# Differences and Similarities in Freshwater and Marine Shoreline Oil Spill Response

February 3, 2011

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## ABSTRACT

There are many similarities between marine, lake and riverine environments, as well as differences that involve an adjustment when transferring oil spill knowledge and experience between these environments. Basic elements of shoreline cleanup decision making and response, SCAT, cleanup endpoints, strategies and tactics, apply in all environments. Major differences result due to the different types of water levels and water exposure/processes in tidal, lake and flowing water which effect oil stranding, band width and behaviour, natural removal and cleanup tactics. Tides and waves are the most important water processes in tidal (marine) waters, waves in lakes, and currents and water flow in streams and rivers. Both water level ranges during the time of stranding and the frequency and duration of subsequent water level changes over time are different in marine and freshwater. Oil dilution and spreading potential are greater in marine environments. In general, biological productivity is lower and there would be less biological impact to the sand, granule, pebble, cobble, boulder, or bedrock shoreline of a lake or river than a similar marine shoreline. Consequently, more aggressive techniques may be considered for freshwater as opposed to marine shorelines. Whether marine or freshwater, most differences with respect to oil spills are found and applied at the specific case level. It is the oiling conditions and environmental setting that affect oil behaviour, persistence and biological effects, and influence and fine tune standard response processes.

## INTRODUCTION

The same technical advisors, specialists, and operational managers may be tasked to deal with spill events that affect marine, lake or riverine environments either as a single spill event or a combination that includes more than one of these environmental settings. A primary goal of spill response is to minimize the impact of the oil and the effects of the response operations as part of the decision process. Decision makers, planners and responders familiar or experienced with one environmental setting must therefore make appropriate adjustments to factor in the environmental differences in order to avoid potential harmful effects or delay weathering and/or recovery. Recognizing that the different environments require an individual approach, Environment Canada commissioned shoreline cleanup manuals for each environment. Many of the key points in this discussion emanate from those manuals and other related recent Environment Canada studies.

There are many similarities in spill response between the marine, lake or riverine environments, in particular with respect to the decision making process and response strategies and to the tactics and techniques that are available. On the other hand, there are significant differences that involve an adjustment when transferring knowledge and experience between these environments. Differences and similarities discussed in this paper include those in

- the physical environment – shore zones, shoreline type, size of the water body, water levels and water related processes,
- the biological environment - productivity, sensitivity and effects, and
- the response environment – assessment and tactics.

For purposes of comparison between marine and freshwater, the latter environment maybe further divided into lake, ponds, rivers or streams.

## DISCUSSION

The fate and behaviour of oil stranded on a shoreline is a function of many factors, most notably the character of the oil, the physical character of the shoreline (shoreline type), the location of the oil (shore zone) and the physical processes at the shoreline, including tides, waves, water levels, water flow and currents.

### Shore Zone Subdivision Definitions

The shore zone is that location in which oil is typically stranded. Different terminology is used for marine, lake and riverine environments to define across-shore zones.

Marine shorelines are divided on the basis of tidal zones. Tides are an important factor in terms of the distribution of stranded oil and the shoreline processes that act on that oil. Marine zonation is based on elevation: (a) the supratidal zone (the area above the mean high tide level where wave activity occurs on an infrequent and irregular basis – i.e. episodic), (b) the upper intertidal zone, (c) the middle intertidal zone, (d) the lower intertidal zone, and (e) the nearshore subtidal zone (the shallow water area adjacent to the intertidal zone and which is always submerged).

Lake shorelines are divided on the basis of the swash zone caused by wave action. These include: (a) the supra-swash zone (the area above the highest annual water level that only occasionally experiences wave activity, as during a storm event), (b) the upper swash zone, (c) the lower swash zone, and (d) the submerged littoral zone (the area below the water line, near the shore that receives sunlight, extending down to the depth where rooted plants stop growing).

River bank (shoreline) zonation for oil spill response is based on water levels, for example: (a) the over-bank (flood plain: inundated only by over-bank flow during flood conditions), (b) the upper bank (under water only during bank-full river stage), (c) the lower bank (exposed only during low flow conditions), and (d) the mid stream ( a shoal or bar separated by water from the river bank).

### Shoreline Type

Shoreline type affects the fate and behaviour of oil and the applicability of response tactics. For purposes of oil spill response, shoreline classification is based on form or morphology and substrate material. The presence or absence of sediments and their size is a key factor as this determines whether the substrate is permeable or impermeable and the extent to which oil can penetrate or be buried.

