RESPONSE TO SPILLS ON LAND

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INTRODUCTION

Many more oil and chemical spills occur on land than occur on water. The large number of spills on land is not really surprising considering the many ten's of thousands of kilometers of pipelines that crisscross both producing and consuming countries and the huge number of transfers between pipelines, storage facilities, rail tankers, and road tankers that take place on a daily basis throughout the world. There are marked differences in the frequency of land spills from country to country, however, that are due primarily to the quality of the infrastructure and to prevention practices.

The behaviour of spilled materials and the relative response strategies for spills on land are quite different to those of marine or freshwater environments. Materials spilled on water generally enter a dynamic environment in which transport and spreading are rapid and in which physical processes act immediately to promote weathering and degradation. By contrast, spills on land generally occur in a more stable environment and move more slowly to affect a smaller area. Rates of natural weathering are slower on land, compared to marine or fluvial environments, due to the lower physical energy levels. Estimates or predictions on the fate, transport, and behaviour of land spills are somewhat easier and more accurate. The removal of oil can be achieved by similar methods (skimming, dispersion, and burning) on different types water bodies, such as rivers, lakes, coastal waters, or the open ocean. Similarly, the cleanup of oil on land, whether the location is a coastline, lake shore, river bank, or terrestrial environment, uses basically the same methods (washing and recovery, manual or mechanical recovery, *in situ* treatment, or chemical treatment).

This discussion focuses on some of the characteristic features of surface oil and chemical spills on land and how these influence the response activities. Examples from personal oil spill response experience are used to illustrate some of the key points.

OIL FATE AND BEHAVIOUR

Response strategies are governed to a large degree by the behaviour of the spilled oil. There are some fundamental differences between spills on land and water that relate primarily to the speed at which oil moves or spreads and the resulting size of the affected area. Oil spilled on water is transported and spread by winds and/or surface currents, which are often variable and only occasionally can be predicted accurately (Murray, 1982). Consequently, the fate, behaviour, and effects of spills on water have a much higher level of unpredictability and uncertainty (Galt, 1995: Lehr *et al.*, 1995). If and when oil reaches water, and does not submerge or sink, then transport and weathering rates can increase dramatically (Table 1).

Table 1 Comparison between Spills on Land and On Water

WATER	**LAND**
OIL BEHAVIOUR	
• oil remains in motion: sometime difficult to locate • moved by winds and/or currents • degree of unpredictability and uncertainty • generally spreads to form a very thin surface layer • weathering and emulsification are active processes	• generally slow-moving or static • collects in depressions or water courses • easy to define location and amount of surface oil • only light oils will spread to form a thin layer; often considerable pooling of oil • weathering slows considerably after approximately 24 hours
RESOURCES AT RISK	
• some are mobile - fish, birds, boats • few resources at risk on the actual water surface • vulnerability is uncertain	• some mobile resources - birds • often many static resources - buildings, vegetation, crops, • except in remote areas, usually many more resources at risk • risks easy to identify
RESPONSE OPERATIONS	
• water based • environmentally dependent - fog, winds, waves, currents, etc. • predominantly mechanical response (booms and skimmers) with potential for burning or dispersant • often requires considerable support	• land based • usually not weather dependent • predominantly manual response in most cases • usually remove a higher percentage of the oil, as weathering slowly and as cleanup standards are more strict

On land, as the ability to predict transport pathways is greater so also it is possible to focus response strategies more closely. Except in rare circumstances, oil, like water, flows downslope and often collects in the same places: creeks, ditches, streams, and rivers. The rate of downslope movement is a function of the oil viscosity, air/ground temperatures, slope steepness, and the surface condition (roughness, vegetation type, soil type, permeability, etc.). Surface conditions on land are rarely flat so that the thickness of layers of oil varies considerably and the oil often collects and forms pools in depressions. The rates of the various weathering processes are largely dependent on the proportion of the surface area that is exposed. These rates would be expected to be slower on land when compared to oil on water, where oil thins, usually, to thicknesses often of only a few millimeters. Also, after a short time period, oil on land reaches a stable condition and the likelihood of further movement and of additional weathering is minimized, which is not necessarily the case on water.

