Table 7-69 Environmental Characteristics Observed at Selected Access Points on the Red River in September, 2016

Access Point	Latitude Longitude	Notes
		Wildlife observed: American crow

7.6.2 High Consequence Area Assessment for the Red River

As defined in Section 7.0, HCAs include populated areas, drinking water source areas, ecologically sensitive areas, and commercially navigable waterways. Sensitive AOIs include Minnesota drinking water management areas, native plant communities, sensitive lake shores, recreational areas, tribal lands, and protected areas of several types (e.g., national forests, military lands, state parks). The principal HCAs include the population centers of Pembina, ND and St. Vincent, MN (Table 7-70). The Red River also flows past recreational areas, protected areas, and environmental AOIs (Table 7-71). These include water access sites and Bureau of Land Management land. The locations of the HCAs and AOI are shown in Figure 7-36.

Table 7-70 High Consequence Areas Potentially Affected by a Release of Cold Lake Blend or Bakken Crude Oil at the Red River Crossing Location

HCA Type	HCA Subtype	Description / Locations
Environmentally Sensitive Area	N/A	N/A
Population Area	Other Population Area	Pembina, ND
	Other Population Area	St. Vincent, MN
NOTE: Data for the HCA analysis were obtained from the United States Department of Transportation: Pipeline and Hazardous Materials Safety Administration (USDOT PHMSA) HCA datasets plus additional HCAs compiled by Enbridge during 2010 and 2013.		

Table 7-71 Areas of Interest Potentially Affected by a Release of Cold Lake Blend or Bakken Crude Oil at the Red River Crossing Location

AOI Type	AOI Subtype	Description / Locations
Recreational	State Land	Water Access Site
Protected Area	Bureau of Land Management	BLM Land
Environmental	US NRCS Easement	Emergency Watershed Protection Program - Floodplain Easement
	Site of Biodiversity Significance	St. Vincent 11
NOTE: Data for the AOI analysis were derived from multiple datasets provided on the Minnesota Geospatial Commons website, USGS Protected Areas Database of the United States and the Minnesota Department of Transportation.		

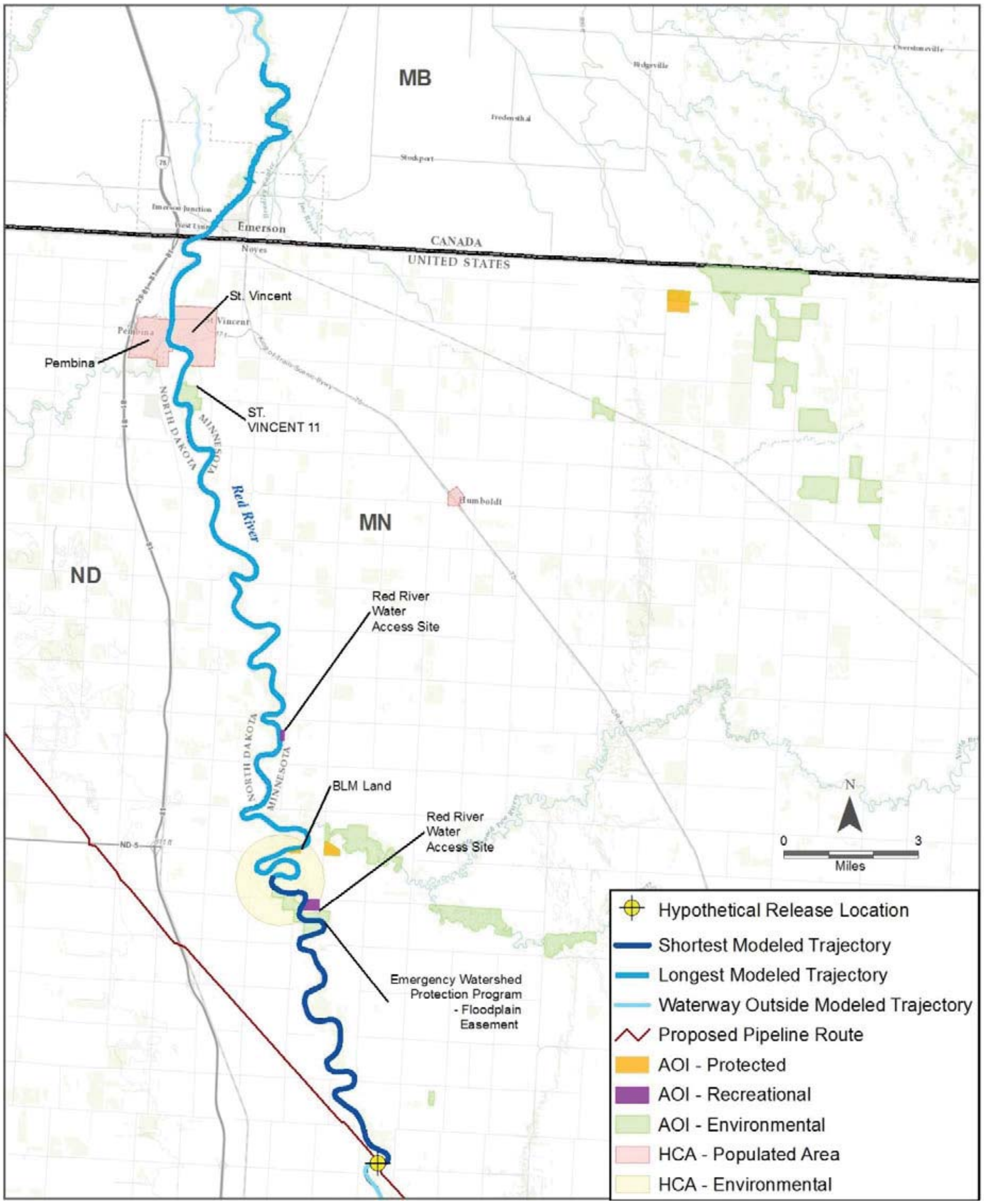


Figure 7-36 High Consequence Areas and Areas of Interest Potentially Affected by a Crude Oil Release at the Red River Crossing Location

7.6.3 Selection of Key Ecological and Human Environment Receptors for Red River

Taking into account environmental characteristics of the Red River, the potential interactions of released crude oil with key ecological and human environment receptors were screened to identify key receptors for the subsequent environmental effects analysis. The rationale and results of this screening step are provided in Table 7-72.

Table 7-72 Key Ecological and Human Environment Receptors for the Red River

Receptor	Relevance for Inclusion as an Environmental Receptor for the Red River Scenario	Selected (Y/N)
Terrestrial Receptors		
Soils	Low. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Red River with no holdup of oil on land. In the event of an actual oil release, oil remaining on or in the soil would be physically remediated to established standards.	N
Groundwater	Low. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Red River with no holdup of oil on land. In the event of an actual oil release, effects on groundwater quality would be localized and/or negligible.	N
Terrestrial Vegetation	Low. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Red River with no holdup of oil on land. Any oil that reaches soil would be physically remediated and vegetative cover would be restored as part of the cleanup process.	N
Aquatic Receptors		
Rivers (Red River)	High. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Red River with subsequent physical transport downriver.	Y
Lakes	Low. It is possible that under severe flood conditions the Red River could interact with Lake Stella (a small lake approximately 0.5 miles away from the nearest bank of the Red River). However, an assumption made in the fate modeling for this scenario is that released oil would remain in the Red River after a release.	N
Sediment	High. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Red River with subsequent physical transport downriver. This allows potential interaction and/or deposition of crude oil residues to sediments.	Y
Shoreline and Riparian Areas	High. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Red River with subsequent physical transport downriver. This allows potential interaction with shoreline and riparian habitat.	Y

Table 7-72 Key Ecological and Human Environment Receptors for the Red River

Receptor	Relevance for Inclusion as an Environmental Receptor for the Red River Scenario	Selected (Y/N)
Wetlands	Low. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Red River with subsequent physical transport downriver. There is negligible to no wetland habitat in the vicinity of the predicted release trajectory.	N
Aquatic Plants	Low. The high suspended sediment load of the Red River limits light penetration and opportunities for the development of a substantial aquatic plant community.	N
Benthic Invertebrates	High. The Red River at supports a diverse benthic invertebrate community.	Y
Fish	High. The Red River supports fish.	Y
Semi-Aquatic Wildlife Receptors		
Amphibians and Reptiles	High. The Red River supports amphibians and reptiles.	Y
Birds	High. The Red River supports a diverse bird community.	Y
Semi-aquatic Mammals	High. The Red River supports semi-aquatic mammals.	Y
Human and Socio-Economic Receptors		
Air Quality	High. The communities of Pembina, ND and St. Vincent, MN are located approximately 30 miles north of the hypothetical release location. Effects on air quality have the potential to temporarily disrupt human use and occupancy patterns.	Y
Human Receptors	High. The communities of Pembina, ND and St. Vincent, MN are located approximately 30 miles north of the hypothetical release location. Effects on air quality or the presence of crude oil residues in aquatic and riparian habitat have the potential to temporarily affect human health.	Y
Public Use of Natural Resources	High. The Red River downstream of the crossing is shared by two public water access sites. In addition, Fort Daer Landing and Recreation Area as well as Pembina State Park are also along the trajectory of the modeled release. Effects on air and water quality, or the presence of crude oil residues in the sediment and riparian habitat, could potentially disrupt public use of natural resources (e.g., drinking water, hunting, fishing, recreation).	Y

7.6.4 Modeled Conditions at the Release Location

A description of key modeling assumptions for the environmental effects analysis for the Red River scenario is provided in this section. The OILMAP Land software was used by RPS ASA to simulate hypothetical releases of Cold Lake Blend and Bakken crude oils into the Red River (Chapter 5.0) for a 24 hour period, or until the released crude oil reached the border between the United States and Canada. A longer time period was not modeled as it was assumed that emergency response measures to prevent farther downstream transport of released oil would be in place within the 24 hour period. While OILMAP Land does provide an indication of the downstream extent of oiling and mass balance of oil within the modeled period, it does not quantify the amounts of oil components dissolved into the water column (Chapter 5.0). No overland transport of released Cold Lake Blend or Bakken crude oil was modelled for this hypothetical release location, as it was assumed that released oil would directly enter the watercourse (Chapter 3.0). This is a worst-case assumption for a release of crude oil near the watercourse.