As described in Sergy (2008), the majority of shoreline types used for purposes of oil spill response are similar in marine, lake and riverine environments. Marine environments have a few additional varieties to describe Arctic coastlines and freshwater environments have additions to capture different types of mud, clay or sediment cliffs and banks and organic/vegetated shorelines. Lakes, pond, rivers and streams have similar shoreline types, although rivers/streams are more often in the form of banks and midstream bars rather than beaches.

For all freshwater environments, the wooded uplands adjacent to lakes are included as an additional shoreline type when this terrestrial environment is oiled as a result of temporary inundation during high seasonal water levels or surge events.

Both marine and freshwater wetland environments may be subdivided differently if and when required for spill response. Marine wetlands include salt marshes, mangroves, and supratidal meadows. In salt marshes distinctions are often made between (i) estuarine systems, (ii) wide or fringing salt water systems and (iii) lagoon or tidal flat systems. Freshwater wetlands include marshes, swamps and could include bogs and fens. The nomenclature is not standard, however commonly used subdivisions in freshwater marshes are made for (a) deep water (e.g. reeds) (b) shallow water-land interface (e.g. rushes) and (c) wet meadow transition (e.g. sedges, grasses).

### Waves and Water Levels

Differences in the physical process at the shoreline, primarily waves, water level changes, water flow and currents, influence the decision process for marine and freshwater environments. In particular, oil stranding, behaviour, and natural removal are affected significantly by water-related processes. Tides and waves are the most important water related processes in tidal (marine) waters, waves in lakes, and currents and water flow in streams and rivers.

The water level at the time oil is stranded initially controls which across-shore zone(s) of the shoreline may be contacted by the oil and subsequently affects the exposure of that oil to weathering processes, in particular by the physical action of water. Oil makes contact with the shore at the water line and is spread over a band width dictated by the range in water level at the time (see Figure 1). In the marine environment, the band width is wider due to the astronomical and meteorological tides and large variations occur, for example, between oiling during a calm-water neap tide period as opposed to oiling with a wind-driven set up during a spring tide phase. In the latter case, oil frequently is stranded in the supratidal zone and subsequently only affected by physical coastal processes at the next similar combination of winds and tides. If the event occurs during a period of tropic or equinoctial spring tides this tidal elevation would be repeated only after approximately three months. Water levels in the marine environments can change significantly (several meters) over short time frames (hours to days) whereas those in lakes, notwithstanding seiches, are typically over longer time periods (days to weeks) or are seasonal (weeks to months). In the case of lakes and ponds the width of shoreline oiling in most cases is less, being a function primarily of the rollup distance of waves on a shoreline. Wide rivers can have sufficient fetch to generate waves, creating a vertically fluctuating waterline and a shoreline swash zone similar to lakes. A similar fluctuating shore-water interface is created by strong currents or turbulent fast flowing water of streams and rivers. In these cases a wider band of oil may strand or be splashed above the waterline. Waves are not usually a factor on small rivers; consequently, the width of oiling along the banks of small rivers is typically quite narrow as oil strands only at the shore-water interface. Slow moving quiet rivers and backwaters do not typically have rapid vertical displacement of the water level so that the width of an oil band may be very narrow. The band width will vary with the slope of the substrate and a vertical bank may only experience a very thin line of oil. Currents/water flow, especially in fast moving rivers also affects oil stranding. Rivers flow in one direction except for local eddies, whirlpools, or reversals at river mouths due to tidal effects, and the across channel flow rates are not uniform. The distribution of oil along fast flowing river banks is influenced by the movement of oil due to the flow/currents pattern.

Changing water levels affect oil fate, natural removal process, and operational activities such as staging, and access, particularly if the shore zone is narrow or there is a steep backshore. In marine environments, changes in tidal water levels are daily events that are usually predictable. Even oil deposited on a spring tide likely would be worked two or four weeks later on the next new or full moon phase. Conversely, oil stranded in the supratidal zone due to storm events typically persists for longer periods and the rates of natural removal by water-related processes may be very slow. This timing may delay natural rates of removal by months, for example following the Prince William Sound, Alaska spill in 1989 during which much of the oil was stranded on equinoctial spring tides, or by years, for example in the Esporsa Marshes following the “Metula” spill in Chile (Owens and Sergy 2005).

