# Regional Contingency Planning Using the OSCAR Oil Spill Contingency and Response Model

by

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## Abstract

Oil spill contingency planning requires the quantitative comparison of alternative response options so that the most appropriate, effective and/or cost-effective option can be recommended.

A model system for Oil Spill Contingency and Response (OSCAR) has been used to evaluate first line oil spill response strategies for different fields in the Norwegian sector of the North Sea. The system consists of a three-dimensional numerical model of the physical and chemical behavior and fate of spilled oil, and an oil spill response simulation of various currently available mechanical recovery and dispersant application systems. By providing a quantitative and more objective assessment of response performance, the response can be dimensioned based on physical or biological criteria set for the region in question. The cost, effectiveness (as defined on the basis of various criteria) and environmental benefit of various options can be compared.

The paper demonstrates how weathering studies combined with modelling of probable spill scenarios can be used to develop relevant, site-specific contingency plans. The effect of oil type, spill size and release conditions on response performance is clearly demonstrated.

## 1. The need for quantitative analysis of oil spill response options

Offshore oil exploration, production or transportation activities present the small risk of an oil spill. This risk may be minimized by good engineering and operating practice, but can never be entirely eliminated. Oil spill contingency plans are developed to assess the risk and to decide which response method (mechanical containment / recovery, dispersant use or possibly in-situ burning) is the most suitable way of dealing with potential oil spills. These decisions need to be made on a site-specific basis and with realistic oil spill scenarios. The scale of the response must be consistent with the perceived risk. It is obviously not feasible to plan a response to the biggest possible spills at all locations. The response system that is deployed must be as effective as possible within the constraints of available resources.

In some circumstances it is possible to use qualitative criteria to decide between alternative response approaches; if dispersant use is not likely to be effective because of the oil type or is not permitted by local regulations, mechanical recovery is the only realistic active option. In other cases, dispersant use may be the preferred option. Once the decision has been taken as to which response strategy is most appropriate, the amount of resources (equipment and personnel) that need to be deployed must be determined. This requires decisions to be made about the purpose of the response.

The general principle of any oil spill response is very clear: the response should reduce the negative effects (environmental, amenity or financial) that could be caused by the oil spill if no response were undertaken. This is easy to define in principle, but much more difficult to translate into practice because it does not define concrete performance targets. Using the above definition it is necessary to predict the total amount of damage that an oil spill would cause before estimating how much of this damage would be prevented by the proposed response. This process has been formalized as the NEBA (Net Environmental Benefit Analysis) process. It requires considering the overall environmental effects of the response and non-response, rather than concentrating on more limited, but much more easily defined, aspects such as the amount of oil recovered, dispersed or burned or the consequences to one particular natural resource. It is unlikely that all the data concerning the sensitive resources, their complex interactions and the effect of oil pollution upon them, could be gathered or analyzed to give an absolutely ‘correct’ NEBA answer. NEBA therefore frequently involves making value judgements regarding the relative worth of these resources. This is not a weakness of NEBA - it focuses attention on the real purpose of oil spill response, rather than expending effort on subsidiary issues and details.

Other approaches have been devised to quantify the effects of an oil spill. The NRDA (Natural Resource Damage Assessment) approach, practiced by federal and state authorities in the USA, attempts to estimate injury to natural resources caused by oil pollution and to use economic theory for assigning market and non-market values to public natural resources. Quantifying the likely effectiveness of any potential response strategy could therefore be, in principle, straightforward; the effects of a potential oil spill on sensitive resources could be predicated by the use of appropriate models and a NRDA damage value calculated. The exercise could then be repeated, taking into account the predicted effectiveness of the response operation. The difference between the two damage values could be considered to be the ‘benefit’ of conducting the response. This could even be compared to the cost of mounting the response operation to give an estimate of the ‘cost-benefit’ of the response. Although simple in theory, this approach cannot be rigorously applied in practice. Both NEBA and NRDA assessments can only be as good as their input information (threatened resources and the effect of oil pollution upon them) and simplification is inevitable. In some cases there may not be enough information to be able to conduct anything other than a cursory analysis.

Other factors also indicate that quantitative comparisons of oil spill response options are useful in the oil spill contingency planning process. Establishing and maintaining a credible oil spill response system costs money. The oil industry is cost-conscious and there are constant pressures to reduce costs and increase costefficiency. The costs associated with the purchase and stockpiling of equipment plus the training and establishment of response personnel can be large. It is in the responder's interests to know that the resources devoted to response are being deployed as effectively as possible. The planned oil spill response must be as cost-effective as possible. Even though one can always do more cleanup by using more resources, the marginal environmental benefit tends to decrease with increasing cost.

Several different factors have to be taken into account when quantifying the performance or effectiveness of alternative oil spill response strategies:

- Oil characteristics and behavior (including weathering);
- Surface slick and subsurface dispersed oil plume trajectories;
- Resource maps;
- Response option performance.

Because of the complex interrelationships among many of these factors, simple calculations are not sufficient and numerical or computer modeling is used in the analysis.

## 2. Oil spill contingency planning in Norway

The oil companies operating off the coast of Norway are directed to develop contingency plans that meet specifications set by the Norwegian Pollution Control Authority (SFT). The minimum response requirements described in the regulations are given in terms of response times and specifications for the booms and skimmers. For dealing with minor and moderate spills (< 100 tons), as well as in the early stages of larger spills, response equipment needs to be located close to the production platform. The regulations demand a response time of less than one hour, a minimum capacity for the oil recovery system of 50 $m^3$/hour, and a sweeping capacity of 0.1 $km^2$/hour (Norwegian Petroleum Directorate, 1994). These regulations are transformed into required skimmer and boom dimensions by a few simple calculations. The skimmer type is chosen on the basis of pump capacity and effectiveness, either claimed by the manufacturer or reported in third-party test results. To meet the sweeping capacity requirement it is usual to assume a boom operating speed of 1 knot in a J-formation and the required boom length is therefore about 200 m. The estimated cleanup capability, compared to the actual capability, depends only on whether one overestimates or underestimates the average oil slick thickness and the leakage through the boom. The error could go either way, depending on the release conditions and the spreading properties of the oil, and can easily lead to a grossly over- or under-dimensioned response capability. The effect of different oil types, spill sizes and release conditions does not need to be considered in order to meet the minimum requirement specified by the authorities.

The situation is changing. Recent pronouncements from SFT state that the response alternative chosen should be the one that minimizes the environmental damage that would be caused by the oil spill - in line with the NEBA philosophy. A strict interpretation of this statement would suggest that all alternatives (chemical, mechanical and biological) should be evaluated, regardless of cost, before selecting the most effective option. However, SFT also considers that response should also be based on cost-effectiveness. The oil companies must prove to the authorities that their choice of response, if it deviates from the minimum standards of mechanical recovery, is environmentally sound for their particular operation.

The Oil Spill Contingency And Response (OSCAR) model system was developed by SINTEF for the specific purpose of comparing alternate oil spill response strategies. Given site-specific information on the probability of accidental events, probable release conditions, oil type and environmental resources, as well as a set of criteria for success, a contingency plan based on quantitative analysis can be tailored for the operation.