Light crude oils or product may infiltrate soil or sediments, but may also evaporate rapidly, whereas penetration for other oil types is dependent on the porosity and permeability of the surface materials (Table 2).

Table 2 Summary of Terrain Types for Spills on Land

IMPERMEABLE	PERMEABLE Non-Vegetated	PERMEABLE Vegetated
• bedrock • man-made solid • ice	• mud-silt (soil) • sand • mixed sediment • pebble - cobble • boulder - rubble • snow	• grassland • brush and shrubs • forest • wetland

RESPONSE STRATEGIES AND TACTICS

When spills occur on land, the oil generally is static after a short time period, or moves only slowly, so that detection is straightforward and recovery operations generally proceed in an orderly and progressive manner.

After the initial emergency phase of a response to a spill, operations on land do not have the same dynamic character as compared to marine, coastal, or river spills. Materials that can penetrate below the surface layer present a range of different problems, particularly with respect to detection and recovery, that are dealt with in other presentations in this session.

Most response strategies focus on containment and control as near to the source as possible to minimize the spread of the spilled material. An important response strategy is to prevent the spilled material reaching streams and rivers because of the significant difference in rates of movement on land and water (compare the Komi and Desaguadero examples discussed below).

Response methods for containment and protection on land include, barriers, berms, and trenches of different sizes, materials and configurations (see CONCAWE, 1983). The selection of appropriate techniques is dependent on the amount and type of material spilled, the slope of the terrain, the surface materials, and the available time to construct and intercept. One operational objective, if possible, should be to contain the spilled material in such a way as to make recovery easier, for example, by damming to create a pool of sufficient depth to allow the use of skimmers. Recovery techniques are basically the same as are used on coasts: washing; manual, mechanical or suction removal; and *in situ* treatment (burning and land farming).

