IBP416_03

CONTINGENCY PLANS AND RESPONSE STRATEGIES FOR OIL SPILLS INTO RIVERS

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Abstract

Oil that is spilled into a river enters a dynamic environment. An effective response can only succeed if the dynamics of the river system are understood and if the strategies and tactics match these conditions. Oil is transported downstream at the speed of the current and an estimate of the rate of movement is essential to identify effective intercept locations. Boom performance is affected by local surface water velocities as entrainment of oil typically begins when velocities exceed 0.4 m/s. However, boom configurations can be effective in current velocities as great as 2.5 m/s. Response operations can be successful if staging or control locations have been identified as part of contingency planning and if booms are deployed to take into account local surface current characteristics. Tracking and control of submerged or sunken oil is difficult and may not be practical. Recovery operations for sunken oil depend on the channel depth, current velocities, and on the distribution and concentration of the oil.

Introduction

Oil spill contingency plans typically include the first response strategies that enable an operations team to quickly identify resources at risk and the steps that can be taken immediately to minimize the spread and the impacts of the oil. The development of effective and practical first response strategies requires an understanding of the river character and of the behaviour of oil in rivers. This knowledge can then be used to develop response objectives and strategies that are compatible with the environmental conditions at the time of a spill. This discussion summarizes the key elements of the behaviour of oil in rivers and describes some of the strategies that can lead to a successful response.

1 River Character

There is a great range in river character from small creeks or streams in ravines or canyons to wide meandering channels in a floodplain or delta region. All rives and streams, however, have a common feature that is the movement of water down slope to the sea or a lake.

Generally, the waters of a river move in one direction (downstream) but locally within a channel there are back eddies, whirlpools, and other dynamic hydraulic features that alter the simple unidirectional flow pattern. Water motion within a channel is not uniform and is affected by friction at the channel bottom and margins and by the channel geometry. Flow velocity is usually faster on the surface and in the center of a channel, away from banks and the bottom, and velocities increase as a channel narrows and decrease as a channel widens. In

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a meandering channel, the flow is faster in the deeper water on the outside of a meander bend and is slower in the shallower water on the inside of a bend.

Understanding river currents is essential for response planning. One of the tasks in a spill response is to estimate the speed of the leading edge of a plume as the oil is transported downstream. This information is then used to select practical intercept sites so that containment equipment can be deployed ahead of the leading edge of the plume. A second task is to estimate local surface water velocities as the configuration of containment boom is directly affected by surface currents. Entrainment of oil under a boom typically occurs when the relative current velocity exceeds approximately 0.4 m/s (0.75 knots) (ExxonMobil, 2002).

If the lower reaches of a river at the coast are tidal, the flow within the channel may reverse. A similar effect results from meteorological tides (storm surges) that pile water against the coastline. Marine waters are denser than the fresh or brackish river waters. During flood tides this often creates a condition in which river water flows downstream at the surface with a countercurrent of denser saline water flowing upstream below (Figure 1). This condition is called a “salt-wedge effect” and the contact zone between the marine and river waters is referred to as a density front. The surface flow direction where a density front intersects the water surface on both sides is towards the front. This front is a natural barrier that is a natural collection area for surface oil and debris. In the case of very large rivers, such as the Amazon, the discharge is so great that the river water dominates the coastal environment. The Amazon plume extends up to 20 km into the Atlantic Ocean and prevents any incursion of marine waters both at the surface and at depth in the river channels.

2 The Behaviour of Spilled Oil in Rivers

2.1 Oil Transport and Weathering

A critical response operation objective following an oil spill on land is to prevent that oil from reaching moving water. Once oil reaches, or is spilled directly into, a river, creek, or stream, the oil enters a dynamic environment and is immediately and often rapidly transported downstream so that the size of the affected area also increases, and the length of time that the oil stays in motion also increases dramatically (Owens, 2002). This change from typically a slow movement down slope on land to dynamic transport conditions by moving water completely alters the character of the response operation.