The two crude oil types provide bounding cases for oils that range from light (e.g., Bakken crude oil having low viscosity and density) to heavy (Cold Lake Blend/Winter Blend, heavy diluted bitumen crude oil types having higher viscosity and density). Seasonal variations in river flow, temperature, wind speed, and snow and ice cover were all considered at the release location. A summary of key variables is provided in Table 7-73.

In the event of an actual release, the downstream extents of CLB and Bakken crude oil may be more similar, and the effects of CLB may extend farther downstream than predicted, with patchy coverage.

Table 7-73 Environmental and Hydrodynamic Conditions for the Three Modeled Periods for the Red River Crossing

Season	Month	Air Temperature (°C)	Wind Speed (m/s)	Average River Velocity (m/s)
Low Flow (Winter)	February	-14.68	5.19	0.31
Average Flow (Summer)	August	19.78	3.98	0.44
High Flow (Spring)	April	4.02	5.05	1.02

NOTE:
A velocity of 1 m/s is equivalent to 2.25 miles per hour.

The highest average flow velocity of the Red River coincides with the spring freshet (i.e., April-June), a result of rising temperatures and snowmelt. Average flow would typically occur during summer and fall seasons. August, the month with the warmest temperature, was selected to represent the maximum amount of evaporation. The lowest flow rate occurs in winter (i.e., February), and was typified by freezing conditions and probable ice cover on water.

The crude oil release volume was calculated as a full bore rupture, with a maximum time to response in the pipeline Control Center of 10 minutes, followed by a 3-minute period to allow for valve closure. The release volume therefore represents the volume of oil actively discharged in the period of time required to detect and respond to the event (taking into consideration the pipeline diameter, pipeline shutdown time, pipeline design flow velocity), followed by the volume of oil lost due to drain-down of the elevated segments of pipeline. The maximum

13-minute response time to valve closure is an Enbridge standard for safe operations and leak detection. This includes the combination of identification of the rupture, analysis of the pipeline condition, pipeline shutdown and full valve closure in the affected pipeline section. While 13 minutes is the maximum time for valve closure, this is a conservative assumption, since a response through to valve closure is expected to occur in less than 13 minutes in a full bore rupture leak scenario. Based on these assumptions, the site-specific hypothetical release volume was estimated to be 13,856 bbl of Bakken, CLSB, or CLWB crude oil.

7.6.5 Summary of Predicted Downstream Transport of Bakken and Cold Lake Crude Oils

A summary of the predicted downstream trajectory and mass balance of CLB and Bakken crude oils, under the three seasonal scenarios, is provided in Figures 7-6-6 and 7-6-7, respectively. These simulations are assumed to provide bounding conditions for a release of heavy or light crude oil types. The fate of most types of crude oil, if released, would lie within the envelope of predictions for the CLB and Bakken crude oil types. The Cold Lake crude oil was assumed to be CLSB for the high flow and average flow scenarios, and to be CLWB for the low flow (winter) scenario. As noted in Chapter 5.0, while OILMAP Land does provide an indication of the downstream extent of oiling and mass balance of oil within the modeled period, it does not quantify the amounts of oil components dissolved into the water column.

The maximum simulation duration using OILMAP Land was 24 hours, as it was assumed that emergency response measures to prevent or reduce further downstream transport of released oil would be in place within that length of time. Symbols on the drawings indicate the river seasonal flow condition (high corresponding to spring freshet, average corresponding to summer-fall conditions, and low corresponding to winter flow under ice). Numbers associated with the symbols indicate the predicted location of the leading edge of the released oil in the river after 6, 12, 18 or 24 hours. Numbers other than these (e.g., 20.3) indicate the time in hours of the predicted termination of downstream transport of the released oil due to adhesion or holdup of the oil along the river banks. Tables inserted within the Figures also provide information on the mass balance (i.e., oil remaining on the surface of the river, adhering to river banks, or evaporated to the atmosphere) of the released oil at relevant points in time after the start of the release.

7.6.5.1 Red River Release During High Flow (Spring) Period

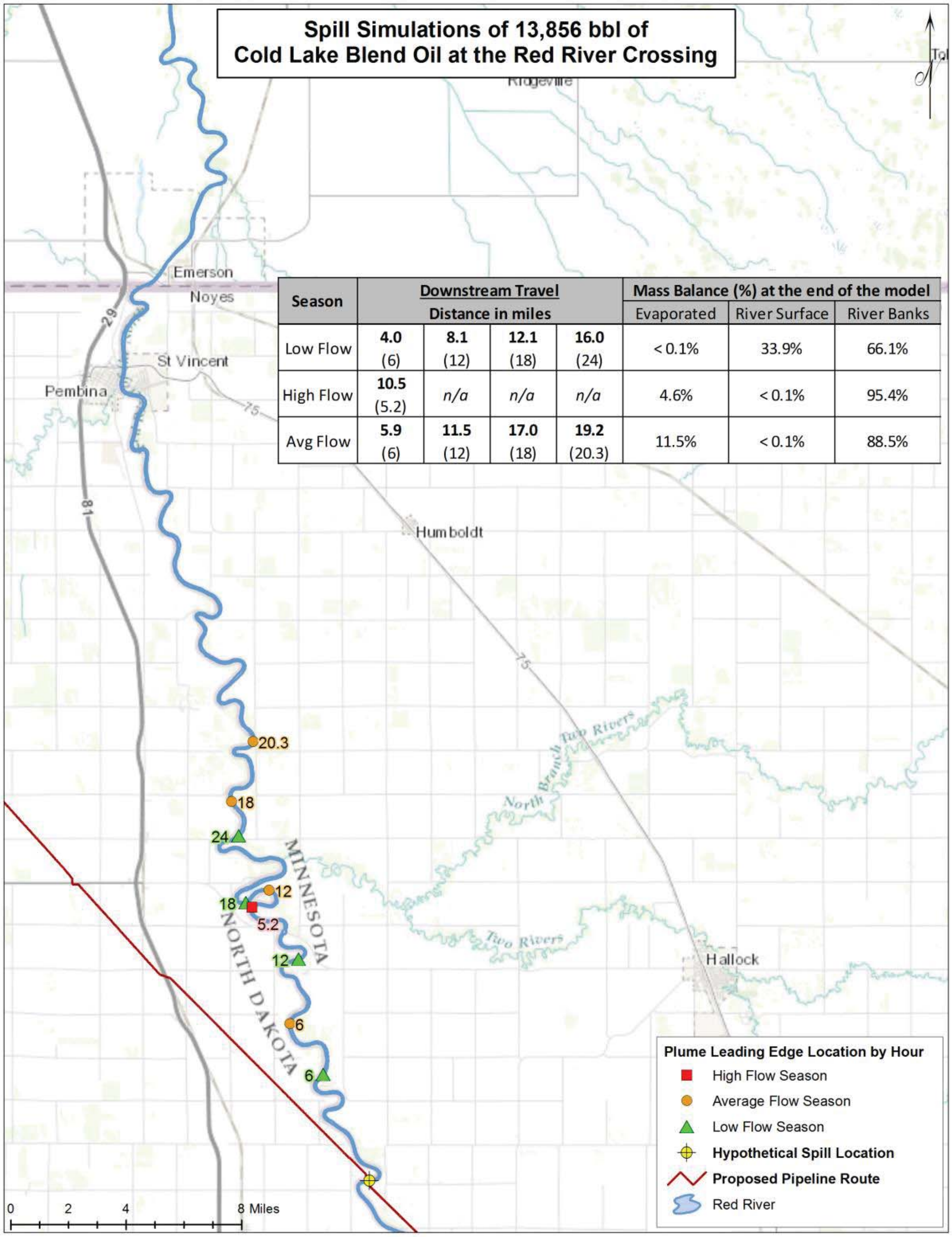
Under the high river flow scenario, CLB was predicted to travel approximately 10.5 miles downstream in the Red River within 5.2 hours of the release (Figure 7-37). Beyond this point in time the model predicted that the oil would have been lost from the water surface, mainly as a result of adhesion to shoreline (95.4%), with the balance evaporating.

Bakken crude oil was predicted to be transported approximately 40.3 miles downstream within 18.5 hours of the release (Figure 7-38). The transport of floating oils was predicted to pass through

Pembina, ND and St. Vincent, MN, and into Canada. At this time, approximately 58.6% of the Bakken crude oil was predicted to adhere to shorelines and approximately 41.4% to have evaporated into the atmosphere. None of the oil was predicted to remain on the water surface after 24 hours of the release.