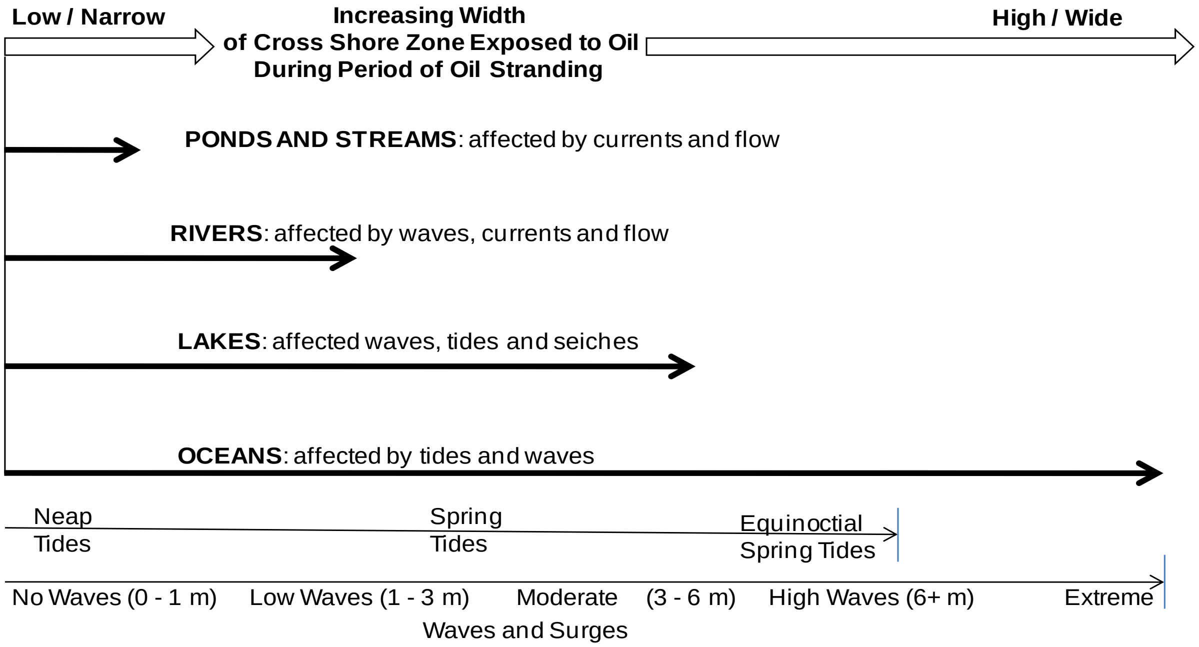

Figure 1. Relative Comparison of Short Term Water Level Ranges/Height at Time of Oil Stranding

Changes in water levels in lakes or ponds and rivers or streams due to seasonal runoff, local precipitation events, or wind events may be of the same magnitude as, or greater than, astronomic tides in marine environments, but are less predictable in terms of both timing and magnitude. The time scales involved for water level variations in freshwater may be short-term or seasonal but typically responders can expect a seasonal long term change of water levels in small lakes and ponds and streams due to the local annual hydrological cycle. Changes depend on the interplay between inputs (precipitation, snow melt, run-off, groundwater) and outputs (evaporation, transpiration, consumptive uses, and outflow), and the regulation of flow by man (dams, weirs). Streams and small rivers are more susceptible to rapid changes (hours to days), such as flash floods, in response to precipitation and run-off. Oil that is stranded during a period of higher water levels in a river or stream will remain above the limit of water action until the next period of similar higher water levels, which could be as much as a year in cases of seasonally related changes. As water levels change less frequently in freshwater marshes than in tidal marine marshes, edge effects are typically greater in freshwater marshes and inundation more likely in tidal marshes.

The size of a standing body of water and the water flow conditions in running waters control the potential spreading, transport, and dilution of spilled oil and therefore the size of the affected area, the length of oiled shoreline, and the amount of oiling/impact relative to the size of the water body. The size of any water body affects the potential for wave generation, which is one of the key elements in natural cleaning of oiled shorelines. The smaller the water body, the more likely that oil will be concentrated and stranded as thicker deposits, which in turn could result in a more severe environmental impact but in a relatively small area and facilitate control and recovery by the response team. As the size of the water body increases: (1) the ability to control or contain the oil decreases; (2) the affected area increases in size; (3) the ability to protect sensitive resources at risk decreases; and (4) the scale and cost of the response will increase (Figure 2). At the same time, (5) the oil is spread over a wider area so that concentrations are lower and (6) the potential for wave generation increases, with the result that (7) the potential for natural weathering and self-cleaning increases. Although generally not advocated as a solution, dilution due to the size of the water body does play a major role in oil fate and control. A small spill in a small pond is captive and the oil is in a limited volume and area of water.

