels of the priority model. An example is given in Fig. 5.

- Oil drift trajectory, allowing a visual representation how wind, currents, and other processes might move and spread oil that has spilled on the water (Fig. 6).

- Auto-location, where the user enters the latitude and longitude for a specific location and is immediately presented with a standardized digital map of the area in question The location of interest is pinpointed as a marker on the map.

- Shoreline summaries, allowing the user to interactively query selected areas of the map and obtain statistics of the length of shoreline with different habitat types.

- Daylight availability, where operational light and twilight are calculated for any given location and date. These calculations are also available on an annual basis, showing daylight availability for individual months (Fig 7).

- Oil slick presentation, where input on location and dimensions of an oil slick are used to automatically generate a representation on the screen, where the mass of oil is calculated from the input data.

Examples of Application

The computer-based system is primarily designed for oil spill response operational use, but other areas of application have emerged during the development process. Selected examples of use are given below.

Potential groundings

On several occasions, the Norwegian Coastal Administration has used the system when ships have reported problems and there is a potential for grounding. In these instances, the auto-location routine of the user-interface provides a near-immediate overview of the situation, locating the vessel and presenting a digital nautical chart of the surrounding area. Situation maps are generated and distributed to relevant parties.

Cleanup operations from wrecked ships

In the past few years there have been several groundings of ships along the Norwegian coast, with concomitant oil spills. During the subsequent oil spill cleanup operations, the computer-based system has been applied in analysis of suitable cleanup strategies as well as in calculation of total sum of human and technical resources required in the cleanup operation.

Oil Spill Contingency Analysis

Results from oil drift simulations have been used as an input to a series of analyses in the dimensioning of the national oil spill response plan for oil spills from ships. Different

scenarios have been analyzed in terms of contaminated coastline, cleanup methods, and oil spill response resources required.

Oil Spill Response training

The most extensive testing and application of the computer-based system has been undertaken in large scale oil spill response exercises run by NOFO on behalf of the Norwegian operators. Each exercise involves several hundred personnel. The computer-based system is set up in the oil spill operation's mobile command-center where computers are linked in a wireless network. In this setting, the system is on-line throughout the exercise and the map from the GIS part of the system is displayed on a dedicated screen in the operations central.

Analysis of shoreline benthic communities

The GIS data in the system has been applied in an integrated concept for semi-quantitative analyses of the potential damage of acute oil pollution on seashore habitats (Moe *et al.* 2000a, b). This model describes the impact as a function of the immediate extent and the duration of damage, and is based on the integral of the inherent physical and ecological characteristics of the beaches relevant to the fate and significance of oil; i.e. community specific sensitivity and recovery potential; oil accumulation capacity and retention ability of the substrate; and in this regard, the ice cover and wave exposure. The model is implemented by tailored GIS routines for identification of the shoreline sensitivity and vulnerability, and in this respect, estimations of potential environmental damage. A national coverage was achieved in 2003.

Lessons learned

Several of the lessons learned in development and use of the computer-based system may be relevant for oil spill response measures in other geographical areas. A few of the lessons learned are discussed below.

- Standards are important and should be viewed as prerequisites for rapid exchange of information in situations with tight time constraints.

- Guidelines and manuals should be prepared for all relevant aspects and they need to be suitable for translation into algorithms that can be used by the system.

- Establish a "common ground" for communication. There are many people involved in an oil spill operation and their background and use of technical terms will vary. One example is the use of latitude and longitude information for all marine parties, while the land based part use UTM coordinates. On line conversion of knots to meters per second is another example.

- Apply maps in communication. A simple map can communicate an idea much faster and more effectively than a discussion without the visual aid.

Acknowledgments

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Tables

Table 1. Initial sensitivity of the priority model, derived from the combination of shoreline habitat and degree of wave exposure.