## 3. Model Description

The OSCAR model system (Reed et al, 1995a; Aamo et al, 1996) has been developed to supply a tool for objective analysis of alternative spill response strategies. OSCAR provides a basis for comprehensive, quantitative environmental impact assessments in the marine environment. Key components of the system, shown schematically in Figure 1, are SINTEF's oil weathering model (Aamo et al, 1993; Daling et al, 1990, 1991), a three-dimensional oil trajectory and chemical fates model (Reed et al, 1995b), an oil spill combat model (Aamo et al, 1995, 1996), and exposure models for fish and ichthyoplankton (Reed et al, 1995a, 1996a), birds, and marine mammals (Downing and Reed, 1996). The model calculates and records the distribution in three physical dimensions plus residence time of a contaminant on the water surface, along shorelines, in the water column, and in the sediments. The model is embedded within a graphical user interface in WINDOWS NT/95, which facilitates linkages to a variety of databases and tools. The latter allow the user to create or import wind time series, current fields, and grids of arbitrary spatial resolution.

An oil and chemical database supplies chemical and toxicological parameters required by the model. Results of model simulations are stored at discrete time-steps in computer files, which are then available as input to biological exposure models.

## 4. Methodology

The following sequence of steps should be undertaken to create a relevant, site-specific oil spill contingency plan based on simulated scenarios.

1. <u>Define and map the vulnerable resources in the region</u>.
   Natural resource mapping is the most obvious example, but other resources that might be threatened by oil pollution - for example tourist beaches, fish farms or industrial plants - should also be identified. Conventionally, the focus has been on coastal and shoreline resources. Relevant information may not be available for offshore locations.
2. <u>Formulate oil spill scenarios</u>
   Probable or extreme events can be selected on the basis of probability studies. This can be done for existing installations or during the planning phase for new installations where proposed technical or engineering solutions may be considered to reduce the risk.
3. <u>Assemble environmental data for the region</u>
   Typical wind and current data need to be obtained on a scale that is appropriate for the study. The weathering properties of the most likely oil types that could be spilled should be established.
4. <u>Select the relevant response options</u>

Options should include existing and proposed types of response, such as mechanical recovery equipment (booms and skimmers) or dispersants. All aspects of the operation need to be considered. The availability and performance of the recovery ships or dispersant application aircraft need to be considered. This should be based on equipment specifications as well as prior experience. Response resources outside the local region, but which might be required to combat larger spills, should be included. Several options with different amounts of equipment should be run to correctly dimension the response to the oil spill scenario. The resources available for response will be a major consideration.

5. Set criteria for measuring response effectiveness
   As discussed earlier in this paper, the prime measure of effectiveness of a particular response should be the reduction in an oil spill's negative effects caused by the response. However, a more pragmatic and simpler measure of success may need to be used if environmental data are not available.
   The measure of success of a response has been judged, in the past, to be the amount of oil 'dealt' with i.e. the amount of oil recovered or dispersed, compared to the amount of oil released. This takes no account of the environmental injury that would be caused by exposure of organisms to the oil before it is recovered or dispersed. Other factors such as natural dispersion and evaporation would need to be taken into account if even a rudimentary mass balance is to be used as an assessment of the effectiveness of the operation.
   Where coastal pollution is the obvious hazard from the oil spill, the amount of oil that hits the shoreline when a particular response is implemented can be compared to the amount that hits without response. This is an improvement on the above measure of success because the amount of oil hitting the shore will probably be related in some way, although not in a linear or direct way, to the amount of environmental damage that is done.
   In situations such as a small spill offshore, the oil may naturally disperse before hitting the shore. The option of not responding at all might be justified if the only criteria for success was the reduction in shoreline contamination. The negative environmental effects caused by oil components in the water and oil on the surface prior to natural dispersion are therefore assumed to be non-existent or minimal unless a potential for exposure (area- and time-related) is used. Without adequate environmental data it is not possible to judge the effects of this exposure, but it does give a quantifiable indicator of the results of any response.
6. Run simulations with response options and with no response
   Computer simulations which integrate all the previous factors should then be run. The minimum response requirements can also be used as the comparative baseline.
7. Evaluate results
   The results from the simulations may be in several different forms, depending on the selected measure of success. It is important that these results are used as an aid to decision making, not as a substitute. All oil spill response is an exercise in damage limitation and no oil spill response can be judged to be 100% successful - some damage is likely to have been caused. Whether it is significant and whether the response averted substantial damage is often the

subject of post-spill debate. The object of oil spill contingency planning is to maximize the chance of achieving as good a result as possible, if and when a spill occurs.

8. Select response strategies

   Having quantitatively evaluated a selection of options that are technically, logistically and financially feasible the 'best' response can be recommended with a high degree of confidence.

## 5. Case Studies

To illustrate the importance of taking information such as oil type and release conditions into account when developing a contingency plan, two sets of simulations are described here. The first set compares the effect of altering the response time for mechanical cleanup for three different oil types. The second set of simulations shows the difference in cleanup effectiveness between a subsurface blowout and a surface release.

### 5.1 Varying the time for first response to spills in the Ula, Veslefrikk and Gullfaks fields

In this case study, the following questions are of interest:

1. If the minimum response time is changed from 1 to 2 or 4 hours, what would be the change in cleanup performance ?
2. Would the consequent decrease in cleanup performance have environmental significance ?
3. To what degree does the oil type affect cleanup effectiveness when the response time is delayed ?

By increasing the response time from 1 to 4 hours, significant cost savings can be achieved by coordinating the standby response among several neighboring platforms.

The choice of the simulated release scenario is based on the most probable accidental event (0.01-0.1 events/year), which is a small release in the order of 50 $m^3$, typically caused by over-topping during loading. All cases were simulated for three different oil types: Ula, Veslefrikk and Gullfaks crudes. Ula and Veslefrikk crudes form stable emulsions quite rapidly, whereas the Gullfaks crude spreads quickly and does not form a stable emulsion. Wind speeds of 5 m/s and 10 m/s were used to cover the range in which reasonable effectiveness can be achieved with mechanical response. Deployment was simulated for the Foxtail VAB-80 skimmer and the NORLENSE-800 boom (250 meters), which is a typical configuration of equipment for standby vessels in the North Sea. Model parameters for the equipment are shown in Table 1. The effectiveness given in Table 1 accounts for leakage through the boom.

Several measures of success were used from the model for comparision of response effectiveness. These were:

- Amount of oil recovered,
- Life time for the surface slick,
- Maximum areal coverage of surface oil during the simulation, and
- Surface exposure.

The surface exposure is defined as the areal coverage of oil integrated over time, and can be interpreted as a potential risk to birds and sea mammals, whose natural habitat is the sea surface.

*Table 1 Parameters for mechanical cleanup.*

| | |
|---|---|
| Operational speed (m/s) | 0.5 (1 knot) |
| Boom opening (m) | 75 (30% of 250 meters in a J-formation) |
| -> sweeping area ($km^2$/hour) | 0.135 |
| Maximum recovery rate ($m^3$/hour) | 20 (25% of the pump capacity of 80 $m^3$/hour; Lorenzo et al, 1995) |
| Onboard tankage capacity ($m^3$) | 500 |
| Effectiveness (%) | 80 (in 5 m/s wind; NOFO, 1994)<br>60 (in 10 m/s wind; NOFO, 1994) |
| Cruise speed (m/s) | 6 (12 knots) |

Figures 2-4 show the results for releases of 50 $m^3$ of Ula, Veslefrikk and Gullfaks crudes, respectively. The figures show amount of oil recovered, life time, maximum areal coverage and surface exposure relative to the scenario with the quickest response (1 hour). The quickest response cases are also shown in the figures, and are identified by having all values equal to 1. Figure 5-7 show the final mass balances (after 24 hours, which is the time window for the first-line response) for releases of 50 $m^3$ of Ula, Veslefrikk and Gullfaks crudes, respectively.