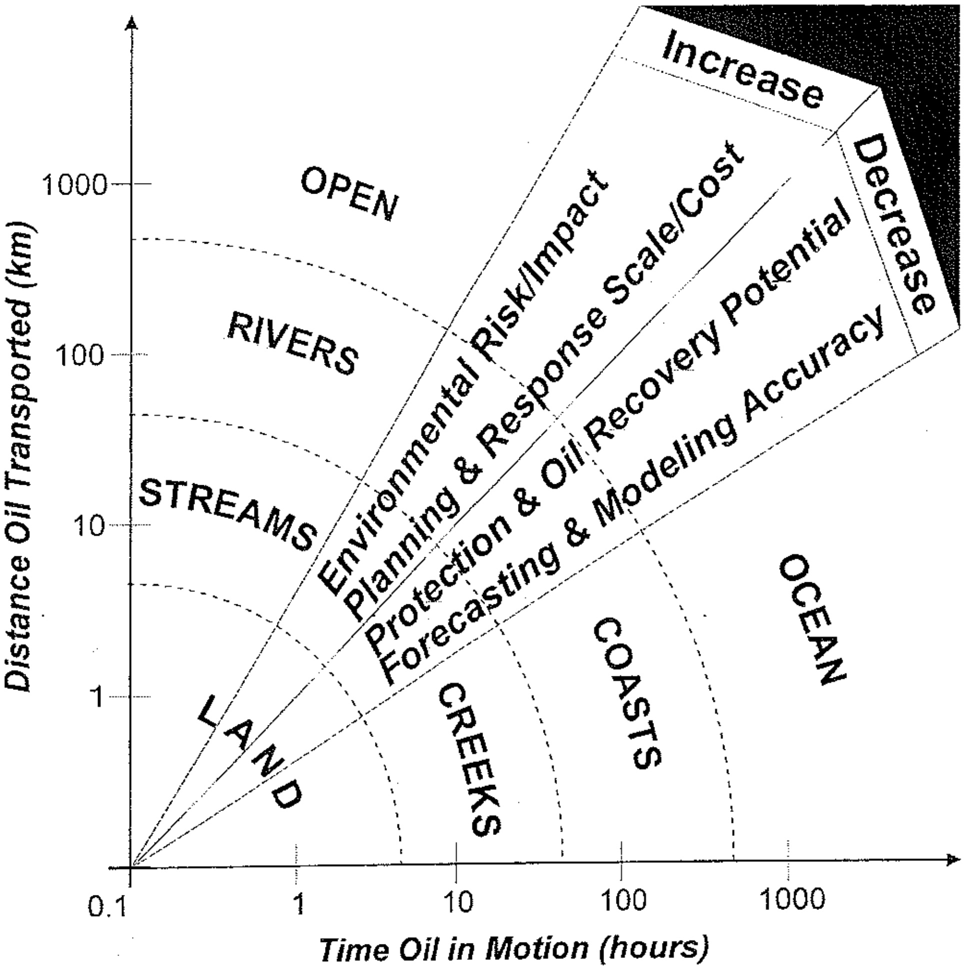


Figure 1 Time-space schematic for spills in different environments.

Spills on land have the potential to have a great impact on human use activities and resources. As a result, in cases where the spill is in a populated area, frequently there is the requirement to clean or treat to a higher level than in a more physically dynamic marine, coastal, or riverine environment where nature is more active in the degradation and weathering processes (see Desaguadero example discussed below). With the presence of a local population, frequently there is a greater involvement of civilian agencies, such as the police or army, to ensure site security, for both the responders and the general public.

THE 1995 KOMI PIPELINE SPILLS, RUSSIA

A series of pipeline spills occurred in the Usinsk area of the Komi Republic, Russia, in 1994-1995. Large volumes of crude oil and produced water were spilled into a range of mixed woodlands and shrub environments, floating bogs, tundra, and river and stream banks (Table 3)(Owens and Sienkiewicz, 1997).

From an operational viewpoint, for land spills that reach water there is a need to differentiate between large rivers where only one bank is surveyed or cleaned at a time, and small rivers, streams, ditches, or creeks where both banks can be surveyed or cleaned at the same time. Rivers have a variety of valley types that include canyons, bluffs, flood plains, levees, and deltas, and channel types that include straight, meandering, braided, and anabranched (or anastamosed) reaches. By contrast, small streams and creeks tend to be confined to canyons or channels but have a wide range of channel forms that include cascades, rapids, pools, riffles, glides, and jams. As floating oil and chemicals can move very rapidly on rivers or streams, control and protection strategies may involve the identification of practical interception points and even the pre-staging or pre-deployment of equipment to establish control and prevent spreading downstream (Owens and Douglas, 1999).

COMPARISON BETWEEN SPILLS ON LAND AND WATER

One consequence of the differences outlined in Table 1 and illustrated schematically in Figure 1, has been the higher level of concern for spills on water and so a greater emphasis on research and planning has occurred as compared to land spills. For example, the analysis of sensitivity issues, the concept of Net Environmental Benefit, and the evaluation of cleanup endpoints have been the subject of much discussion for marine and coastal spills (e.g., Baker, 1997; Michel and Benggio, 1999: Michel *et al.*, 1995), yet these topics largely have been ignored for oil spills on land. One attempt has been made, however, to produce an environmental sensitivity index for rivers and streams (Hayes *et al.*, 1997). Similarly, there are few dedicated manuals or guidelines for oil spills on land (e.g., CONCAWE, 1983) compared to the plethora of manuals for spills on water (API/NOAA,1994: CONCAWE, 1981; IMO, 1988, 1995, 1997: MPCU, 1994; NOAA, 1992; etc. etc.). One application for winter oil spills on land could be to use the manuals that have been developed for ice and snow conditions at sea (e.g., Owens *et al.*, 1999). Also, there has been no study for oil spills on land comparable to the comprehensive "Oil in the Sea" review (NRC, 1985), which is currently being updated.

In considering the differences and similarities of response operations between spills in different environments, there are some clear trends between spills on land, small creeks and streams, rivers and coasts, and the open ocean (Figure 1). The primary driving force behind these trends is the increasing rate of transport, spreading, mixing, and weathering in these different settings. One of the consequences is that planning for land-based spills can be quite site-specific and can focus on identifiable potential risks and impacts, more so than river, coastal, or marine spills as forecasting of spill movements can be more accurate. From a response standpoint, the consequences are that the scale of the response increases with the size of the impacted areas, and the amount of oil that is recovered greatly decreases.