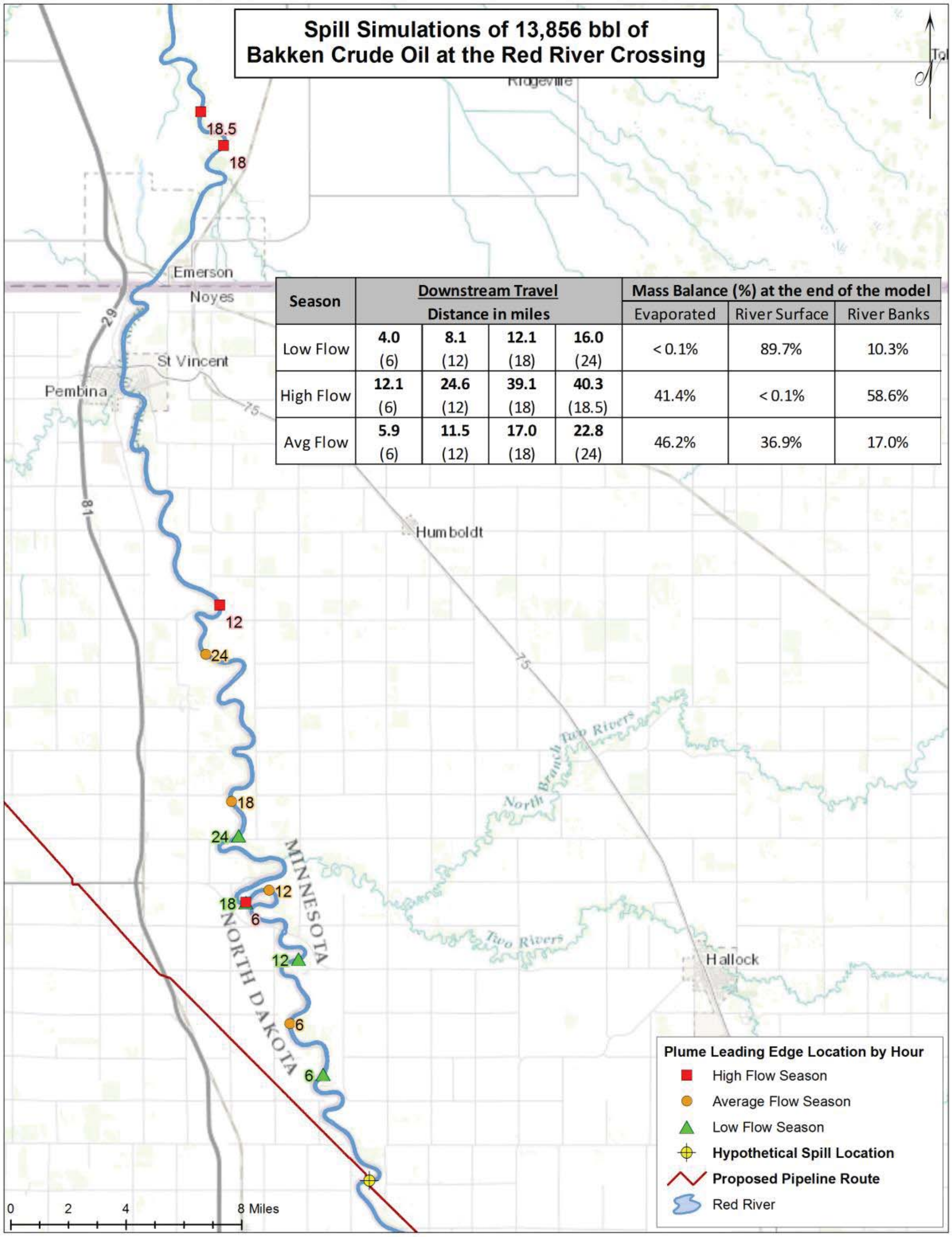
The release of Bakken crude oil under high flow conditions was predicted to result in oiling farther downstream than for the CLB. The difference in the extent of downstream transport was a result of the difference in the shoreline oil retention between the two oil types. Because of its higher viscosity and adhesiveness, larger amounts of CLB are predicted to strand, as a thicker layer of oil on a given length of shoreline, than for the Bakken crude oil. Conversely, the same amount of Bakken crude oil could affect a greater length of shoreline with a lesser thickness of oil, in addition to affecting a greater overall length of the river. This result is based upon the assumption of 100% shoreline oiling coverage (i.e., all shoreline was oiled to its maximum holding capacity as oil made its way downstream). In the event of an actual release, the downstream extents of CLB and Bakken crude may be more similar, and the effects of CLB may extend farther downstream than predicted, with patchy coverage.

A larger proportion of the Bakken crude oil was predicted to evaporate to the atmosphere than was predicted for the CLB. This was due in part to the lighter and more volatile character of the Bakken crude oil. In addition, the greater downstream transport of the Bakken crude oil took more time, and resulted in more water surface area with oil, both of which could allow more of the released oil to evaporate. Volatile components of the CLB would continue to evaporate after becoming stranded on shoreline, but this process was not included within the OILMAP Land model for stranded oil.



Season	Downstream Travel Distance in miles				Mass Balance (%) at the end of the model		
					Evaporated	River Surface	River Banks
Low Flow	**4.0** (6)	**8.1** (12)	**12.1** (18)	**16.0** (24)	< 0.1%	33.9%	66.1%
High Flow	**10.5** (5.2)	*n/a*	*n/a*	*n/a*	4.6%	< 0.1%	95.4%
Avg Flow	**5.9** (6)	**11.5** (12)	**17.0** (18)	**19.2** (20.3)	11.5%	< 0.1%	88.5%

Figure 7-37 Predicted Downstream Transport of Cold Lake Blend Oil at the Red River Crossing Location



Season	Downstream Travel Distance in miles				Mass Balance (%) at the end of the model		
					Evaporated	River Surface	River Banks
Low Flow	**4.0** (6)	**8.1** (12)	**12.1** (18)	**16.0** (24)	< 0.1%	89.7%	10.3%
High Flow	**12.1** (6)	**24.6** (12)	**39.1** (18)	**40.3** (18.5)	41.4%	< 0.1%	58.6%
Avg Flow	**5.9** (6)	**11.5** (12)	**17.0** (18)	**22.8** (24)	46.2%	36.9%	17.0%

Figure 7-38 Predicted Downstream Transport of Bakken Crude Oil at the Red River Crossing Location

7.6.5.2 Red River Release During Average Flow (Summer-Fall) Period

Under average river flow, CLB crude oil was predicted to travel up to 19.2 miles downstream, within 20.3 hours of the release (Figure 7-37). After this time, there would be little CLB on the river's surface as the model predicted that most of the released oil would have stranded along shorelines (88.5%) or evaporated (11.5%). Emergency response measures to prevent further possible downstream transport of oil would be in place within 24 hours of the release.

Under average river flow, Bakken crude oil was predicted to be transported approximately 22.8 miles downstream, over the full 24-hour modeled period (Figure 7-38). Approximately 17.0% of the Bakken crude oil was predicted to oil the shorelines of Red River, with 46.2% predicted to evaporate into the atmosphere, and 36.9% to remain on the river surface at the end of the 24 hour simulation. If left unmitigated, the remaining Bakken crude oil on the river surface after 24 hours could be expected to continue downstream. The oil would continue to weather and would oil shorelines until all of the oil was removed from the water surface.

Under average flow conditions, the CLB was predicted to travel farther downstream than during high river flow condition. This is a result of less interaction between the released oil and shorelines. Under average flow conditions the stream shorelines are assumed to be a mixture of grass and mud. Under high flow conditions, with water spreading into riparian areas, shorelines of the Red River are assumed to be vegetated. As a result, it was assumed in the modeling exercise that under average flow conditions, the shorelines would hold less of the viscous CLB oil type than during high flow conditions. The muddy shoreline present under average flow conditions is assumed to be capable of retaining about 150 bbl of CLB crude oil per mile of shoreline, whereas a grassy shoreline is assumed to be capable of retaining about 1,260 bbl of CLB crude oil per mile.

Slightly more of the released CLB crude oil was predicted to evaporate under the average river flow condition than under the high river flow condition (Figure 7-37). This difference is due largely to the warmer temperatures in the summer-fall season as compared to the spring freshet, as well as the shorter length of time that the oil was free on the water surface (i.e., the simulation for the average flow period terminated after 20.3 hours compared to the shorter duration of 5.2 hours for the high flow period.

When compared to the CLB under average river flow conditions, the Bakken crude oil was predicted to be transported farther downstream before reaching the 24 hour model limit of the simulation. This difference was attributable to the lower shoreline oil retention value for the low viscosity Bakken crude oil, when compared to the more viscous and adhesive CLB. Although not modeled here, it is expected that a medium crude oil would exhibit fate and transport properties intermediate between those of the Bakken and CLB crude oil types, with a tendency to behave more like the Bakken crude oil. This is because the viscosity and adhesiveness properties of a medium crude oil would typically be higher and, therefore, more similar to those of the Bakken crude oil, than to the CLB.