For the Ula crude (Figures 2 and 5) the reduction in amount of oil recovered is about 7% in 5 m/s wind, when the response time is increased from 1 to 4 hours. However, the life-time of the slick is nearly doubled, and the areal coverage increases by 50%. This causes the surface exposure to increase with a factor of about 2.5. In 10 m/s wind, the reduction in the amount of recovered oil is about 15%, but since natural dispersion is more dominant at 10 m/s, life-time, areal coverage and surface exposure do not increase as much as in the 5 m/s case. Surface exposure increases by a factor of about 1.5 in this case.

The Veslefrikk crude has emulsification properties similar to those of the Ula crude, and an increase in the response time gives very similar effects for the Ula and Veslefrikk crudes. However, with Gullfaks crude, which does not form a stable emulsion and spreads and disperses rapidly, the effect of increasing the response time is more dramatic. The amount of oil recovered is reduced by 25% in 5 m/s wind, and by 90% in 10 m/s wind. In 5 m/s wind, the life-time is increased by a factor of 4, maximum areal coverage by a factor of 2.5 and surface exposure by a factor of 6. Since the Gullfaks crude disperses rapidly in 10 m/s wind, increasing the response time from 1 to 4 hours does not affect the surface oil as much as in the 5 m/s case. The changes are more signicant than for the emulsifying oils.

An increase in response time from 1 to 4 hours, appears to have limited significance for the total amount of oil recovered 24 hours after releasing a highly emulsifying oil (the amount of oil recovered is reduced by 2-4 $m^3$). On the other hand, response time is crucial to the cleanup effectiveness for a low-emulsifying oil that spreads rapidly. Note, however, that what cannot be recovered is mainly oil that evaporates or disperses naturally. This leaves about the same amount of oil on the sea surface after 24 hours regardless of response time within the range studied here (1-4 hours). The surface exposure increases, increasing the potential risk of impact on birds and sea mammals. Thus, the final conclusion on whether the response time may reasonably be delayed or not, must depend on the following questions:

1. Is it crucial that spilled oil be recovered as soon as possible ? If so, as little as possible should be allowed to evaporate, spread or disperse, and a quick response is required in cases where these natural processes are rapid.
2. Is the main objective to eventually remove all the surface oil? If so, natural dispersion and evaporation may be acceptable means of surface oil removal.
3. Is the rate of oil removal critical? If so, a quick and high capacity response may be required in order to keep the surface exposure to a minimum.

The answers to these questions, from a cost-benefit standpoint, are highly dependent on the types and density of natural resources in the region. Without adequate knowledge about these resources, it is not possible to decide which of the response options will be most effective in the NEBA context.

## 5.2 The effect of release conditions on cleanup performance

In this case study, the following questions were of interest:

1. How does application of dispersants compare to mechanical cleanup in the case of a subsurface blowout from one of the satellites at the Troll field?
2. How do release conditions affect mechanical cleanup performance?

In this case, the choice of release scenario is based on the most extreme accidental event, which is an uncontrolled subsurface blowout of 9000 $m^3$ per day of Troll crude from a depth of 330 meters. In order to simulate optimal conditions for mechanical cleanup, calm weather, with winds in the order of 5 m/s from the south, is assumed. The background currents are about 10 cm/s to the north, and the temperature is 10°C. The initial oil film thickness and width of the oil slick gathering at the surface is calculated by a dedicated subsurface blowout model (Rye and Brandvik, 1997).

In addition to a no response reference case, five different response alternatives are considered. Focus is on the application of dispersants, but one mechanical cleanup alternative is included for comparison. The selected response alternatives are as follows:

1. Application of dispersants from 3 helicopters, with the dispersant depot placed onboard a standby vessel. The first helicopter will arrive at the spill site 1 hour and 45 minutes after the start of the blowout. The other two helicopters will arrive at the spill site after 2.5 and 3.5 hours, respectively. Dispersants are loaded into the helicopter buckets directly from the standby vessel, which is assumed to carry 50 $m^3$ of dispersants. This corresponds to 17-18 trips with the helicopter bucket, which carries 2.8 $m^3$ of dispersants. The helicopter has to refuel at the Troll A platform, which is situated about 30 km to the south-east of the spill site (see Figure 8). It is assumed that the helicopter must refuel before every other

application trip. The application area stretches from a safety zone of 500 m from the spill site and 1500 meters down-stream. Dispersants are applied continously until mechanical equipment arrives at the scene, after approximately 10 hours.

2. Application of dispersants from 3 helicopters, with the dispersant depot placed on the Troll B platform. This scenario is identical to the previous one, except that dispersants must be loaded from a platform. The response times, size of the dispersant depot and application area are the same as in the previous scenario.
3. Application of dispersants from 3 helicopters, with the dispersant depot placed at the Sture terminal. The first helicopter will arrive at the Sture terminal 1 hour and 30 minutes after the start of the blowout. The other two helicopters will arrive at the Sture terminal after 2.5 and 3.5 hours, respectively. Both reloading of dispersants and refueling is done at the terminal, so that each application trip implies a flying distance of 160-170 kilometers. Because of the long flying distance, the payload must be reduced to 2 $m^3$ of dispersant. The size of the dispersant depot and application area are the same as in the previous two scenarios.
4. Application of dispersants from one helicopter, with the dispersant depot placed onboard a standby vessel. This scenario is identical to scenario number 1, without the second and third helicopters.
5. Mechanical cleanup with the currently existing equipment. The current field contingency is based on traditional mechanical cleanup, and is dimensioned according to the requirements set by the authorities.

The chemical response actions simulated in this case study are based on the Response 3000D helicopter bucket, which was recently developed to meet the dispersant application needs of the Norwegian oil companies. The most important capabilities of the bucket include two dosage settings, direct filling of dispersants through a suction hose, and a high payload capacity. The bucket is described in detail in Brandvik et al, 1997 (in these proceedings). The two dosage settings are designed for thin oil films, which typically develop from subsurface blowouts, and for thick emulsions, respectively. Table 3 shows the application parameters used here. As shown in the table, the dispersant-to-oil ratio used is 1:50. This is assumed to be sufficient to successfully treat an oil film with an average thickness of less than 0.25 mm, which is the relevant thickness in this case (Rye, 1995). A dispersant application effectiveness of 80% is assumed for the given weather and release conditions. This means that 80% of the dispersant sprayed effectively penetrates the oil. According to weathering and dispersability tests performed on emulsified Troll crude samples, the window of opportunity for dispersant application is about 9 hours (Figure 9a). However, experiments performed on thin oil films in the SINTEF flume basin, suggest that such thin layers will not emulsify (Strøm-Kristiansen, 1995). This widens the window of opportunity for dispersant application considerably (Figure 9b). The oil in the application area defined in the simulations has been on the surface about 0.5-2 hours, which is well within the window-of-opportunity. It is only fair to mention at this point, that many uncertainties prevail concerning the weathering and spreading behaviour of oil released from the bottom of the sea!