Table 3 Komi Oil Spills - Site Characteristics (recovered oil is for the period March through September, 1995)

SITE	OILED AREA (ha.)	STREAM LENGTH (km)	VOLUME OF OIL RECOVERED (m^3)	TERRAIN CHARACTER
1	27.5	20.3	76,537	raised bogs, system of small, low-gradient, meandering streams
2	0.4	6.7	208	small, low-gradient, meandering stream
3	4.4	14.5	3,792	small, low-gradient, meandering stream
4	9.4	n/a	58,350	raised bogs, lowland seasonally-submerged forest, small area of upland forest
5	30.7	n/a	52,340	bog (floating in parts) and marsh
6	6.8	3.7	2,171	raised bog and small low-gradient meandering stream
TOTAL	*79.2 ha*	*55.2 km*	***193,398 m^3***	

The primary strategic and operational objective of this response was to prevent the spilled oil from entering the Kolva River. This was achieved by the construction of several dams, one of which was over 1000 m in length and 11 m high, across the tributary streams.

Considering the huge volumes of oil (more than 1 million barrels) spilled, it is important to note the very small size of the total impacted area (approximately 80 hectares) (Table 3). If any of the oil had reached the Kolva River the potential size of the impacted area would have increased dramatically and the spill could have effected hundred's of kilometers of river and the lives of hundreds or thousands of people. The response effort would have been magnified greatly in terms of the time and cost to recover the oil, as well as in terms of the geographic size of the operational area. Also, there was no human use impact in the remote and unpopulated area covered by the oil, so that it was not considered necessary to clean or remove all of the oil. The cleanup objective was to remove to the point that no potentially mobile oil remained that could be carried downslope or down stream to the Kolva River.

THE WHATCOM CREEK SPILL, USA

This small spill of approximately 1 million liters of gasoline, which occurred on 10 June, 1999, impacted about only 5000 m of a creek. The accident, however, resulted in a fire in the creek and the tragic loss of three lives. The fire could have been of disastrous proportions if the gasoline had ignited later, as the leading edge was only some 250 m from a major highway during rush hour and beyond the bridge is the central business district of the town of Bellingham.

Although the spill was on land, the gasoline quickly reached a small creek (Hanna) that was only a few tens of centimeters wide and a few centimeters deep. However, this was sufficient to carry the oil rapidly, in the space of an hour or less, through 2500 m of the Hanna and Whatcom Creek system. The oil was accidentally ignited and the fire that ensued stopped 250 m east of the Interstate 5 highway bridges, however, some of the oil traveled further downstream but did not ignite.

This response was limited in geographic area to a 10-km length of the creek system. However, the operations were complicated by the terrain (steep wooded (burnt) canyon walls, waterfalls, and occasionally deep water) and by the very public nature of the location. Private citizens were observed in the area, within a few minutes of the fire, despite the obvious hazards of burning trees, falling limbs, and the presence of unburned gasoline. Even after the cleanup operations began, it was virtually impossible to maintain complete site security despite a 24-hour system of security guards.

Whatcom Creek is a salmon spawning habitat and the objectives of the stream operation were to remediate the streambed affected by the spilled gasoline and to accelerate its recovery to a healthy biological system. The definition of the cleanup standard was developed by a Chemical Toxicity Working Group and literature values of toxicity of gasoline constituents to salmonid juveniles were converted to lowest effects concentrations. Over 400 water column and over 100 sediment or sediment pore water sample were collected as part of the monitoring program and by September its was determined that a substantial risk of chronic toxicity did not exist in Whatcom Creek (Owens *et al.*, 2000).