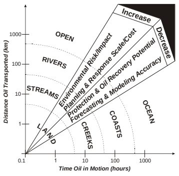

Figure 2. Time-space schematic for spills in different environments. (from Owens 2010)

Biological Effects and Shoreline Sensitivity

The bulk of our scientific and technical knowledge and experience with respect to biological effects and shoreline sensitivity to oil comes from marine oil spills. A number of studies which have reviewed and synthesized the results of freshwater effects or saline versus freshwater effects have highlighted the relative limited amount of knowledge concerning freshwater biota effects and sensitivity to oil (Vandermuelen et al. 1987; API 1999; Trett et al. 1989). In a comprehensive review of freshwater case studies, Taylor et al. (1995) concluded that spill effects and recovery in freshwater are highly variable and that few spills have prolonged effects. Generally we can say this is similar in marine environments. Taylor et al. point out differences due to hydrodynamics (as discussed above) in that impacts and oil persistence in fast flowing systems (rivers) are relatively short lived, as opposed to quiescent ponds and small lakes where oil may persist for extended periods. More recently Shigenaka (2010) also concluded that there is a variable range of impact for both seawater and freshwater so that generalization is difficult and that differences may be more explained by physical process, as outlined above. A few interesting items from his review relate to amphibians which are unique to freshwater and that several researchers have stated that salinity increased the toxicity of hydrocarbons in salmonids (Rice et al. 1984; Moles et al. 1979). Shigenaka identified the potential importance of life history stages as well as animal behaviour and habits which are an important point that warrant consideration in assessing potential impact differences between marine and freshwater.

Despite the potentially difficult task of generalizing, some broad statements regarding differences between marine and freshwater environments can be supported. Typically, in sand, granule, pebble, cobble, boulder and bedrock shorelines, the abundance of aquatic biota in the shoreline zone of streams, rivers, lakes and ponds is substantially less compared to their equivalent tidal marine shorelines. Marine intertidal zones are wetted on a frequent and regular basis and organisms have adapted to colonize and utilize this habitat. The intertidal zone is often rich with attached (sessile) and mobile organisms both on bedrock surfaces and within sediments. River and lake shorelines present a more hostile environment since water wetting is irregular, a result of waves, currents or rapidly changing water levels such as from rain storms, with typically freezing air and water temperatures in winter months. Freshwater organisms in that area above the water line are more subject to desiccation, in particular on exposed rock surfaces, and most organisms in this zone are mobile (not sessile) in order to survive.

In general, there would be less biological impact to the sand, granule, pebble, cobble, boulder, or bedrock shoreline of a lake or river than a similar marine shoreline in terms of cleanup techniques and operations. Consequently, more aggressive techniques may be considered for freshwater as opposed to marine shorelines. Notwithstanding this statement, there is a caveat pertaining to the effects below the water-line, in the shallow water zone adjacent to the shoreline of rivers and lakes. Potential effects of particular concern are small streams and ponds, and shallow rivers where a major portion of the water column and/or the river/lake bed may be impacted by either the spill or the response.

In contrast, differences between marine and freshwater are less relevant for mud flats and in particular for wetlands because both have relatively high biological productivity, ecological significance and sensitivity to cleanup operations. Clearly there are large differences in species composition between salt marshes and freshwater marshes, as the latter have more plant species due to the absence of salt stress. Marine marshes typically have a dense root system with better weight-bearing capacity than the more porous root systems of freshwater wetlands and marshes. This property can affect tactics, operations, and oil penetration. Oil fate and behaviour are different between salt and freshwater marshes, nevertheless, despite the differences, the overall high sensitivity means all wetlands must be treated with special consideration and each marsh system warrants an individualized treatment plan.

An important difference to emphasize relates to response operations in shallow freshwater environments. The assessment of river and lake shoreline sensitivity to response operations must consider the shallow water zone adjacent to the shoreline, just at and below the land-water interface. In this area the biological productivity increases dramatically, as compared to the actual shoreline zone, and plants and animals are susceptible to disturbances as a result of cleanup activity. Habitat sensitivity is further increased where this zone is used for fish feeding or spawning or as shelter during early phases of the life cycle.