In order to compare the effectiveness of the simulated chemical response cases to traditional mechanical cleanup, one scenario with mechanical response is described here. The recovery units simulated are described in Table 3. All four systems may be mobilized for a response action on the Troll field within the response times given in the table. In the simulations, all four systems are mobilized. The effectiveness for the mechanical equipment is taken from the Norwegian Clean Seas Association's contingency manual (NOFO, 1994), and represents leakage through the boom system at 5 m/s wind.

*Table 2 Parameters for the Response 3000D helicopter bucket.*

| | |
|---|---|
| Application rate (l/min) | 200 |
| Tankage capacity ($m^3$) | 2.8 (2.0 when operated from land) |
| Spraying width (m) | 25 (actually in excess of 30 m in the final configuration of the bucket) |
| Operational speed (m/s) | 30 |
| Cruise speed (m/s) | 50 |
| Delay for dispersant loading and refueling (minutes) | 30 (5 minutes for dispersant loading, 10 minutes for refueling, and 15 minutes for unforeseen delays. |
| Maximum endurance with full payload (hours) | 2 |
| Dispersant-to-Oil Ratio (DOR) | 1 part dispersant to 50 parts oil |
| Effectiveness (%) | 80 |

*Table 3 Parameters for mechanical cleanup.*

| Vessel<br>Skimmer<br>Boom | Far Scout<br>Transrec 250<br>NOFI 800 S | Ocean Knarr<br>Transrec 250<br>NOFI 800 S | Normand Jarl<br>Foxtail VAB 8-14<br>NOAS 800 | NN<br>Foxtail VAB 8-14<br>NOAS 800 |
|---|---|---|---|---|
| Operational speed (m/s) | 0.5 (1 knot) | 0.5 (1 knot) | 0.5 (1 knot) | 0.5 (1 knot) |
| Boom opening (m) | 72<br>(30% of 240 m) | 72<br>(30% of 240 m) | 60<br>(30% of 200 m) | 60<br>(30% of 200 m) |
| -> sweeping area ($km^2$/hr) | 0.13 | 0.13 | 0.11 | 0.11 |
| Max. recovery rate ($m^3$/hr) | 250 | 250 | 80 | 80 |
| Cruise-speed (m/s) | 4 (8 knot) | 4 (8 knot) | 4 (8 knot) | 4 (8 knot) |
| Effectiveness (%) | 80 (5 m/s wind) | 80 (5 m/s wind) | 80 (5 m/s wind) | 80 (5 m/s wind) |
| Tankage capacity ($m^3$) | 1000 | 1000 | 1000 | 1000 |
| Time to Mobilize (hours) | 2 | 6 | 6 | 5 |

*Table 4 Summary of the results of the simulations after 10 hours. The response alternatives are as follows: no response, 1 - three helicopters, depot onboard boat, 2 - three helicopters, depot on the Troll A platform, 3 - three helicopters, depot on the Sture terminal, 4 - one helicopter, depot onboard boat, og 5 - mechanical cleanup.*

| Response Alternative # | No Resp. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Amount of oil succesfully treated with dispersants (tons) | | 1986 (59%) | 1936 (58%) | 1038 (31%) | 751 (22%) | 366* (11%) |
| Amount of oil dispersed, naturally and chemically (tons) | 24 (1%) | 1578 (47%) | 1524 (45%) | 810 (24%) | 600 (18%) | 15 (<1%) |
| Amount of oil evaporated (tons) | 446 (13%) | 389 (12%) | 391 (12%) | 415 (13%) | 422 (13%) | 407 (12%) |
| Amount of oil on the surface (tons) | 2876 (86%) | 1376 (41%) | 1428 (43%) | 2120 (63%) | 2323 (69%) | 2559 (76%) |
| Number of completed application trips | | 17 | 17 | 13 | 7 | |
| Dispersant consumption ($m^3$) | | 48 | 48 | 26 | 20 | |

* amount of oil recovered mechanically.

Table 4 summarizes the results for the different response alternatives 10 hours into the simulations. Figure 10 shows the results graphically. As the table shows, alternatives 1 and 2 clearly stand out from the others in terms of total effectiveness. For alternatives 1 and 2, respectively, 1986 and 1936 tons of oil have been successfully treated and will disperse over time. The table also shows that the degree of natural dispersion is very low (see the no response case). Thus, of the amount reported to be naturally and chemically dispersed, practically everything is chemically dispersed. At higher wind speeds, and particularly when breaking waves occur, the degree of natural dispersion will probably increase considerably, since the oil slick in this case is relatively thin and widespread. The percentage of oil that is evaporated is about the same in all cases, and is low due to the fact that fresh oil is continously released in a blowout.

Even for alternatives 1 and 2, which are the favorable ones in this case, quite a lot of oil is still on the sea surface after 10 hours (about 40%). However, some of this oil is successfully treated with dispersants, and will disperse over time. The results from the simulations show quite clearly that mechanical recovery is difficult in the case of a subsurface blowout. This is caused by the thin and wide oil slick that results from the blowout, which will require very large boom systems to collect. There is also some uncertainty as to whether the oil will emulsify or not on its way up to the surface, and experiments suggest that *surface* slicks of this thickness will not emulsify (Strøm-Kristiansen, 1995).

If emulsification does not occur, mechanical recovery is even more difficult due to the low viscosity of the oil (100-200 cP, while the optimal viscosity for mechanical recovery is around 1000 cP). However, on a longer time scale, it is possible to mobilize large boom systems from shore in order to collect the oil and thereby optimize recovery. This would most likely increase the effectiveness of mechanical recovery. It is worth noting, though, that even dispersant application from one helicopter appears to be more effective in removing oil from the surface than mechanical recovery in this case.

As Table 4 shows, the dispersant application action is twice as effective, with the amount of oil removed from surface as the measure of success, when dispersants are stored offshore compared to onshore. This is, of course, due to the delay caused by the long distance between the spill site and the depot on shore, and also the reduction in payload required to fly such long distances. In the simulations, the size of the depot is assumed to be at least 50 $m^3$. If it is inappropriate to store such large amounts of dispersants on the Troll B platform, the depot could be distributed over several offshore installations.

In order to compare the effectiveness of mechanical recovery of a subsurface blowout to that of a surface release, the fifth response alternative was simulated again with oil released at the surface. Figures 11 and 12 show the mass balances for the subsurface blowout and the surface release, respectively. The amount of recovered oil is about four times higher for the surface release, due to the much thicker and narrower slick.

## 6. Conclusions

The complexity of interrelationships among factors affecting the success of a particular reponse option for a particular oil spill requires the application of a numerical modelling system for reliable comparison of alternatives. The SINTEF OSCAR model system is used here, as it has been thoroughly calibrated and tested (Aamo et al, 1996).

Results of the case studies carried out here demonstrate that oil characteristics can play a decisive role in the effectiveness of an oil spill response, especially in winds exceeding 5 or 6 m/s. For emulsifying oils, an increase in the initial response time from 1 to 4 hours will have only small effect on the amount of oil recovered mechanically, whereas environmental exposures, computed as surface area integrated over time, may increase significantly. In addition, the total time required to complete a cleanup, and therefore the costs associated with the action, also increase with increased delay between spill start and time of first resonse. Compared with the costs associated with maintaining on-site response capabilities to achieve rapid response, the small risk of spillage may make acceptable the higher cost associated with longer response actions in case of a spill.