Shoreline habitat	Degree of wave exposure		
	1	2	3
Cliffs	1	1	1
Rocky shores	2	1	1
Boulder beaches	3	2	1
Stone/gravel beaches	3	2	2

Sandy beaches	2	2	1
Clay/silt beaches	3	3	3
Anthropogenic structures	1	1	1

Figures
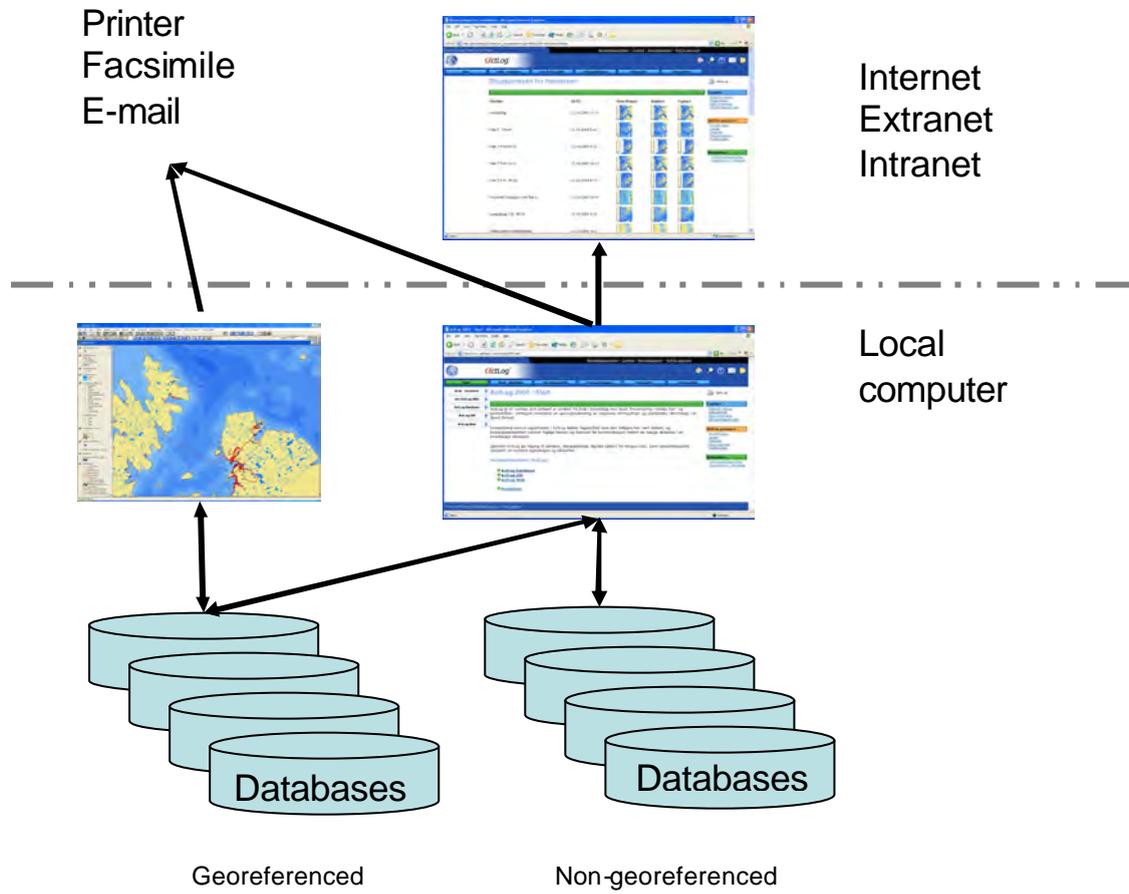
Figure 1. Structure of the computer system.