7.6.5.3 Red River Release During Low Flow (Winter) Period

Under low river flow conditions, CLWB was predicted to be transported a total of 16.0 miles downstream over the full 24-hour modeled period (Figure 7-37). Approximately 66.1% of the CLWB was predicted to become trapped under ice along the margins of the Red River, with 33.9% remaining in the river below the ice at the end of the 24 hour simulation. If left unmitigated, the CLWB remaining in the Red River after 24 hours could be expected to continue to move downstream until all of the oil was trapped along the river margins, or had accumulated in fissures and hollows in the river ice. This would provide only temporary storage of the oil, and oil would be expected to re-mobilize in response to changes in flow rates, and particularly during the spring breakup of ice. With the CLWB below the ice of the river, evaporation of oil to the atmosphere would be negligible in the short-term. However, emergency response measures to prevent further possible downstream transport of oil would be in place within 24 hours of the release.

Under low river flow, Bakken crude oil was predicted to be transported approximately a total of 16.0 miles downstream over the full 24-hour modeling period (Figure 7-38). Approximately 10.3% of the Bakken crude oil was predicted to become trapped along the river margins, while the remaining 89.7% was predicted to remain in the river, below the ice, at the end of the 24 hour simulation. If left unmitigated, the remaining Bakken crude oil in the river after 24 hours would be expected to continue to move downstream, with some accumulating along the river margins and some accumulated in fissures and hollows under the river ice.

As with the CLWB, the accumulation of released Bakken crude oil under the ice would be unstable, and oil would be expected to re-mobilize in response to changes in flow rates, and particularly during the spring breakup of ice. Evaporation of the Bakken crude oil to the atmosphere would also be negligible in the short-term. Less of the Bakken crude oil was predicted to accumulate at the river margins under the ice, when compared to the CLWB under low river flow conditions. This was due to the differences in shoreline oil retention between the two oils (i.e., lower viscosity and adhesion of the Bakken crude oil). For this reason, the Bakken crude oil was predicted to have greater mobility under the ice in winter.

7.6.6 Qualitative EHHRA for the Red River

In this section, the likely environmental effects of a crude oil release at the pipeline crossing location on the Red River are described. A worst case crude oil release from a mainline pipeline, such as described here, would be an unlikely event (Chapter 4.0). The proposed pipeline would carry a variety of crude oil types, ranging from very light (e.g., Bakken crude oil) to heavy (e.g., diluted bitumens such as CLB). Therefore, the following discussion describes the likely environmental effects of a crude oil release on relevant ecological and human environment receptors (identified in Section 7-6-3), using the predicted geographic extent of effects of released Bakken or CLB crude oil types over the 24 hour simulations as bounding conditions. Effects of season (including temperature, river flow conditions, and receptor presence/absence and sensitivity) were also considered in the analysis. The rationale supporting the effects analysis, based on case studies describing the effects of crude oil releases on the various ecological and human environment receptors, was provided in Section 7.1 and Table 7-72.

7.6.6.1 Terrestrial Receptors

For this modeling scenario, the hypothetical release of crude oil is assumed to enter the Red River with no overland flow. Environmental effects on soils, terrestrial vegetation and groundwater quality are assumed to be localized, limited in spatial extent, and readily remediated using conventional clean-up techniques. The environmental effects of a crude oil release on land cover receptors will not be considered further for this scenario.

7.6.6.2 Aquatic Receptors

The aquatic environmental and ecological receptors that are considered in the assessment for the Red River are river water and river sediment quality, shoreline and riparian river bank habitat, benthic invertebrates, and fish.

Crude oil released to the Red River during the spring (high flow condition) is predicted to travel downstream, interacting with vegetation and seasonal shoreline areas in the riparian floodplain as it moves north. The distance travelled would depend upon river flow and oil type. Based on OILMAP Land simulations, light oil is predicted to travel father downstream than heavy oil. For heavy oil, stranding on shore would be the primary fate, with only small amounts of evaporative weathering of the oil occurring within the first 24 hour period. For light oil, stranding would remain the primary fate, but considerably more of the released oil could be lost to evaporation.

The effects of oil releases on benthic invertebrates and fish depend on characteristics of the released oil and environmental conditions at the time of the release. Acute toxicity to fish is commonly but not always observed in association with crude oil releases, and is an indicator that, at least briefly, concentrations of dissolved hydrocarbons (particularly mono-aromatic hydrocarbons, some low molecular weight PAHs, and short-chain aliphatic hydrocarbons) are sufficiently high to cause acute toxicity due to narcosis. Light oils have low viscosity relative to heavier oils. Turbulence in the river water could potentially disperse the light oil as small droplets in the water column, increasing the potential for toxic fractions of the light oil to dissolve into the water column. As a result, the potential for acute toxicity to fish and invertebrates would be greater for the light oil than for heavier oils. However, the large volume of water flow associated with the spring period freshet in the Red River may also dilute and limit the maximum dissolved hydrocarbon concentration in water, as compared to periods of lower water flow.

There would also be high potential for chronic effects of released crude oil on fish eggs and embryos (i.e., induction of deformities or mortality collectively termed blue sac disease). Many of the fish species present in the Red River spawn in the spring and early summer. The eggs and embryos of these species could be exposed to total PAH concentrations in the river water that could be sufficiently high to induce deformities or cause mortality. In addition the potential for phototoxicity, caused by an interaction of ultraviolet (UV) light with PAHs accumulated in fish tissues, would be greatest for a crude oil release in summer due to high light intensity and long day length. Small fish that are lightly pigmented or transparent (i.e., embryos, larval and juvenile fish) are most susceptible to phototoxicity. The risk of phototoxicity would be mitigated by high concentrations of suspended sediment present in the water of the Red River, which would reflect, scatter and absorb light, limiting the penetration of UV light into the water column.

Entrainment of small crude oil droplets in the water column also enhances the potential for light crude oils to interact with suspended sediment particles in the water column resulting in the formation of OPAs. Such aggregates may subsequently be preferentially deposited in areas of still or slowly moving water, such as oxbows and backwaters. Formation of true oil-particle aggregates is less likely to occur with heavy crude oils such as diluted bitumen, as the higher viscosity of the oil precludes the ready formation of fine droplets in the water column (Zhou et al. 2015). However, heavy oils can still contact sediment particles along the shoreline, and some accumulation of both light and heavy oils in depositional areas is likely, although the precise mechanisms of deposition may vary. Neither crude oil type is likely to reach a density greater than that of the water and sink directly to the sediment within the first few days following release.

Crude oil released during the summer-fall (average flow) period is predicted to travel downstream, stranding on muddy river banks and losing volatile components of the oil to evaporation as it moves north. Results provided in Section 7.6.5 provide bounding cases for the products likely to be carried in the pipeline. The OILMAP Land simulations indicate that crude oil would be carried between 19.2 and 22.8 miles downstream from the point of release under summer-fall average-flow conditions. For heavy oil, stranding on shore would be the primary fate, with only small amounts of evaporative weathering of the oil occurring. For light oil, evaporation would be the primary fate, with a considerable amount of released oil potentially remaining on the surface of the Red River, and only a modest amount adhering to the river banks. The lower river flow in summer-fall compared to spring could result in higher concentrations of water soluble components in the river; however, along with lower flow rates, there would also be less turbulence in the water column and a reduced tendency for crude oil to be dispersed as fine droplets in the water column. As a result, and taking into consideration the relatively large size of the Red River, narcotic effects on fish and benthic invertebrates are unlikely during the summer season. Also taking into consideration the lower river flow and turbulence, deposition of crude oil residues to sediment in areas of still water is less likely during the summer season than during the spring period.

Crude oil released during the winter (low flow) period could potentially pool on the frozen river surface. If the release was to occur directly to the river below the ice (as is assumed in the OILMAP land model), or if there were openings in the ice that the released oil could penetrate, the oil could travel downstream under the ice, accumulating in the narrow gap between the ice and the river sediment, or accumulating in hollows under the ice as it moved north. Results provided in Section 7.6.5.3 provide bounding cases for the products likely to be carried in the pipeline. The OILMAP Land simulations indicate that crude oil would be carried approximately

16 miles downstream from the point of release under winter low-flow conditions. For both oil types, the winter ice would effectively inhibit evaporation, while providing greater potential for dissolution into the water column during the period of lowest dilution flow. The more viscous heavy oil would be predominantly trapped along the river margins, whereas a large fraction (about 33.9%) of the light crude oil would remain mobile at the interface between the river water and the underside of the ice. Therefore, a spill in winter could cause mortality to fish due to narcosis. This result would be more likely for the light crude oil, which would spread out over a larger area, than for the heavy crude oil, which would tend to remain in thicker localized accumulations. Fish eggs and larvae would generally not be present during the winter, so effects on these life stages due to blue sac disease are not likely, although crude oil residues in water and sediment could, if not adequately remediated, affect fish eggs and larvae in the following spawning season. Phototoxicity is not likely to occur following a release of crude oil in winter due to short day length and lower light intensity in winter, reflection and absorbance of light by snow and ice cover on the river, and absorbance of UV light by DOC in the water beneath the ice.

Both crude oil types could be accumulated in sediment, and both would be subject to re-mobilization with spring breakup of the ice, and increasing water flow rates.

7.6.6.3 Semi-Aquatic Wildlife Receptors

Habitat downstream of the hypothetical release location supports amphibians (e.g., salamander, mudpuppy), reptiles (e.g., turtles, snakes), semi-aquatic birds (e.g., ducks, geese) and semi-aquatic mammals (e.g., muskrat, otter). Details on predicted environmental effects for amphibians and reptiles, birds and mammals are provided below.