Comparison of response options for an underwater blowout from a depth of 330 meters demonstrates that mechanical cleanup is a weak alternative, due to the thinness of the resulting oil slick. The use of chemical dispersants appears much more promising in this case, but only when the dispersant depot is (a) adequate in magnitude for the event, and (b) relatively close at hand. If the dispersant aircraft, in this case helicopters, have to travel more than 10 or 20 kilometers to re-load, the lost time is clearly reflected in the overall effectiveness of the response.

These results clearly demonstrate the usefulness of the OSCAR model in evaluating quantitatively alternative oil spill response strategies on a regional basis. Regional analyses, in which regional environmental impacts are balanced against regionally shared response costs, represent a rational and responsible approach to oil spill response planning, and can be expected to become more common in the future.

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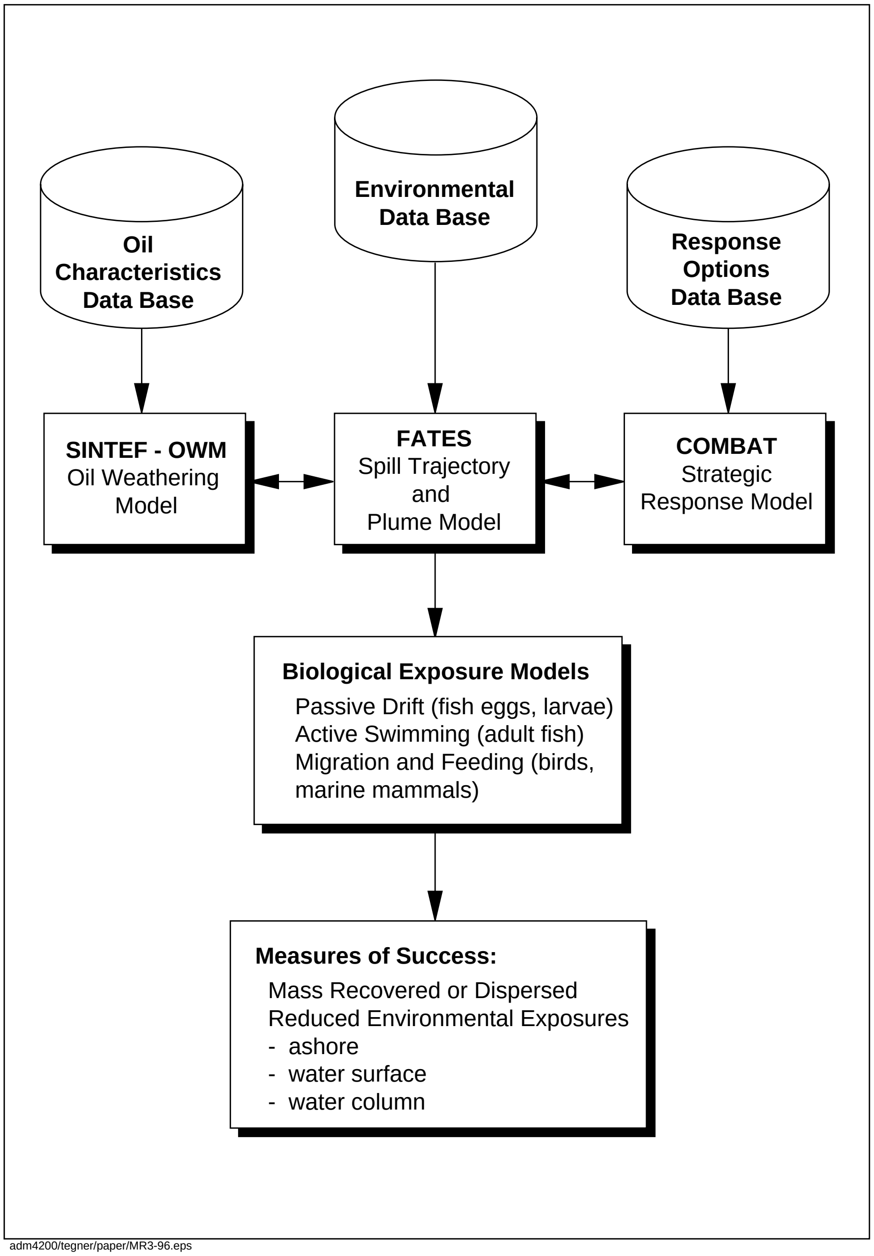

Figure 1 Schematic overview of the OSCAR system.

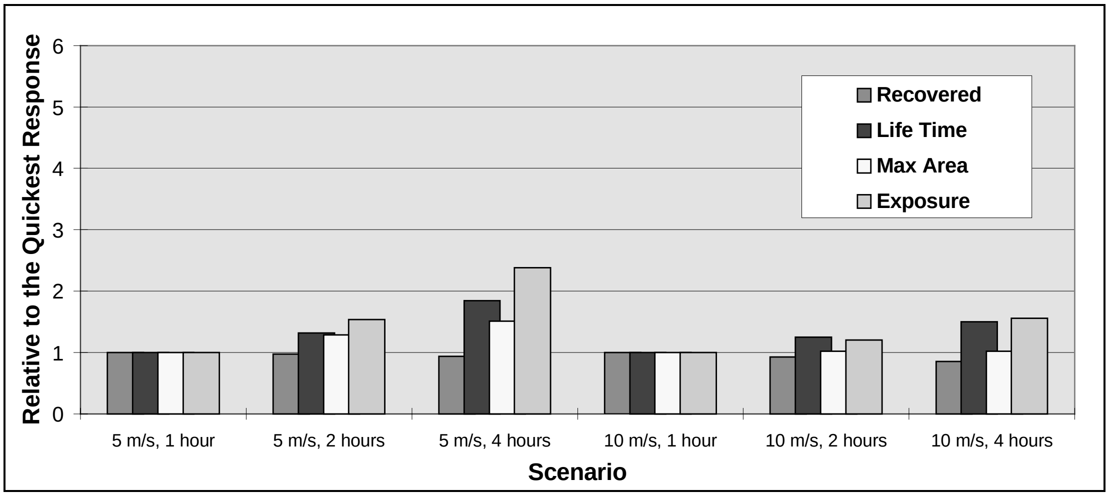

Figure 2 Summary of the simulation results from the release of 50 m$^3$ of Ula crude over 20 minutes.

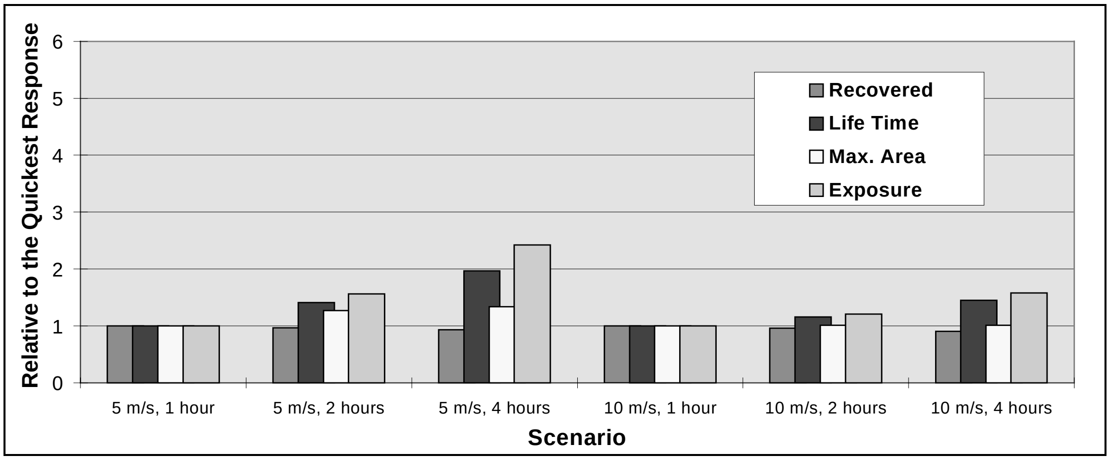

Figure 3 Summary of the simulation results from the release of 50 m$^3$ of Veslefrikk crude over 20 minutes.