Figure 2. Illustration showing how the applicability of different cleanup methods is presented for each habitat shoreline type. For each method ("Tiltak" in Norwegian), hyperlinks to detailed descriptions of the method is provided.
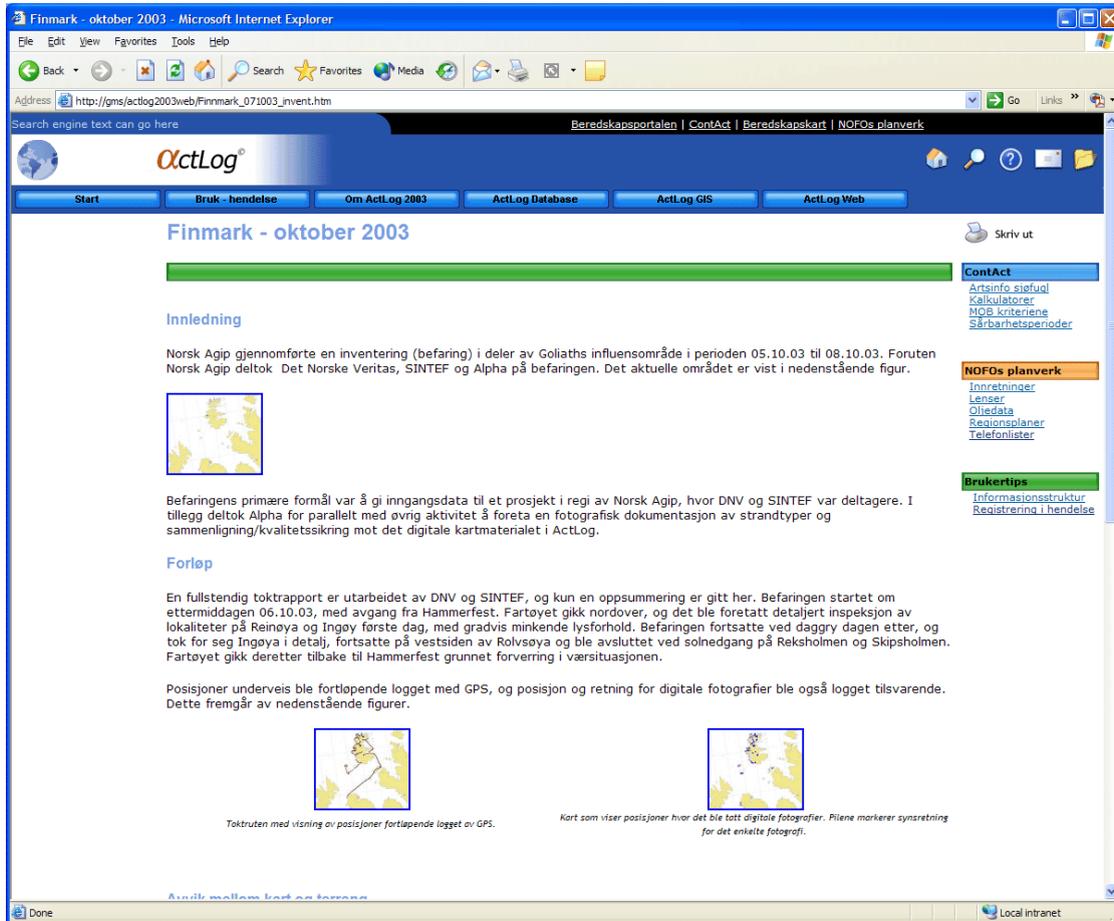
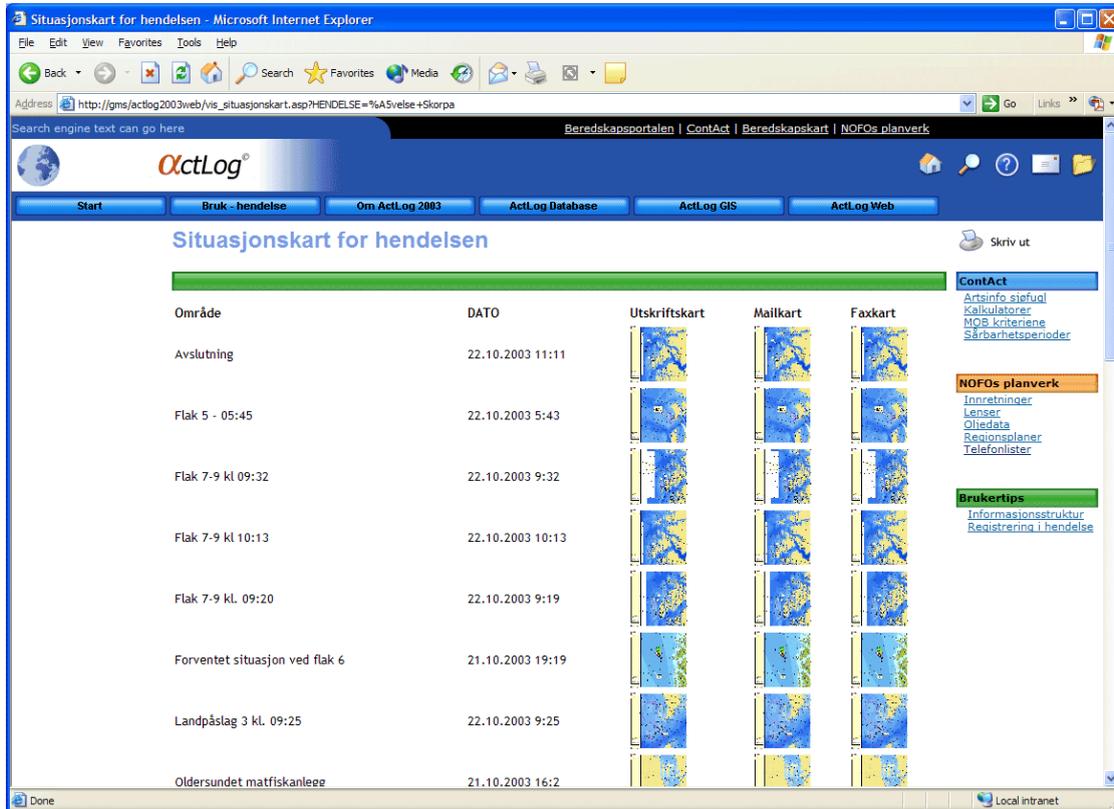Figure 3. Illustration showing how results from field verifications are presented in the web interface..