7.6.6.3.1 Amphibians and Reptiles

Crude oil released to the Red River during the spring (high flow) and summer-fall (average flow) seasons is predicted to travel downstream, interacting with vegetation and seasonal shoreline areas. The distance travelled would depend on the flow conditions, as well as oil and shoreline type. The OILMAP Land simulations indicate that light oil will travel father downstream than heavy oil. A crude oil release during the summer-fall period would not be likely to have direct effects on riparian habitat and, therefore, effects on reptiles (e.g., snakes) in the riparian zone would be minimal. Downstream transport of released crude oil in summer-fall would not travel as far north as in spring (between 19.2 and 22.8 miles downstream from the point of release) meaning that possible oil-organism interactions would be fewer in this season than in spring.

Within the oil-exposed habitats along the river that support amphibians (adults, juveniles, and eggs), oiling effects including mortality would be observed. Turtles appear to be relatively tolerant of external crude oil exposure, and although these animals are likely to become oiled, mortality of turtles as a result of this exposure is less likely. Reptiles like lizards and snakes are primarily terrestrial species and are less intimately associated with aquatic environments. As a result, exposure of these animals to released crude oils would be limited. After the Kalamazoo River oil spill in 2010 snakes did not appear to be highly exposed to spilled oil. A release of light crude oil during the spring would likely have a greater effect than in summer due to the greater predicted downstream transport distance and interaction with greater areas of riparian and wetland habitats than later in the year.

Amphibians and reptiles undergo a winter dormancy period when temperatures drop below approximately 41 to 45°F. At this time, amphibians and turtles typically bury themselves in river bottom substrates or other similar habitats. Therefore, during the winter (and likely up until April or May when winter ice is gone), these animals would have very little exposure to released oil moving on the water surface or within the water column.

7.6.6.3.2 Birds

Aquatic and semi-aquatic birds are those that use rivers, wetlands, and riparian areas as components of their habitats, particularly for nesting and feeding. These birds belong to a variety of guilds including but not limited to waterfowl, divers, gulls and terns, raptors, shorebirds, waders, and some songbirds. They have a variety of dietary preferences, including piscivory, insectivory, omnivory and herbivory. What they have in common is that if exposed to external oiling, their ability to maintain body temperature may be compromised, leading to death as a result of hypothermia. Even if they survive their initial exposure to crude oil, the exposure may require an increase in metabolic rate to survive. In turn, this may compromise other life functions such as reproduction or growth. Birds that survive external oiling may experience toxicological stresses as a result of ingesting crude oil residues while preening or attempting to clean and restore the normal properties and functions of feathers. Birds can also transfer potentially lethal quantities of crude oil residue from their feathers to the external surface of eggs, resulting in death of developing embryos.

Unlike many other vertebrate receptors, aquatic bird species in the northern temperate zone are nearly all seasonal migrant species which leave their summer (and often breeding) habitat in the fall for wintering areas farther south where they can find open-water habitat. However, some birds (e.g., Canada goose) will opportunistically remain in freezing conditions if there is reliable open water and a source of food available. Timely capture and rehabilitation of oiled birds may help to mitigate the environmental effects of a crude oil release.

During the spring (high flow) season, many migratory birds would be returning to riverine habitats in Minnesota and North Dakota, or migrating through these areas on their way to breeding habitats farther north. With cold water temperatures prevailing, aquatic and semi-aquatic birds contacted by crude oil are likely to die as a result of hypothermia. Only birds in the affected river reach, which could range from 10.5 to 40.3 miles in extent, would be affected; birds upstream, farther downstream, or occupying other nearby habitats would likely be less affected as it is assumed that emergency response measures to prevent or reduce further possible downstream transport of oil would be in place within 24 hours of the release.

Environmental effects of a crude oil release in the summer-fall period are likely to be of similar or lesser magnitude. With rising water temperatures, mortality of lightly oiled adult birds due to hypothermia becomes less likely than in the spring. However, in the early summer, environmental effects could include egg mortality due to transfer of oil from the feathers of lightly oiled adult birds in the nest. Chronic adverse effects on the health of birds that survive their initial exposure to crude oil are also possible as a result of ingesting crude oil residues while preening, or while consuming food items. However, as in the spring, effects are expected to be limited to areas where birds can physically contact oil, which could range from 19.2 and 22.8 miles downstream along the Red River from the release point.

In the winter months, ice cover on the Red River would strongly limit the opportunities for aquatic and semi-aquatic birds to occupy this habitat. Therefore, adverse effects on the health of aquatic and semi-aquatic birds are not likely for a release of crude oil during the winter.

7.6.6.3.3 Semi-aquatic Mammals

While the semi-aquatic mammal species found in Minnesota include terrestrial species such as moose and raccoon, this assessment focuses on species that have a primary association with the aquatic environment such as muskrat and beaver (herbivores), American mink (carnivore-piscivore) and river otter (piscivore). These species are at more likely to come into contact with an oil release in water than terrestrial mammals.

Effects to semi-aquatic mammals are typically described in terms of direct physical effects (e.g., hypothermia due to loss of insulation), direct toxicological effects (e.g., gastro-enteropathy caused by ingestion of crude oil residues while grooming oiled fur or ingesting food), and indirect effects caused by changes to habitat (e.g., land cover and food availability). The spatial extent along the Red River where effects may occur, and the magnitude of effects, is related to the type of oil released, season and flow rate. Effects on semi-aquatic mammals relate more to the amount of time spent in the water (and consequent exposure to physical oiling) than to dietary preferences. Timely capture and rehabilitation of oiled mammals may help to mitigate the environmental effects of a crude oil release.

During the spring (high flow) season, with cold water temperatures prevailing, semi-aquatic mammals contacted by crude oil are likely to die as a result of hypothermia. Based on the OILMAP Land simulations, the potentially affected river reach could range from 10.5 to 40.3 miles in extent. Therefore, although mortality of a considerable number of semi-aquatic mammals could be expected, large-scale (i.e., regional) population level effects are unlikely. Environmental effects of a crude oil release in the summer-fall period are likely to be of similar or lesser magnitude than in spring. With rising water temperatures, mortality of lightly oiled semi-aquatic mammals due to hypothermia is less likely. Chronic adverse effects on the health of semi-aquatic mammals that survive their initial exposure to crude oil are also possible as a result of ingesting crude oil residues while grooming, or while consuming food items. However, as in the spring, effects are expected to be limited to areas of oil exposure.

In the winter months, muskrat and beaver are likely to reduce their activity levels, although American mink and river otter would remain active. Animals that became oiled in the winter would likely die rapidly as a result of hypothermia.

7.6.6.4 Human and Socio-Economic Receptors

Crude oils are complex mixtures of hydrocarbon compounds. Light crude oils typically contain more VOCs as compared to heavier crude oils, although diluted bitumen may contain similar amounts of VOCs to some light crude oils, depending upon the type and amount of diluent. Air quality in the vicinity of a crude oil release, and along the downstream corridor, would be affected by the release of VOCs (such as benzene, which is often used as an indicator substance) primarily within the first 24 hours of an oil release. The communities of Pembina, North Dakota and St. Vincent, Minnesota could potentially be exposed to hydrocarbon vapors under certain circumstances, and were identified through the HCA analysis as being "other" (i.e., smaller) population areas. Under high flow conditions in the Red River, the OILMAP Land modeling indicated that the leading edge of released Bakken crude oil could reach these urban areas in under a day. Setbacks afforded by the riparian floodplain of the river generally assure that residences are approximately 120–140 yards away from the river as it passes through Pembina and St. Vincent, although this distance would be reduced during the spring freshet. Under the winter release scenario, the ice cover is assumed to strongly limit release of volatile hydrocarbons to air.

Typical human health effects associated with short-term (acute) inhalation of volatiles from crude oil include headache, dizziness, nausea, vomiting, cough, respiratory distress, and chest pain. Short-term or repeated skin contact with crude oil may result in dermatitis. The case studies (Section 7.1) do not reveal any instances of human fatality as a result of inhalation of crude oil vapor. Similarly, ATSDR (1995) reports that there are no known instances of human fatality as a result of inhalation of vapor from fuel oils, which would be comparable to light crude oils.

The potential for inhalation exposures to the public would be greatest near and downwind from the release site while the released oil is on the water surface (i.e., 3 miles east of Bowesmont, North Dakota and 9 miles southwest of Hallock, Minnesota, as well as near the Red River). There are three residences within a mile of the proposed Red River crossing location. In the unlikely event of a crude oil release, residents close to or downwind of the release trajectory would become aware of a strong hydrocarbon odor.

Most of the volatile hydrocarbons would be lost within the first 24 hours following a release of crude oil. Actual or potential exposure to crude oil vapor may result in residents leaving, or being advised to leave their homes for a period of time while emergency response takes place.

The HCA analysis did not identify drinking water intakes that could be affected downstream of the Red River crossing. Based on a search of municipal water supplies for Pembina, North Dakota and St. Vincent Minnesota, it appears that neither of these communities consistently obtains drinking water from the Red River. Rather, people in Pembina, North Dakota can purchase drinking water from the Northeast Regional Water District (http://www.northeastregionalwater.com/index.html) and drinking water is supplied to St. Vincent by the North Kittson Rural Water company (http://www.health.state.mn.us/divs/eh/water/com/waterline/featurestories/ruralwater.html). In the unlikely event of a crude oil release, notifications would be sent to people in the area so that drinking water intakes (should there be any) could be suspended if required.