The effects of response operations in large or deep rivers may be similar to those in lakes and ponds for activities that take place on the shoreline or in the immediate nearshore shallows. In small streams and some shallow rivers there is the additional concern of stream bed disturbance by operations. This concern may particularly important for narrow streams or shallow waters where there is the possibility that a major portion of the stream bottom may be directly or indirectly subjected to disturbance. Where this is not desirable then particular attention should be directed to avoid such damage, although in some instances a conscious decision may be made to ‘clean’ the entire stream bottom from bank to bank.

### Shoreline Cleanup Response

Basic elements of shoreline cleanup response are identical in marine and freshwater environments. The same framework, components and processes for shoreline cleanup decision making (Owens and Sergy, 2008) and those for selection and use of endpoints (Sergy and Owens, 2008) can be applied in both environments. Likewise, the standard set of cleanup strategies and tactics (Owens 2010) are still appropriate in most circumstances. Most differences are found and applied at the site-specific case level, for example, the avoidance of fresh water to flush or wash marine habitats. Whether marine or freshwater, the oiling conditions, oil behaviour and environmental setting primarily influence and fine tune standard response processes.

A few key points emerge in a comparison of marine and freshwater response. Generally, it may be said that:

- the most notable overall influence on differences in response choices and actions is due to the effects of different types of water levels and water exposure/process in tidal, lake and flowing water;
- biological sensitivity and productivity in the zone of the oiled shoreline is lower in freshwater, which for a large part is also shaped by different water level regimes. As a result, more aggressive techniques may be considered for freshwater shorelines as opposed to marine shorelines;
- oil dilution and spreading is greater in marine environments, and this ‘aid’ to response operations and strategies is not available in small freshwater bodies
- particular attention is required with respect to the impact of the response operations to the beds of small streams and some shallow rivers, and likewise to the shallow littoral zone of rivers and lakes as biological activity increases in these zones;
- natural recovery has greater potential in the marine environment. Nevertheless it is an option in freshwater locations of higher energy, where turbulent water flow and wind or current generated waves and swash accelerate oil removal by water-washing processes. Natural recovery is less appropriate for heavy or weathered crude oils and in slow moving rivers, backwaters and sheltered shores where the oil is likely to persist due to low energy conditions or on slow small streams and where the dispersion potential is low. Most streams and rivers undergo relatively large seasonal variations in water elevation and flow which should be considered in the selection of tactics and timing of application. For example, over the course of a season, the zone of oiling may be completely submerged or emergent.

### Shoreline Clean Assessment Technique SCAT

The same principles and procedures of SCAT surveys and documentation apply to marine and freshwater environments. Only minor differences would exist to accommodate the different oiling conditions or physical characteristics, such as shoreline types. One of the frequently used outputs of SCAT data are comparative indices or ratings on the relative severity or degree of shoreline oiling. Detailed observations from SCAT field surveys are translated into a simple index, where oil conditions can be summarily described as Very Light, Light, Moderate, or Heavy (Owens and Sergy 2000). A factor affecting this index is width of oiled area and this should be adjusted to best represent the specific environment. Typically the width criteria for freshwater environments are downsized from the marine standard values (Sergy and Owens 2009) such as shown in Table 1.

| Term | Marine | Freshwater |
|---|---|---|
| Wide | > 6 m | >1 m |
| Medium | > 3 m to 6 m | > 0.2 m to 1 m |
| Narrow | > 0.5 m to 3 m | > 0.02 m to 0.2 m |
| Very Narrow | < 0.5 m | < 0.02 m |

Table 1. Typical SCAT Shoreline Width for Marine and Freshwater

## CONCLUSIONS

There are many similarities in spill response between the marine, lake or riverine environments, and differences that involve an adjustment when transferring knowledge and experience between these environments. The majority of shoreline types used for purposes of oil spill response are similar. Shore zonation is based on different water movement processes. Tides, waves, currents and water flow impart different types of water movement, exposure and processes which produce significant differences in oil stranding, oil conditions, oil behaviour and natural removal, all of which effect response operations. There are differences in frequency and duration of subsequent changes in water levels in tidal, lake and flowing water. In marine environments, changes in tidal water levels are regular daily events that are usually predictable. Changes in water levels in lakes or ponds and rivers or streams due to seasonal runoff, local precipitation events, or wind events may be of the same magnitude as, or greater than, astronomic tides in marine environments, but are less predictable in terms of both timing and magnitude. Oil dilution and spreading potential is greater in marine environments. In general, biological productivity is lower and there would be less biological impact to a sand, granule, pebble, cobble, boulder, or bedrock shoreline of a lake or river than a similar marine shoreline. As a result, in some cases, more aggressive techniques may be considered for freshwater as opposed to marine shorelines. Both marine and freshwater wetlands have relatively high biological productivity, ecological importance and sensitivity to cleanup operations. Particular attention is required with respect to the impact of the response operations to the beds of small streams and some shallow rivers, and likewise to the shallow littoral zone of rivers and lakes where biological activity increases. Basic elements of shoreline cleanup decision making, tactics, response operations and SCAT are identical in marine and freshwater environments. Most differences are found and applied at the specific case level. Whether marine or freshwater, it is the oiling conditions and environmental setting that affect oil behaviour, oil persistence and biological effects of the spill, and influence and fine tune standard response processes.