The transport of oil spilled on land is a function of: oil viscosity, oil volume, ground permeability, vegetation cover, and slope. Once the oil has spread on the ground as far as viscosity and water is a function of hydraulic water motion, water, oil density, and oil viscosity. The rate of movement of oil that reaches moving water is primarily as a function of the river flow. Oil from a 2.8 million-litre spill of diesel into the Monongahela River in the eastern United States in 1988 reached the Ohio River, approximately 40 kilometers miles downstream within 24 hours (Yapa, *et al.*, 1991) and within 5 days had affected water intakes as far as 180 kilometers down stream (Laskowski and Voltaggio, 1989). Similarly, oil spilled from a pipeline rupture into the Río Desaguadero in Bolivia in January

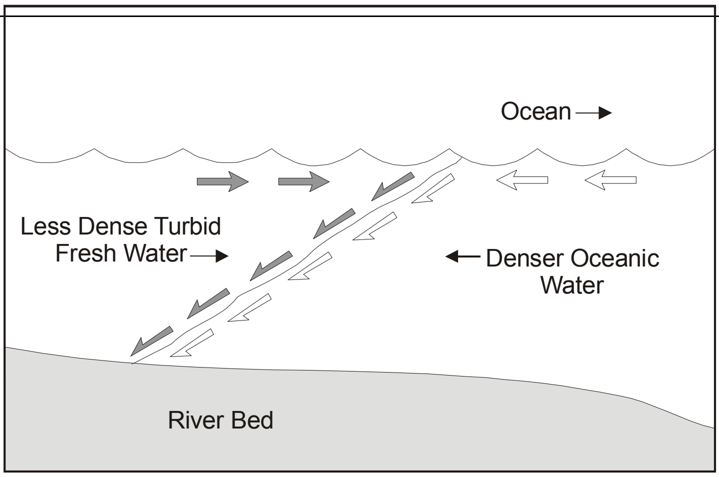

Figure 1. Cross section of a density front created where two distinctly different water bodies converge

2000 was transported 350 kilometers downstream in less than 5 days during flood conditions (Owens and Henshaw, 2002).

As flow velocity is usually faster on the surface and in the center of a channel the leading edge of a plume tends to stay in the center of a channel. Oil in moving water tends to oil to spread rapidly with considerable mixing behind leading edge of oil plume. Turbulence and mixing in river channels occur throughout the water column so that more oil can be kept and moved within the water column than in lakes or oceans, particularly in fast-flowing rivers. Oil that is entrained within the water column may surface in quieter waters as velocity and turbulence decrease. For most oil types the behaviour in rivers has a more three-dimensional component as compared to oil in lake or marine environments.

The speed of oil movement is dominated by the currents and the effect of wind, generally, is a minor. Winds that parallel the current can accelerate the rate of movement, but as rivers are rarely straight this is a very local effect. The primary effect of wind can be to determine which river bank is oiled as oil moves downstream.

One important effect in dynamic river environments, characterized by turbulent hydraulic conditions, is that the weathering processes of dissolution, dispersion, emulsification and biodegradation are accelerated. Higher mixing rates may also increase contact between oil and suspended sediments, a process that has been shown to promote weathering, in terms of dispersion and enhanced biodegradation rates through oil-mineral aggregate formation (Lee *et al.*, 2002).

2.3 Oil Distribution

As well as understanding how oil moves downstream, it is necessary to know where oil likely will be deposited. A critical parameter for river spills is the river stage. Changes in river level primarily result from the interaction of precipitation throughout the drainage basin and the input from tributaries. Rising water levels may wash stranded oil from a river bank and reintroduce the oil into the river system, or may bury oil that has stuck to the river bank or to vegetation. High water levels may result in greater oil contact with river bank vegetation. Oil can wash over the banks and into a flood plain as water levels rise during floods and potentially affect large area of vegetation or agricultural land. A spill during a seasonal flood stage with over-bank oiling may result in a cleanup operation that is more typical of a land spill operation after the flood waters have receded (Owens and Henshaw, 2002). As the river level falls oil can be deposited to coat the banks and, if the water level continues to drop, then this oil will remain until the next period of similar water levels unless it is cleaned.