Relatively little has been published regarding the long-term effects of exposure by humans to crude oil releases. Health effects observed in residents and clean-up workers in the months following an oil release generally do not persist over the long term (Eykelbosh 2014). The International Agency for Research on Cancer (IARC 1989) has determined there is "limited evidence of carcinogenicity" of crude oil in experimental animals and "inadequate evidence of carcinogenicity" of crude oil in humans. Although toxicological effects from short-term exposure to volatile hydrocarbons are reversible when exposure is reduced, other health effects such as anxiety and depression may occur, and may persist, regardless of whether the individual was physically exposed to hydrocarbons.

Effects of a crude oil release on human receptors would generally be similar for the spring (high flow) and summer-fall (average flow) seasons. In summer, the warmer temperatures and slower river flow velocities in the summer would promote more rapid evaporation of volatile hydrocarbons in a smaller area. In the spring freshet period, higher river flow velocity would transport the released oil farther downstream within the first 24 hours, potentially resulting in effects to a larger number of people. The flow modeling suggests that the light crude oil (Bakken) is likely to be transported farther downstream within 24 hours than the heavy crude oil (Cold Lake diluted bitumen). As a result, a release of the light crude oil may affect a larger number of individuals than a release of the heavy crude oil type. Both Bakken crude oil and Cold Lake diluted bitumen are expected to contain similar overall amounts of volatile hydrocarbons, so differences related to the type of released oil are likely to be minor.

No overland transport of released crude oil was modelled for this hypothetical release location. Infiltration of crude oil into soil and subsequently into groundwater would be limited.

During the spring freshet period, the Red River is susceptible to flooding and can overtop its banks and spread into the surrounding farmland. A release of light and medium crude oils during this period would provide a potential pathway for oil deposition to soil in low-lying areas. Light and medium crude oils would be expected to become dispersed over a large area, and are readily biodegraded, so that persistent accumulation of these oil types in riparian areas or temporarily flooded farmland is unlikely. Heavy crude oils and diluted bitumen are more likely to be deposited as thicker layers of more persistent oil, and would likely require more active remediation of affected areas. Soils in the area are predominantly lacustrine clays, silts, and sands (MN DNR 2006) and these soils typically have low to medium permeability (compared to sand/gravel soils). Therefore, penetration of crude oil into flooded soils, and effects on groundwater quality (as a potential source of potable water) are unlikely.

The Red River provides recreational opportunities (e.g., fishing, hunting, boating, swimming, camping) at many locations north of the release location. Emergency response workers, in cooperation with public health and safety officials, would be active in isolating, containing and recovering released crude oil, as well as notifying the public about the release. Recreational activities would be disrupted following a release of crude oil along the predicted downstream migration route. Fisheries regulators and public health officials typically close fisheries until it is confirmed through monitoring that fish consumption is not a threat to public health. This standard approach is an effective mitigation strategy to protect human receptors for contact with constituents in the oil.

7.6.6.5 Summary and Conclusions

Expected environmental effects to key ecological and human environment receptors after a hypothetical large crude oil release to the Red River were assessed for both light crude oil (e.g., Bakken crude oil) and heavy crude oil (e.g., diluted bitumens such as CLB). The discussion of expected environmental effects on receptors is based on these crude oil types as bounding conditions.

Potential terrestrial receptors, aquatic receptors, semi-aquatic wildlife receptors and human and socio-economic receptors were screened to identify those with the most likely interactions with released oil. Selected receptors for qualitative assessment are highlighted in Table 7-72, discussed in detail in Sections 7.6.6.1 to 7.6.6.4, and summarized here in Table 7-74.

Table 7-74 Environmental Effects Summary Table for Pipeline Crude Oil Releases

Receptor	Expected Environmental Effects of Released Crude Oil	Relative Effect: Light Crude Oil	Relative Effect: Diluted Bitumen
Terrestrial Receptors			
Soils	It is assumed in the model that oil would enter directly into the Red River with no hold up of oil on land. In the event of an actual oil release, any oil on land would undergo prompt and effective remediation. Residual effects on plant communities, soil or groundwater quality are unlikely.	SAME	SAME
Groundwater		SAME	SAME
Terrestrial Vegetation		SAME	SAME
Aquatic Receptors			
Rivers	Both light and heavy oil would travel downstream from the release location. Lighter crude oils are expected to travel farther downstream than heavier crude oils in spring and summer conditions, but would be thinner on the water and less persistent where they contact shoreline. Both light and heavy crude oils are predicted to travel similar travel distances under winter conditions, although the heavy oil would be likely to remain trapped along the river edges. Light oils have low viscosity relative to heavier oils and turbulence in the river water could potentially disperse the light oil as small droplets in the water column, meaning potentially toxic fractions of the light oils would more readily dissolve into the water column.	MORE	LESS
Sediment	Lighter crude oils are expected to travel farther downstream than heavier crude oils in spring and summer conditions, with both oil types travelling similar distances under winter conditions. Neither the light nor the heavy oil type is likely to reach a density greater than that of the water and sink directly to the sediment within the first few days following release. The low viscosity of the lighter type crude oils could potentially result in a larger amount of oil entrainment as fine droplets as compared to heavier blends, resulting in the formation of oil-particle aggregates, which could both sink, and enhance biodegradation. Such aggregates may subsequently be preferentially deposited in areas of still or slowly moving water. There also exists the potential for low molecular weight aromatic hydrocarbons to dissolve into the water column, as well as greater potential for deposition of hydrocarbons to the sediment. Under winter conditions, more of the heavy crude oil is predicted to become trapped along the river margins, and this oil is also likely to interact with sediment, resulting in mixing of oil and sediment, or formation of oil-particle aggregates. However, the spring freshet is also a major seasonal factor that can flush river sediments leading to a rapid restoration of damaged habitat, and dispersal of oil-particle aggregates in a way that enhances natural recovery.	LESS	MORE

Table 7-74 Environmental Effects Summary Table for Pipeline Crude Oil Releases

Receptor	Expected Environmental Effects of Released Crude Oil	Relative Effect	
		Light Crude Oil	Diluted Bitumen
Shoreline and Riparian Areas	Both light and heavy oil would travel downstream from the release location. Lighter crude oils are expected to travel farther downstream than heavier crude oils in spring and summer conditions, but would be thinner and less persistent on the water. Crude oil released under ice during the winter would not contact shoreline or riparian areas, although crude oil that was not recovered could be dispersed over a large area during the spring freshet. For heavy oil, stranding on shore would be the primary fate. For light oil, stranding would remain the primary fate, but considerably more of the released oil could be lost to evaporation. Flooding of riparian and wetland habitat in spring could lead to stranding of crude oils in this habitat, with heavy crude oil likely to be deposited as patties or tar balls. This is in contrast to light crude oil which would be deposited as a thin layer or sheen.	LESS	MORE
Aquatic Plants	The high suspended sediment load of the Red River limits light penetration and opportunities for the development of a substantial aquatic plant community. Therefore, effects on aquatic plant communities would be minor.	SAME	SAME
Benthic Invertebrates	Environmental effects on benthic invertebrates would be limited to areas affected by the released oil. In the short-term, the low viscosity of light crude oil would result in greater potential for oil entrainment as fine droplets, as compared to heavier blends. This would enhance dissolution of low molecular weight aliphatic and aromatic hydrocarbons into water (with resulting acute toxicity), in addition to promoting oil-particle interaction and potential deposition of oil to sediment. For heavy crude oil, there would be less potential for dissolution of hydrocarbons into the water, but greater long-term potential for deposition of tar balls and patties as a result of oil interaction with sediment. These could accumulate in depositional areas, resulting in chronic effects on benthic invertebrates.	MORE	LESS
Fish	Environmental effects on fish would be limited to areas affected by the released oil. Light oils have low viscosity relative to heavier oils and turbulence in the river water could potentially disperse the light oil as small droplets in the water column. This would enhance the dissolution of potentially toxic fractions of the light oil into the water column. As a result, the potential for acute toxicity to fish due to narcosis would be greater for the light oil than for heavy oil. Potential chronic effects on fish eggs and embryos (e.g., Blue Sac Disease) could also occur, but would be most likely to occur in spring and early summer, when most species spawn. The potential for phototoxicity, caused by an interaction of ultraviolet light with PAHs accumulated in fish tissues, would be greatest in summer due to high light intensity and long day length. However, the high turbidity of the Red River would act to limit light penetration, reducing this risk.	MORE	LESS

Table 7-74 Environmental Effects Summary Table for Pipeline Crude Oil Releases

Receptor	Expected Environmental Effects of Released Crude Oil	Relative Effect	
		Light Crude Oil	Diluted Bitumen
Semi-Aquatic Wildlife Receptors			
Amphibians and Reptiles	Environmental effects on amphibians and reptiles would be limited to areas affected by the released oil. Light crude oil is expected to travel farther downstream under spring and summer conditions than heavy crude oil, but would be thinner and less persistent on the water. Crude oil released under ice during the winter would not contact shoreline or riparian areas, although crude oil that was not recovered could be dispersed over a large area during the spring freshet. Flooding of riparian habitat in spring could lead to stranding of crude oils in this habitat. Within these habitats, oiling effects on adults, juveniles, and eggs could potentially be observed. Higher potential would exist for effects on amphibians than for turtles, which appear to be somewhat tolerant of external oiling. Dormancy of amphibians and reptiles in winter and early spring means exposure to oil released at this time of year could be negligible, and adverse environmental effects unlikely.	MORE	LESS
Birds	Mortality of oiled aquatic and semi-aquatic birds would be limited to areas affected by the released oil. Few birds are present in winter, so effects would be reduced in that season. Released light crude oil is generally transported farther than heavy crude oil, so environmental effects could be more spatially extensive for light crude oil types. Cold water in the spring, in combination with greater downstream movement of released oil, suggests that environmental effects of released oil could be greatest for a light crude oil in spring, and of lesser magnitude for a heavy crude oil release.	MORE	LESS
Semi-aquatic Mammals	Mortality of oiled semi-aquatic mammals would be limited to areas affected by the released oil. Released light crude oil is generally transported farther than heavy crude oil, so environmental effects could be more spatially extensive for light crude oil types. Cold water in the spring, in combination with greater downstream movement of released oil, suggests that environmental effects of released oil could be greatest for a light crude oil in spring, and of lesser magnitude for a heavy crude oil release. Adverse effects on mink and otter would be particularly severe in winter, due to the effects of oil on the insulating properties of fur, in combination with cold water temperatures. However, muskrat and beaver might be spared due to their lower activity levels in winter.	MORE	LESS