THE OSSA II SPILL INTO THE DESAGUADERO RIVER, BOLIVIA

A pipeline spill of mixed crude and condensate oil occurred on the Bolivian Altiplano, at an altitude of 3,500 m, during a wet-season flood event in January 2000 (Owens *et al.*, in prep). This oil spill of 29,000 barrels, relatively small compared to the Komi spills discussed above, however, spread over a large geographic area and impacted the lives of several thousand people (Henshaw *et al.*, 2001).

The oil spilled directly into the river during the flood season and was carried downstream over 200 km within a few days and, in one section of the river, spread through over 1000 km^2 of wetland flood plains. Thus, typically for an uncontrolled river spill, the impacted area was large. However, the dry season began shortly after the spill and within a few weeks the water level in the channels and wetlands lowered and the response then became typical of a land spill in terms of cleanup standards in a populated region and in terms of the type of cleanup operation that was initiated.

Initial weathering and degradation rates were very high due to extreme turbulence in the flooding river, and over 60% of the volume of the spilled oil was lost (Owens *et al.*, in prep.). The oil that remained and was deposited on the banks and floodplains was then stranded above the zone of active river processes by the falling water levels. These oil deposits were then exposed to much slower weathering rates, more typical of a land oil spill.

The cleanup operations were carried out over a two-month period with a labor force of local inhabitants that peaked at over 3000. In the wetlands area, the plants are used as fodder and chemical analyses were carried out to determine the potential toxicity of the oiled vegetation. The results showed clearly that the oil had lost virtually all of the toxic components, the BTEX's and PAH's (Owens *et al.*, in prep), and the cleanup plan did not require the removal of the oiled plants. The more than 700 hundred local family farmers in the affected wetlands were not convinced by the scientific rationale and argued for cutting of the oiled plants and for deliveries of fodder for their animals. This second-phase cleanup was then carried out and involved cutting over 80 hectares of vegetation.

A team of 25 Community Liaison Officers, 26 agronomists, 11 veterinarians, and 15 physicians and nurses was established to deal with the social and human-use issues. As part of the claims and compensation process, 40 agreements with political and civic representatives, traditional representatives, and production organizations (such as canal owner's associations) were negotiated and signed that covered more than 250 communities. The NGO "CARE" was contracted to deliver the in-kind compensation and to develop and implement the community projects (Henshaw *et al.*, 2001).

One of the lessons learned from this response on land is that the company was placed initially in the left-hand side of the matrix given in Figure 2. In this position, a company may find itself in a position of mistrust, inflated claims, and hostility. A consequence is that the resources needed to manage these issues at the same time as a major spill are huge and could be a significant drain on a small company. To position itself during normal operations in the top right-hand quadrant, requires investment in communities and the environment, primarily in areas close to the pipeline or in areas that could be affected by a spill. This type of investment can be considered another form of insurance (Henshaw *et al.*, 2001) .