## REFERENCES

American Petroleum Institute. 1999. API Publication Number 4675. In: Stalfort D, editor. Fate and Environmental Effects of Oil Spills in Freshwater Environments. Washington, DC: American Petroleum Institute.

Moles, A., S.D. Rice and S. Korn. 1979. Sensitivity of Alaskan Freshwater and Anadromous Fishes to Prudhoe Bay Crude Oil and Benzene. Transactions of the American Fisheries Society, 108: pp. 408-414.

Owens, E.H., 2010. Shoreline Countermeasures. *in* (ed. M. Fingas) "Oil Spill Science and Technology – Prevention, Response and Cleanup", Gulf Professional Publishing, Elsevier, pp. 907-921.

Owens, E.H. and G.A. Sergy. 2000. The SCAT Manual - A Field Guide to the Documentation and Description of Oiled Shorelines: Second Edition. Environment Canada, Edmonton, Alberta. 108 pp.

Owens, E.H. and G.A. Sergy. 2005. Time Series Observations of Marsh Recovery and Pavement Persistence at Three Metula Spill Sites after 30½ Years. Proceedings 28th Arctic and Marine Oilspill Programme (AMOP) Technical Seminar, Environment Canada, Ottawa, ON, 463-472.

Owens, E.H. and G.A. Sergy. 2008. A Shoreline Response Decision-Making Process. Proceedings International Oil Spill Conference, American Petroleum Institute, Washington DC, pp. 443-449.

Rice, S.D., Adam Moles, J.F. Karinen, S. Korn, M.G. Carls, and C.C Brodersen. 1984. Effects of Petroleum Hydrocarbons on Alaskan Aquatic Organisms: A Comprehensive Review of All Oil Effects Research on Alaskan Fish and Invertebrates Conducted by the Auke Bay Laboratory, 1970-81. Seattle, WA: NOAA Technical Memorandum NMFS F/NWC-67.

Sergy, G.A., 2008. The Shoreline Classification Scheme for SCAT and Oil Spill Response in Canada. Proceedings of the 31st Arctic and Marine Oil Spill Program Technical Seminar. Environment Canada, Ottawa, ON, pp. 811-819.

Sergy, G.A., and E.H. Owens. 2009. Indices to Rate the Degree of Oiling on Shorelines. Proceedings 32nd Arctic and Marine Oilspill Program, Environment Canada, Ottawa, ON, pp. 167-175.

Sergy, G.A. and E.H. Owens. 2008. Selection and Use of Shoreline Treatment Endpoints for Oil Spill Response. Proceedings 2008 International Oil Spill Conference, American Petroleum Inst. Washington DC, pp. 847-854.

Shigenaka, G. 2010. Effects of Oil in the Marine Environment. *in* (ed. M. Fingas) "Oil Spill Science and Technology – Prevention, Response and Cleanup", Gulf Professional Publishing, Elsevier, pp. 985-1024.

Taylor, E., A. Steen and D. Fritz, 1995. A Review of Environmental Effects from Oil Spills into Inland Waters. Proceedings of the 18th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Environment Canada., Ottawa, ON, p.1095-1115.

Trett, M.W., J.D. Hutchinson, C.F. Mason, B. Frankland, D.H. Khan, and S. Shales. 1989. Chapter 9: Summary and Conclusions. In: Green J, Trett MW, editors. The Fate and Effects of Oil in Freshwater. vol. 259. Amsterdam, NL: Elsevier Applied Science.

Vandermeulen, J.H. 1987. Toxicity and Sublethal Effects of Petroleum Hydrocarbons in Freshwater Biota. In: Vandermeulen, JH, Hrudey, SE, editors. Oil in Freshwater: Chemistry, Biology, Countermeasure Technology. vol. 267. Oxford, UK: Pergamon Press.