Table 7-74 Environmental Effects Summary Table for Pipeline Crude Oil Releases

Receptor	Expected Environmental Effects of Released Crude Oil	Relative Effect	
		Light Crude Oil	Diluted Bitumen
Human and Socio-Economic Receptors			
Air Quality	Effects on air quality have the potential to temporarily disrupt human use and occupancy patterns. Light crude oils typically contain more VOCs than heavier crude oils, although the VOC content of diluted bitumen may be similar to that of light crude oil, depending on the type and quantity of diluent used in its manufacture. Air quality in the vicinity of the oil release would be most affected within the first 24 hours of an oil release. Under winter conditions, ice cover would strongly limit or prevent evaporation of crude oil vapors to the atmosphere.	MORE	LESS
Human Receptors	Typical human health effects associated with short-term (acute) inhalation of VOCs from crude oil include headache, dizziness, nausea, vomiting, cough, respiratory distress, and chest pain; fatality is not expected. Residents in close proximity would become aware of a strong hydrocarbon odor that would alert them to the presence of a hazard. Most volatile hydrocarbons would be lost within 24 hours following a release. Effects on air quality or the presence of crude oil residues in aquatic and riparian habitat have the potential to temporarily affect human health. Under the winter release scenario, ice cover is assumed to strongly limit release of volatile hydrocarbons to air. Other population area HCAs were identified along the path of the release. Recreational activities would be disrupted following a release of crude oil along the predicted downstream migration route.	MORE	LESS
Public Use of Natural Resources	Emergency response workers, in cooperation with public health and safety officials, would be active in isolating, containing and recovering released crude oil, as well as notifying the public about the release. Light crude oil is predicted to be transported farther downstream than heavy crude oil during the first 24 hours following a release, affecting a larger area. However, the heavy crude oil would form thicker and more persistent deposits where it contacted shoreline and riparian areas. This conclusion is independent of the type of crude oil that could be released.	SAME	SAME

7.7 EXPECTED ENVIRONMENTAL EFFECTS OF LARGE RELEASES OF CRUDE OIL TO THE MISSISSIPPI RIVER AT PALISADE

The proposed pipeline could potentially cross underneath the Mississippi River approximately one mile south of Palisade, Minnesota and immediately east of Route 10. This scenario captures a hypothetical release of crude oil directly to the Mississippi River, with downstream transport to the south and west. The Mississippi River near the release point is relatively flat and contains many oxbows, many of which are known areas of interest for recreational uses of the river (MN DNR 2016m). The Mississippi River passes through mixed farmland and state forest as it flows towards Aitkin, Minnesota. The town of Aitkin is protected from potential floods by a diversion channel, which would presumably be carrying some of the flow of the Mississippi River during the spring freshet period, although not necessarily at other times of the year. As identified in Chapter 4.0, the Mississippi River crosses through the Tamarack Lowlands, a low-lying subsection of the Northern Minnesota Drift and Lake Plains Section that is part of the greater Laurentian Mixed Forest Province.

7.7.1 Description of the Freshwater Environment

The Mississippi River near Palisade, Minnesota flows to the south and west along a winding channel through terrain that is largely flat. The river has a well-defined channel, although there are numerous oxbows and side channels that, depending upon river flow, may or may not be hydraulically connected to the main channel. The river channel near the hypothetical release point is about 180 to 200 ft wide. The banks are mainly forested (ranging from a narrow riparian strip of trees, to extensive woodland on some oxbow peninsulas). Land use outside of the immediate floodplain is mainly agricultural on both sides of the river. Low lying areas of the Mississippi River are subject to flooding (MN DNR 2016m); there are only a few residences in close proximity to the river, and these appear to be predominantly associated with farms.

Downstream of the hypothetical release location, and north of Aitkin, Minnesota, is a spillway and flood diversional channel that transmits water from the Mississippi River upstream of Aitkin, to a point on the same river downstream of Aitkin, a distance of approximately 5.8 miles. The entrance to the flow diversional channel appears to be a passive spillway, with a constriction at the entrance so that water would pass through a narrows approximately 50 ft wide. When the river is in flood stage, some of the water would pass through the spillway, where there would be turbulent flow. However, none of the modeled crude oil release trajectories was predicted to reach the entrance of the flow diversion channel within 24 hours of a hypothetical release event. The average velocity of the Mississippi River changes with season, with slowest velocities (e.g., about 0.74 mph) expected during low flow periods in the winter, and only slightly greater velocities (e.g., about 1 mph) during the spring high flow period.

The vegetative communities in the river oxbows include speckled alder, willows, bog birch, ferns, tall asters, sedges, and wildflowers. Some of the oxbows are covered by forest; others appear to be maintained at an earlier successional stage, possibly due to disturbance caused by periodic flooding. The still waters of the oxbows provide pond and marsh habitat suitable for muskrat, as well as providing spawning and rearing habitat for fish such as northern pike (MN DNR 2016n). Muskrat, beaver, otter, turtles, herons, hawks, osprey, and eagles are commonly observed along the river (MN DNR 2016n).

In this stretch of the Mississippi River, northern pike, walleye, bass and muskellunge are abundant (MN DNR 2016n; MN DNR 2010b). The Tamarack Lowlands Subsection provides important wintering areas for boreal birds in times of food shortage and is home to a predicted 69 SGCN. These include birds (51 species), fish (3 species), insects (5 species), mammals (4 species), mollusks (2 species), reptiles (2 species), and spiders (1 species) (MN DNR 2006). Of these species, 16 are afforded federal or state endangered, threatened, or of special concern status (MN DNR 2006; MN DNR 2016d). It is foreseeable that some of these SGCN could utilize aquatic habitats along the Mississippi River.

The Mississippi River crosses through portions of the Waukenabo State Forest, and sections of land owned by the Bureau Land Management (BLM). The most common land uses in the Tamarack Lowlands Subsection are forestry, tourism, and outdoor recreation, agriculture, and peat mining (MN DNR 2006).

Several access points downstream from the proposed pipeline crossing location were visited in May, 2016, to provide additional insight into baseline environmental conditions for Mississippi River and surrounding environments. Representative site photographs are provided in Figure 7-39 through Figure 7-42. Field observations are summarized in Table 7-75.

Figure 7-39 Mississippi River and Riparian Habitat Approximately 5 Miles Downstream of Pipeline Crossing

Figure 7-40 Mississippi River and Riparian Habitat Approximately 5 Miles Downstream of Pipeline Crossing

Figure 7-41 Mississippi River and Riparian Habitat Approximately 30 Miles Downstream of Pipeline Crossing

Figure 7-42 Mississippi River and Riparian Habitat Approximately 61 Miles Downstream of Pipeline Crossing

Table 7-75 Environmental Characteristics Observed at Selected Access Points on the Mississippi River in May 2016

Access Point	Latitude Longitude	Notes
County Road 10 approximately 3.5 miles east of US Hwy 169 and 5 miles downstream of proposed pipeline crossing	46.709591 -93.484909	*Habitat Description:* River banks are approximately 10 ft high and relatively steep in most areas. Vegetation adjacent to river channel is a mix of floodplain forest (silver maple, cottonwood dominant) with floodplain wet/sedge meadow. Sandbar willow is common in some areas adjacent to the stream channel. The invasive, nonnative reed canary grass occurs occasionally here. *Wildlife observed:* American robin, Baltimore oriole
Mississippi River at Aitkin state water access site, just north of Aitkin, approximately 30 miles downstream of proposed pipeline crossing	46.5424 -93.7131	*Habitat Description:* Plant communities in the vicinity of this location include floodplain forest (silver maple-box elder) and terrace forest (bur oak, elm, green ash). Herbaceous vegetation is generally dominated by natives (especially sedges), but the invasive, nonnative reed canary grass occurs occasionally. *Wildlife observed:* blue jay
Mississippi River at Highway 6 state water access site; 5 miles north of Crosby at southwest corner of bridge and approximately 61 miles downstream of pipeline crossing.	46.5435 -93.9564	*Habitat Description:* River bank is relatively steep and approximately 10-15 ft high. Floodplain forest is present in the lowest areas adjacent to the river. However, due to the high banks of the river, much of the adjacent vegetation is terrace forest (mesic to dry-mesic oak forest with aspen) on sandy soils. *Wildlife observed:* crow, blue jay

7.7.2 High Consequence Area Assessment for the Mississippi River near Palisade Crossing Location

As defined in Section 7.0, HCAs include populated areas, drinking water source areas, ecologically sensitive areas, and commercially navigable waterways. Sensitive AOIs include Minnesota drinking water management areas, native plant communities, sensitive lake shores, recreational areas, tribal lands, and protected areas of several types (e.g., national forests, military lands, state parks).