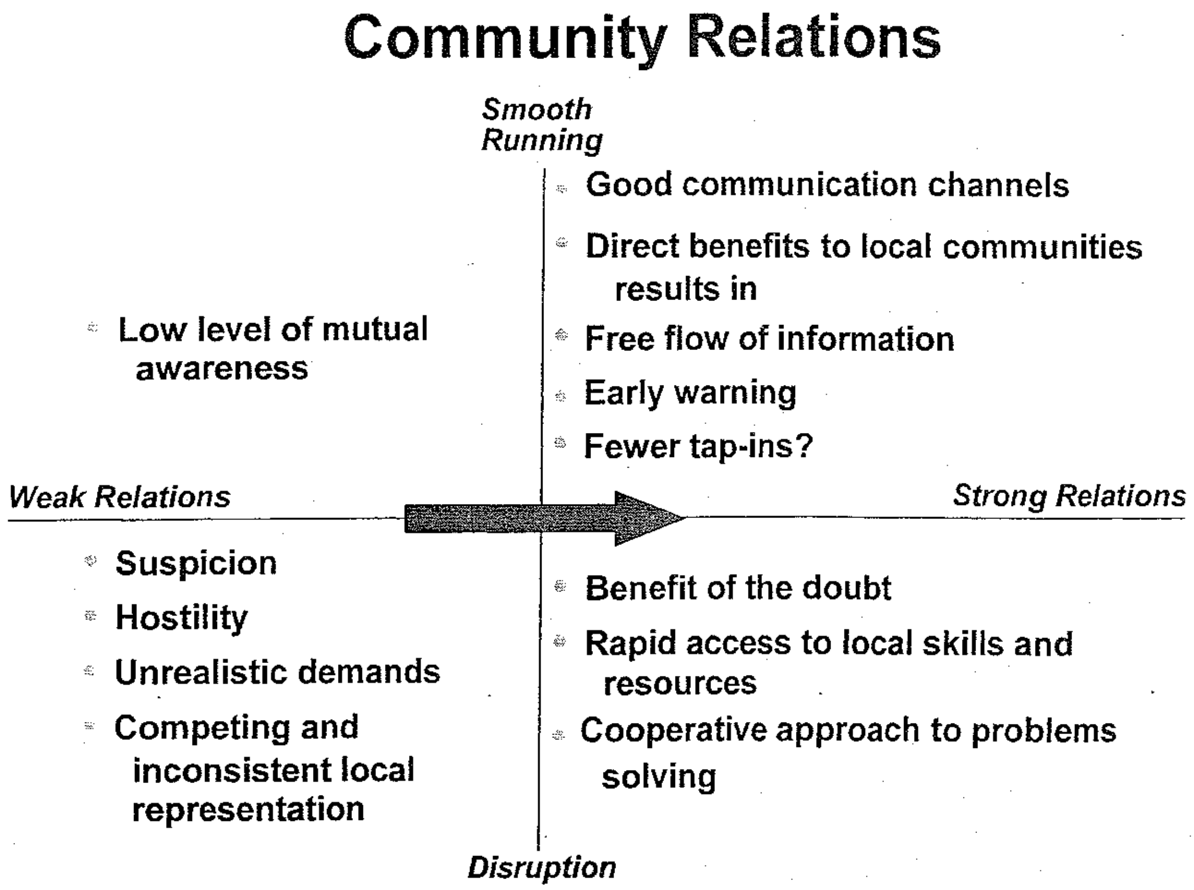
DISCUSSION

Obviously, there exist many hazards associated with generalization when dealing with oil and chemical spills, but some of the potential advantages of a response to spills on land over spills on water include the following:

- usually the impacted area is relatively small in size,
- greater potential for predicting the movement and effects of a spill,
- greater operational opportunities and flexibility, and
- greater recovery potential.

Some of the potential disadvantages with a response to a spill on land include:

- slower rates of weathering and natural attenuation,
- greater potential for impacting human-use activities and resources, and the
- potential for more strict cleanup standards and endpoints.



Community Relations

Smooth Running

- Good communication channels
- Direct benefits to local communities results in
- Free flow of information
- Early warning
- Fewer tap-ins?

- Low level of mutual awareness

Weak Relations

Strong Relations

- Suspicion
- Hostility
- Unrealistic demands
- Competing and inconsistent local representation

- Benefit of the doubt
- Rapid access to local skills and resources
- Cooperative approach to problems solving

Disruption

Figure 2 A community relations matrix (created by J. Shankleman, ERM Social Strategies: from Henshaw *et al.*, 2001).

The differences between response operations on a coast, shore, or on land are primarily associated with operational factors on the one hand and levels or cleanup versus natural attenuation on the other. Spills on land have a greater risk of directly impacting human activities or resources associated with social or economic activities.

Despite these differences, generally the same objectives, strategies, methods, and equipment are used on land spills as on the coast, so knowledge and operational practices can be transferred from one environment (the land) to another (river banks, lakes shores, and the coastline). For example, land farming has long been used to remediate oiled soils, but only recently has mixing or sediment relocation become accepted as a potential treatment tool on coasts (Lee *et al.*, 1997: Lunel *et al.*, 1996). Although this discussion has focused on oil spills, chemical spills on land are very common. Often, the Health and Safety issues associated with field operations and waste management of chemical spills are more serious, as these spills frequently involve hazardous or toxic substances. Many of the operations and safety procedures developed for chemical spills on land can be adapted for oil spills both on land and on the coast.

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