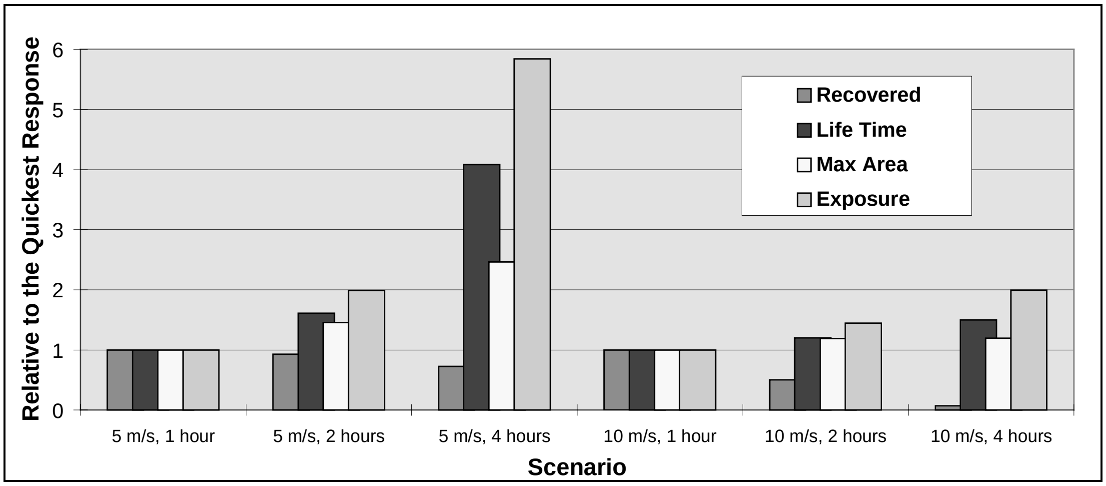

Figure 4 Summary of the simulation results from the release of 50 m$^3$ of Gullfaks crude over 20 minutes.

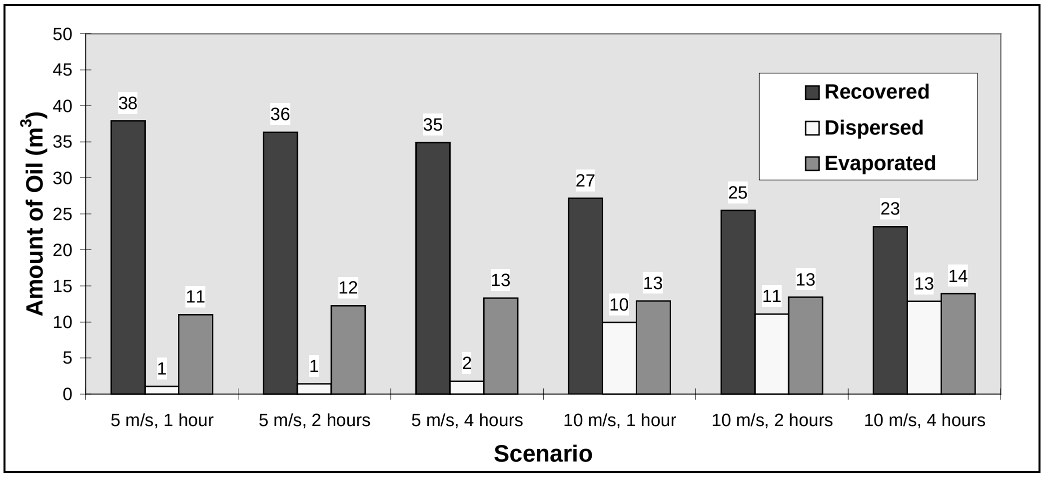

Figure 5 Final mass balance for the release of 50 $m^3$ of Ula crude over 20 minutes.

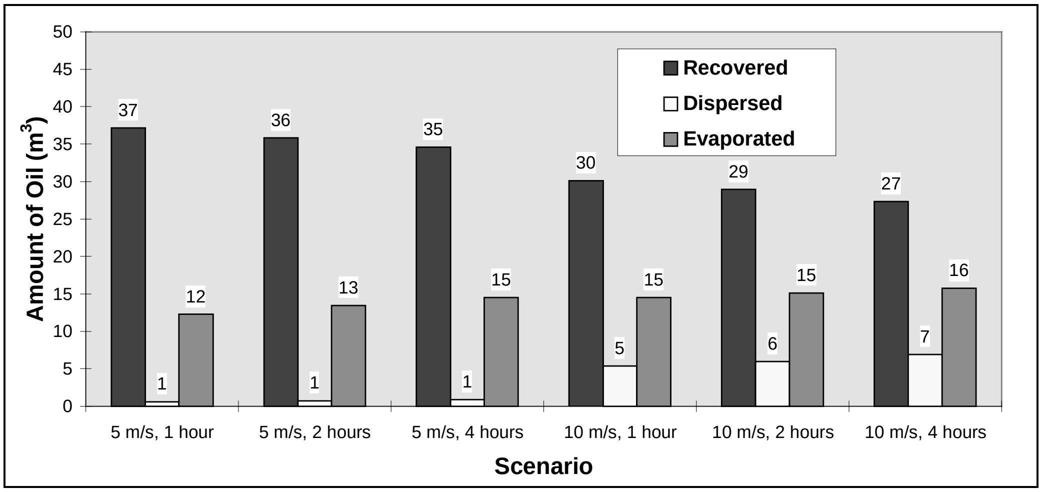

Figure 6 Final mass balance for the release of 50 $m^3$ of Veslefrikk crude over 20 minutes.

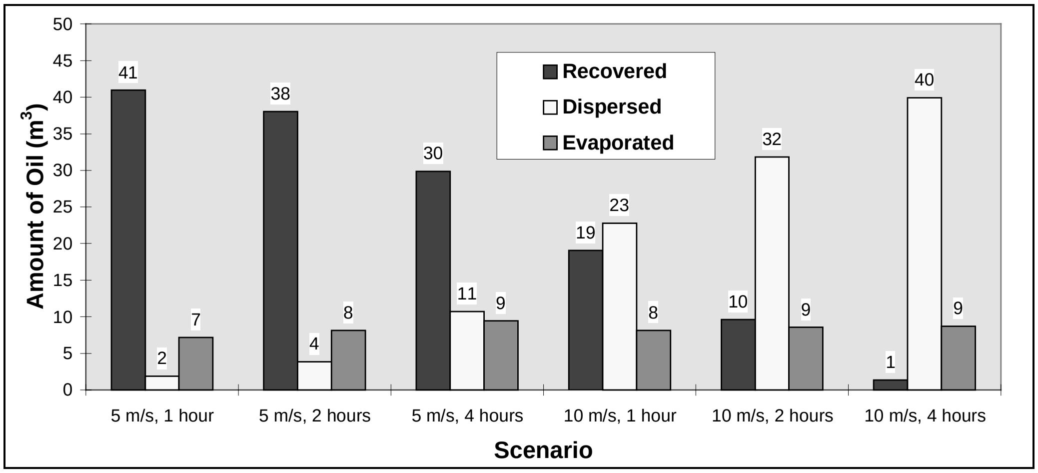

Figure 7 Final mass balance for the release of 50 $m^3$ of Gullfaks crude over 20 minutes.