3 Response Strategies

3.1 Spill Control

The objective of spill response is to minimize additional damage to the environment and human activities. As the movement of oil spilled into river is basically predictable at a regional scale a common strategy is to intercept and contain the oil at a location down river that is accessible for the response team and where there is sufficient time for deployment prior to the arrival of the leading edge of the slick. In areas where there is good access to the river it may be possible to intercept and contain the oil before it is carried long distances downs stream. In the case of the Colonial pipeline spill in South Carolina in 1991 2.1 million litres of No. 2 fuel were contained within about 50 kilometers from the source and a recovery of about 95 per cent (Smith, 1993). By contrast, the Ashland oil spill of diesel fuel in the Monongahela River in 1988 affected almost 800 kilometers downstream and approximately 25 per cent of the oil was recovered (Miklaucic and Saseen, 1989).

In remote areas, a first response tactic that enables this intercept strategy to be feasible and effective is to pre-stage equipment so that it is necessary only to deploy personnel to the location (Owens and Douglas, 1999). Where there is a well-defined risk, such as a pipeline river crossing, with slow currents and no river traffic, it may be practical to pre-deploy the first-level response equipment. Personnel can be deployed must faster, by air, road, or boat, if they do not have to take the equipment to the intercept site. Pre-staging and pre-deployment allow the spill control points to be located nearer to the potential source locations as the response times are greatly reduced.

The recent introduction of self-deploying current rudders (Boom Vanes^{TM}) has reduced set-up time by eliminating the need for a boat to deploy a boom or to set anchoring systems. The boom is pulled out into the current or can be retrieved by a vane that is manipulated from the river bank with a control line. This system has been successfully field tested in currents between 0.25 and 1.5 m/s (Hansen, 2002). Recent equipment development has focused on the control and recovery of oil in fast currents. For example, a sweep configuration, boom the NOFI “Current Buster^{TM}”, was designed for recovery in fast currents and has been tested successfully at 1.8 m/s (Hansen, 2002). Similarly, new skimmer designs have been shown to work effectively in current speeds up to 2.5 m/s.

In streams, creeks, and small rivers, where flow conditions are not energetic, it may be possible to pre-deploy booms near a pipeline crossing or other location where oil may spill into the channel. At these locations, periodic inspections and maintenance are necessary but pre-deployment offers the potential to control a spill close to the source without relying on personnel for this initial containment.

Removal of oil from the water surface can be achieved by controlled burning. The principles and issues associated with burning as well understood (e.g., Fingas and Punt, 2000) and this strategy would be particularly suited to large spills in remote area, where physical control and recovery is not practical, and where there is a threat of extensive damage downstream.

3.2 Streams and Creeks

Stream, creeks and small river channels have relatively low discharge volumes but flow velocities and turbulence, nevertheless, may be high in shallow or constricted sections. Water depth is a common constraint in these small channels and flotation booms may not be effective in the shallow environments. Sorbent booms, filter fences, weirs, flow-through and underflow dams, or other similar containment tactics are appropriate for these shallow, small channel environments.

3.3 Rivers and Fast Currents

Oil is not contained by static booms placed across a channel in currents that exceed approximately 0.4 m/s so that alternative configurations are required. The dynamic containment option that involves the boom system moving downstream with the oil may be effective if the channel is wide and there are no navigation hazards. Alternatively, static booming using cascading sections of boom set at an angle to the current can divert oil to a collection area in currents that are in excess of 2.5 m/s (Hansen and Coe, 2001)(Figure 2). The appropriate containment tactics for a large river channel are dictated primarily by the surface current velocity (Figure 3).

Figure 2 High-angle cascading diversion boom configuration in a fast current, Kolva River, Russia 1995. View from above (left) and at the river bank recovery location (right).

3.4 Tidal Rivers

The role of density fronts in tidal rivers is significant as oil cannot cross these natural barriers. Oil moving downstream towards the coast in freshwater will be stopped if it encounters a well defined body of saline ocean water. An interesting example of understanding the environment. and the behaviour of oil in this context can be demonstrated by considering response strategies for potential oil spills in the region of the mouth of the Amazon If oil is spilled in the Amazon River and is transported to the coast, the oil will stay within the Amazon coastal plume as it is deflected along the coast to the northwest by the offshore Guyana Current and by prevailing onshore winds. In this scenario, the primary threat is to the swamp and mangrove coasts of French Guyana, Suriname, and Guyana that are vast shrimp and fish nursery areas for commercial and subsistence fisheries. The freshwater discharge from the Amazon serves to protect the trans-Guyana coast from offshore oil spills, that is, marine spills that occur outside of the Amazon plume. This oil would most likely follow the offshore Guyana Current that parallels the coastal Amazon plume current, and would potentially impact the Trinidad region.