Figure 4. Results from a database query on situation maps from an oil spill combat exercise. Information provided in the columns is from left to right: Geographical area, date and time stamp for generation of the map, and hyperlinks to different versions of the map (print, web and fax, with appropriate resolution and size of image file).

Figure 5. Example of application of the model for prioritization. To the left, the shoreline is classified according to shoreline type. The middle figure shows the results when initial sensitivity is included. The figure to the right shows the results when overlap with high priority environmental resources is included in the evaluation
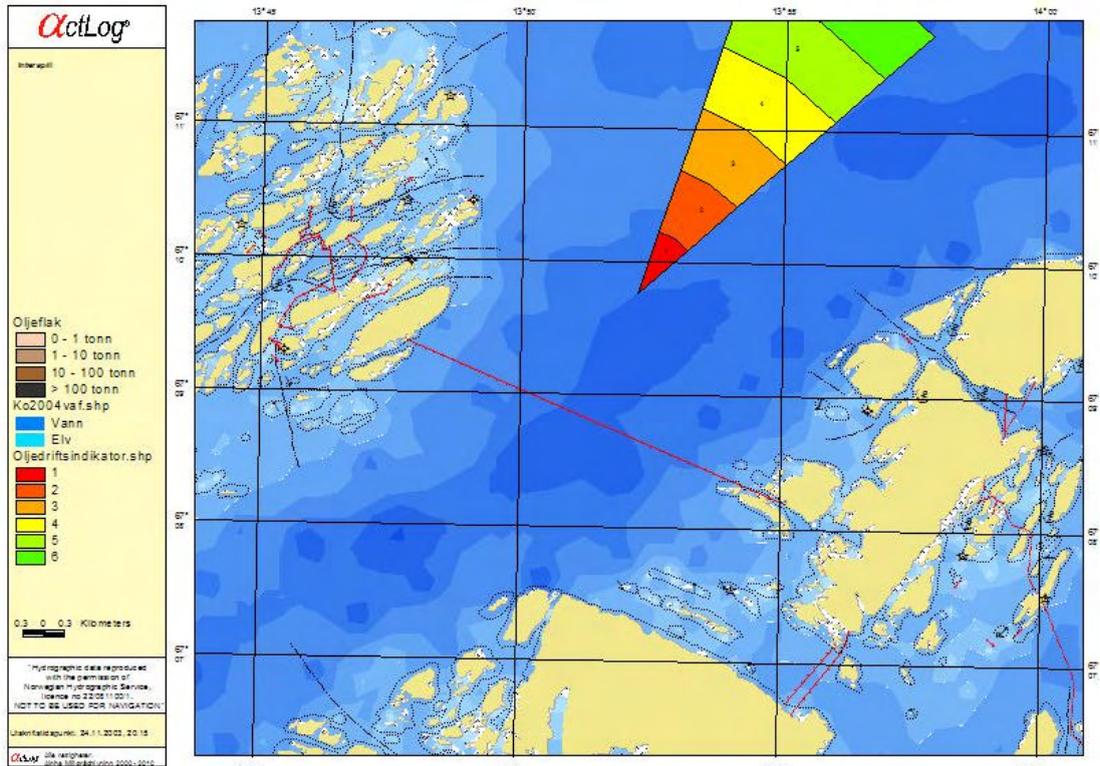
Figure 6. Map generated from the system, showing an indication of oil drift for the next 6 hours.
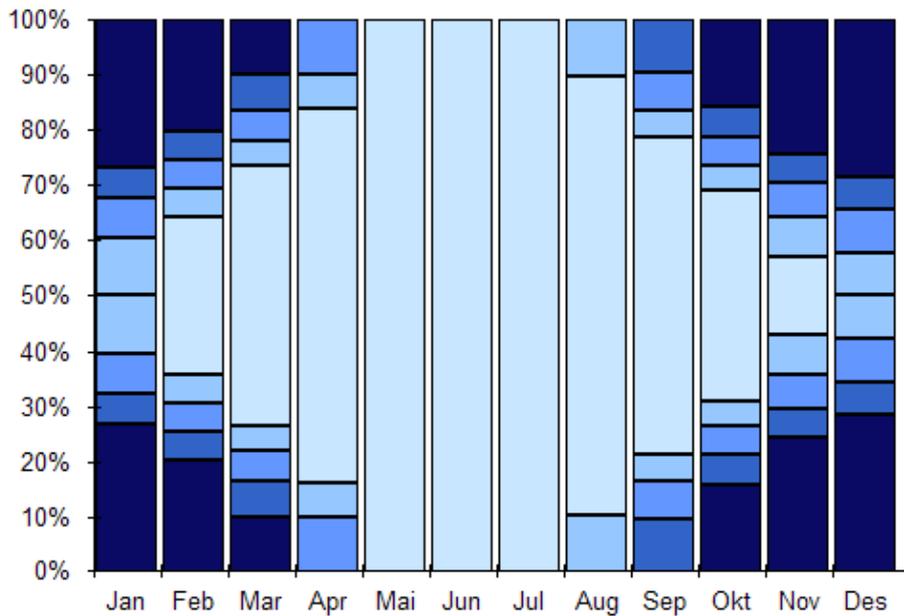

Figure 7. Presentation of monthly variations in daylight (vertical mid section, lightest color), twilight and darkness for the centre of the map.