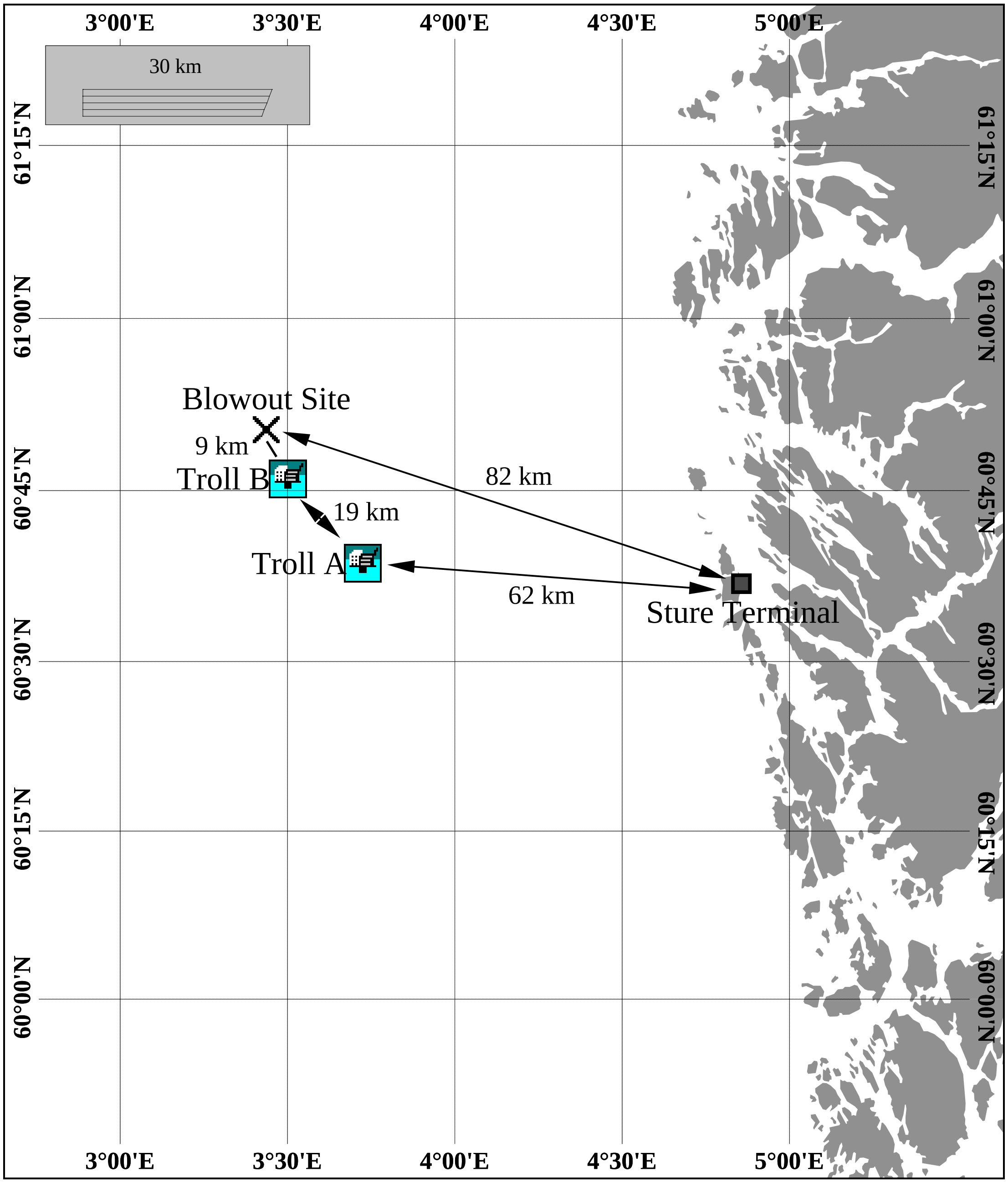

Figure 8 Overview of key locations and distances for simulations at the Troll field.