Rivers or Large Streams **> 0.5 m deep**	Water Current Speed	< 0.5 m/s	Containment or Exclusion Boom
		0.5 to 1.0 m/s	Single Diversion Boom
		> 1 m/s	Multiple Cascading , Diversion, or Fast Current Booms
Small Streams **< 10 m wide and > 0.5 m deep**	Water Current Speed	< 0.5 m/s	Sorbent or Containment Boom Berms or Dams
		0.5 to 1.0 m/s	Single Diversion Boom Berms or Dams
		> 1.0 m/s	Multiple Cascading, Diversion, or Fast Current Booms Berms or Dams
Shallow Rivers or Streams **< 0.5 m deep**	Water Current Speed	0.0 to 1.0 m/s	Barriers, Berms, or Dams on Stream Bed

Figure 3 Decision guide for control on rivers and streams (modified from Exxon, 2002)

3.5 Submerged and Sunken Oil

Oil may sink if the density is greater than that of the river water or if it is entrained by the turbulence in the surface waters. Submerged oil that is denser than the water but not so dense that it will sink or that is entrained by turbulence stays below the water surface and is in the water column. This oil may return to the surface if the water density increases or if the turbulence is replaced by calmer water conditions. Sunken oil is defined as oil that has been deposited on the river bed and that will, most probably, remain there.

The primary difficulty with submerged and sunken oil is that it is extremely difficult to track or monitor the oil. Stationary sunken oil may be easier to locate than submerged oil but there are no proven techniques for locating oil that is neutrally buoyant and suspended in the water column. Various grab sampling devices have been employed to find sunken oil (Castle *et al,.* 1995) but these are generally unsatisfactory as they sample only one discrete position at a time and will probably miss scattered oil patches (Brown et al.,1998). There have been a few cases where some success has been reported but these frequently have been situations which the oil is contained within the sunken ship or barge. Other than these situations, successful recoveries often have involved the removal of heavy oil which has pooled in depressions of river beds or in shallow near-shore areas of lakes or the sea. These response operations have generally used divers with suction equipment or dredges and have been confined to small areas.

An integral part of spill management is to set realistic expectations. Occasionally it is possible to track or detect submerged oil, locate sunken oil, protect underwater resources, such as water intakes, or contain and recover submerged or sunken oil. If detection is not possible or recovery is not feasible then this message must be clearly stated so that the objectives and expectations of the response operations are clearly understood by all involved and by the public. In reality, for most open water scenarios none of the response options are practical.

4 Conclusions – Contingency Plans and Response Strategies

A key element for a successful response to a river spill is to understand the dynamics of the river and to match strategies and tactics to these conditions. Plans and strategies for oil spills into rivers can build on the following points:

- Successful containment strategies to minimize oil spreading and the size of the effected area depend largely on the selection of practical intercept locations ahead of the moving oil plume.
- It is possible to contain oil in fast currents with cascading boom configurations that do not resist the force of the current that is transporting the oil.
- Response times can be reduced and environmental impacts minimized by the deployment of pre-staged equipment to pre-planned intercept or control points. Pre-staging can greatly reduce the mobilization and deployment times. Personnel can be deployed must faster if they do not have to transport the equipment, so that control points can be located nearer to the potential spill source.
- In addition, response times can be further reduced with self-deploying boom vane systems that do not require boat support to place the boom.
- Recent advances in boom and skimmer designs have produced response equipment that can operate successfully in fast currents (up to approximately 2.0 and 2.5 m/s respectively).
- Controlled burns can be highly effective for oil removal and have many applications provided that there is no risk to sensitive habitats, people, or property.

Very different strategies and tactics are required if the response involves submerged or sunken oil in rivers. Tracking and detection is often very difficult, interception and control usually impractical, and recovery both difficult and rarely completely successful. For submerged oil a key aspect of a response operation is to understand the difficulties and the safety issues and to communicate this information to ensure that there are no false expectations.

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