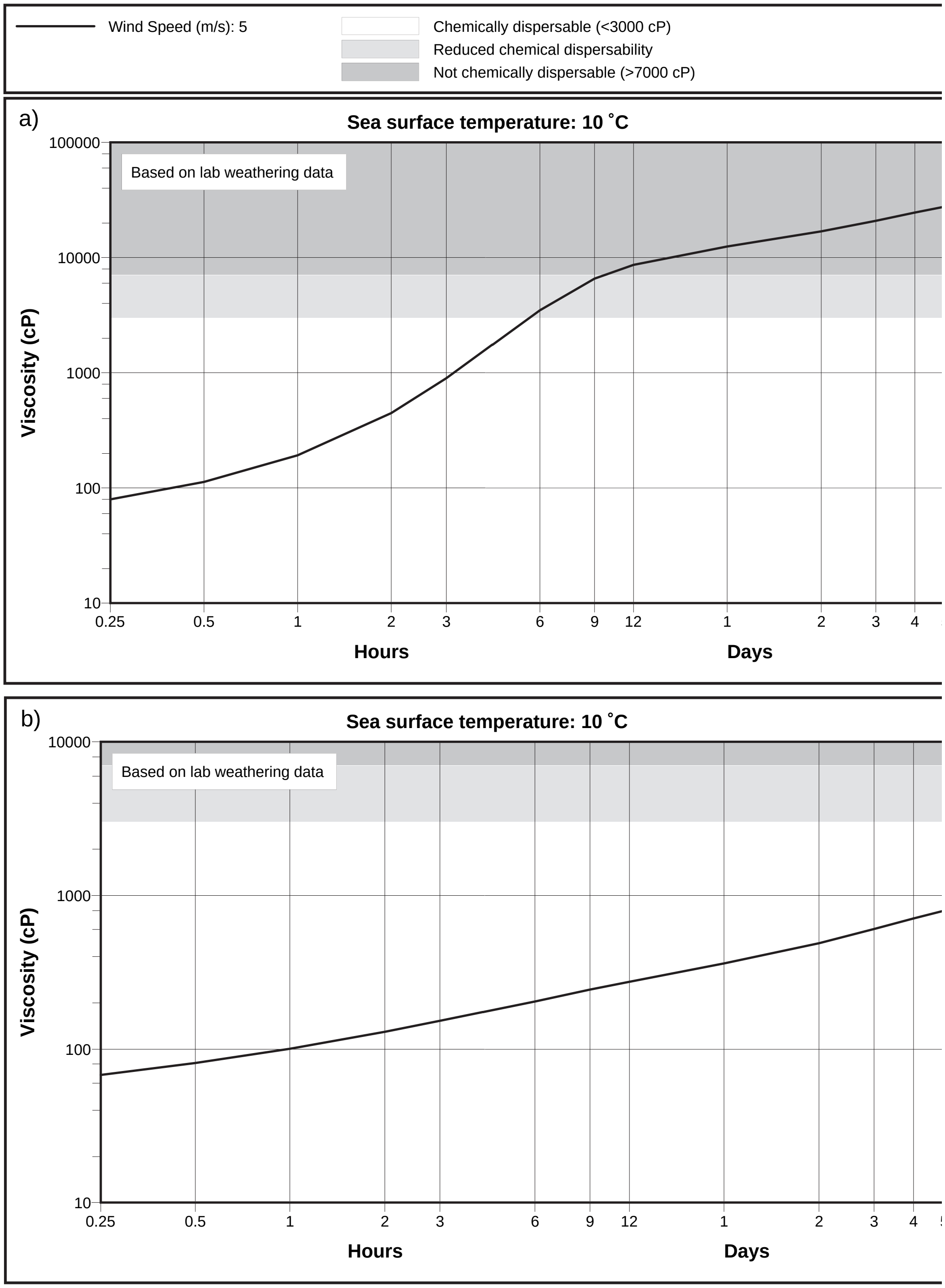

Figure 9 Viscosity of emulsion (a) and water-free oil (b) at 5 m/s wind and oil film thickness between 0.1 and 0.3 mm. Optimal chemical dispersion is obtained for emulsion up to 6 hours after release, and for water-free oil for more than 5 days after release. Favorable effects can achieved for emulsions up to 10 hours after release. Experiments suggest that an oil film with a thickness of 0.25 mm will not emulsify, which implies a very wide window-of-opportunity for dispersant application.

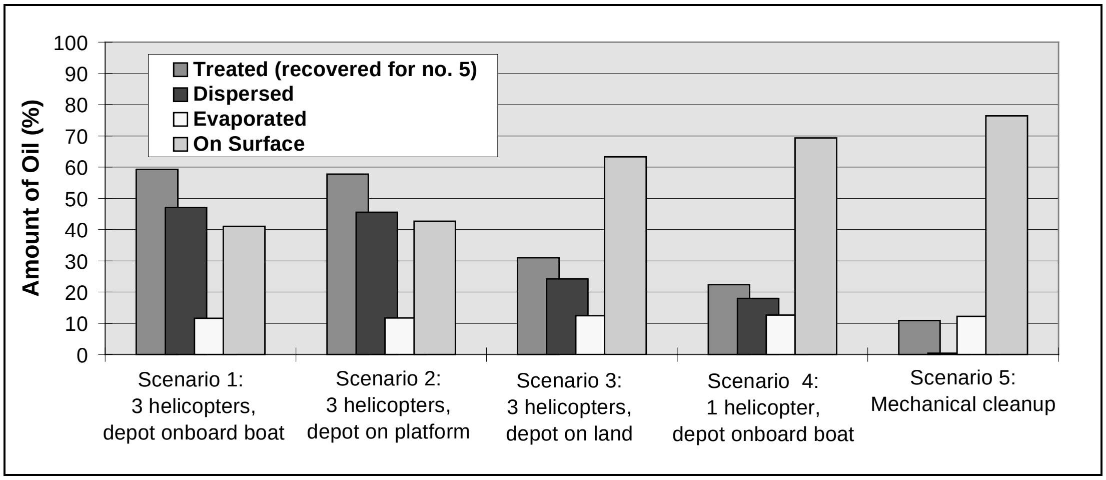

Figure 10 Summary of simulation results for the five different reponse alternatives for dealing with a subsurface blowout at the Troll field.

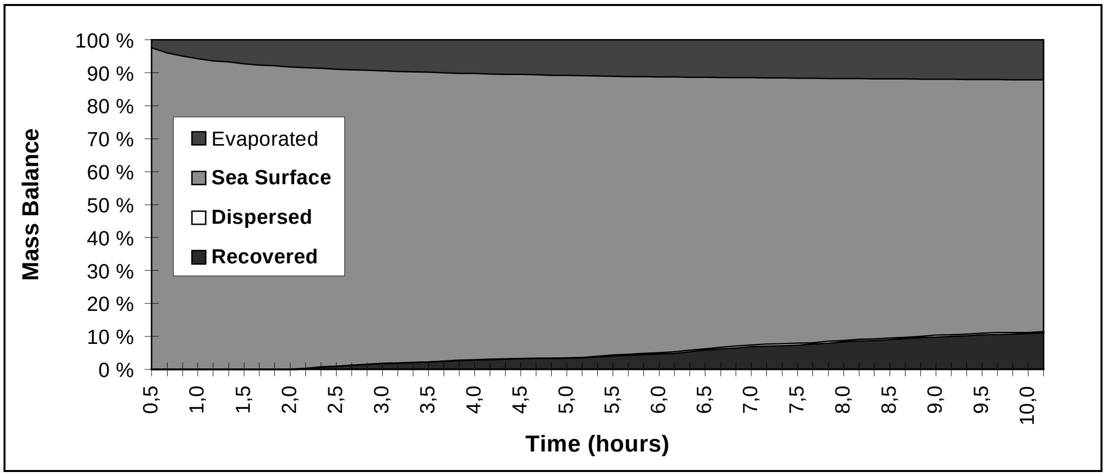

Figure 11 Mass balance for mechanical cleanup of the subsurface blowout at the Troll field.

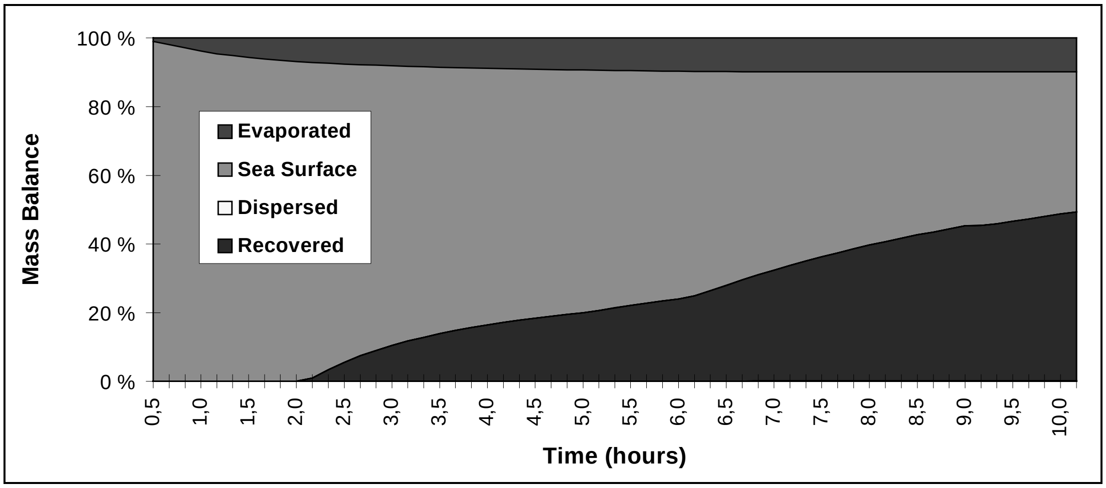

Figure 12 Mass balance for mechanical cleanup of a surface release of the same size as the simulated subsurface blowout at the Troll field (Figure 11).