Under low and average flow conditions, floating plumes of CLB and Bakken crude oil are not predicted to pass HCAs. However, under high flow conditions, floating plumes of both oil types are predicted to pass through habitat that has been identified as an environmentally sensitive area (Table 7-76). The Mississippi River downstream of Palisade also flows through several protected areas and environmental AOIs (Table 7-77). As with the HCAs, floating plumes of CLB and Bakken crude oil under low flow conditions are not predicted to pass the AOIs. However, under average and high flow conditions, both oil types are predicted to pass BLM lands and the

Waukenabo State Forest (Table 7-77). The locations of the HCAs and AOIs are shown in Figure 7-43.

Table 7-76 HCAs Potentially Affected by a Release of CLB and Bakken Crude Oil at the Mississippi River near Palisade Crossing Location

HCA Type	HCA Subtype	Description / Locations
Environmentally Sensitive Area	N/A	N/A
NOTE: Data for the HCA analysis were obtained from the USDOT PHMSA HCA datasets plus additional HCAs compiled by Enbridge during 2010 and 2013.		

Table 7-77 AOIs Potentially Affected by a Release of CLB and Bakken Crude Oil at the Mississippi River near Palisade Crossing Location

AOI Type	AOI Subtype	Description / Locations
n/a	N/A	N/A
Protected Area	Bureau of Land Management	BLM Land
	State Forest	Waukenabo State Forest
NOTE: Data for the AOI analysis were derived from multiple datasets provided on the MN Geospatial Commons website, USGS Protected Areas Database of the U.S., and the MN Department of Transportation.		

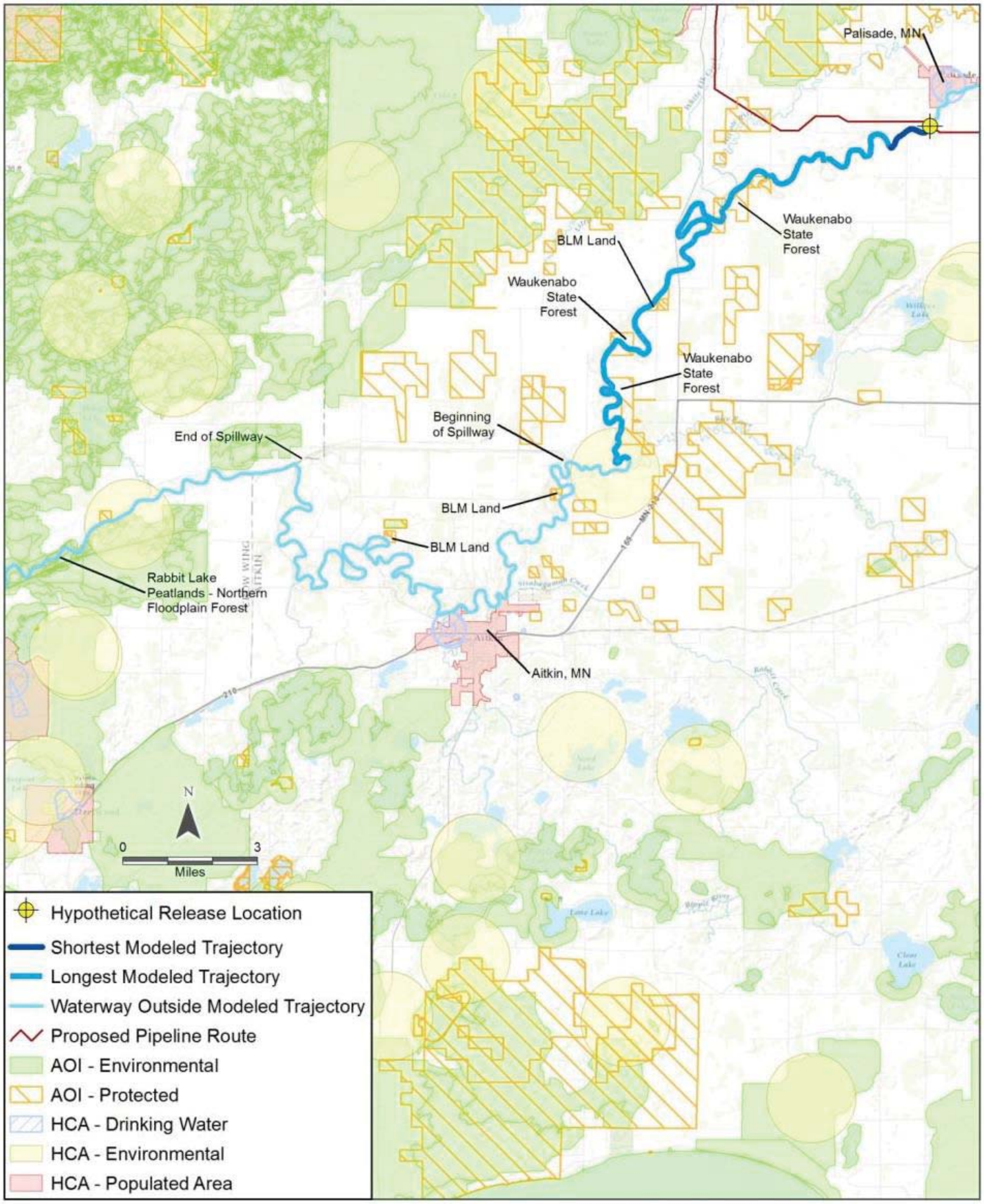


Figure 7-43 HCAs and AOIs Potentially Affected by a Crude Oil Release at the Mississippi River near Palisade Crossing Location

7.7.3 Selection of Key Ecological and Human Environment Receptors for Mississippi River near Palisade Crossing Location

Taking into account environmental characteristics of the Mississippi River near Palisade, the potential interactions of released crude oil with key ecological and human environment receptors were screened to identify key receptors for the subsequent environmental effects analysis. The rationale and results of this screening step are provided in Table 7-78.

Table 7-78 Key Ecological and Human Environment Receptors for the Mississippi River near Palisade

Receptor	Relevance for Inclusion as an Environmental Receptor for the Mississippi River near Palisade Scenario	Selected (Y/N)
Terrestrial Receptors		
Soils	Low. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Mississippi River with no holdup of oil on land. Any oil that reaches soil would be physically remediated to established standards.	N
Groundwater	Low. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Mississippi River with no holdup of oil on land. In the event of an actual oil release, effects on groundwater quality would be localized and/or negligible.	N
Terrestrial Vegetation	Low. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Mississippi River with no holdup of oil on land. Any oil that reaches soil would be physically remediated and vegetative cover would be restored as part of the cleanup process.	N
Aquatic Receptors		
Rivers (Mississippi River)	High. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Mississippi River with subsequent physical transport downriver.	Y
Lakes	Low. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Mississippi River with subsequent physical transport downriver. There is no relevant lacustrine habitat in the vicinity of the predicted release trajectory.	N
Sediment	High. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Mississippi River with subsequent physical transport downriver. This allows potential interaction and/or deposition of crude oil residues to sediments.	Y
Shoreline and Riparian Areas	High. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Mississippi River with subsequent physical transport downriver. This allows potential interaction with shoreline and riparian habitat.	Y
Wetlands	High. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Mississippi River with subsequent physical transport downriver and potential interaction with wetlands along the river and oxbows.	Y

Table 7-78 Key Ecological and Human Environment Receptors for the Mississippi River near Palisade

Receptor	Relevance for Inclusion as an Environmental Receptor for the Mississippi River near Palisade Scenario	Selected (Y/N)
Aquatic Plants	High. Mississippi River supports aquatic plant communities.	Y
Benthic Invertebrates	High. Mississippi River supports benthic invertebrate communities.	Y
Fish	High. Mississippi River supports fish communities.	Y
Semi-Aquatic Wildlife Receptors		
Amphibians and Reptiles	High. Mississippi River supports amphibians and reptiles.	Y
Birds	High. Mississippi River supports waterfowl and other birds.	Y
Semi-aquatic Mammals	High. Mississippi River supports semi-aquatic mammals.	Y
Human and Socio-Economic Receptors		
Air Quality	High. The community of Palisade, Minnesota is approximately one mile north of the hypothetical release location. Some homes are located along the downstream flow path for released crude oil. Effects on air quality have the potential to temporarily disrupt human use and occupancy patterns.	Y
Human Receptors	High. The community of Palisade, Minnesota is approximately one mile north of the hypothetical release location. Some homes are located along the downstream flow path for released crude oil. Effects on air quality or the presence of crude oil residues in aquatic and riparian habitat have the potential to temporarily affect human health.	Y
Public Use of Natural Resources	High. The Mississippi River near Palisade, Minnesota is shared by the Waukenabo State Forest. The drinking water intake for Palisade is upstream of the hypothetical release location so effects on water quality for residences in the area are not expected. Effects on air and water quality, or the presence of crude oil residues in the sediment, riparian or wetland habitat, could potentially disrupt public use of natural resources (e.g., drinking water supplies, hunting, fishing, recreation).	Y

7.7.4 Modeled Conditions at the Release Location

A description of key modeling assumptions for the environmental effects analysis for the Mississippi River near Palisade, Minnesota scenario is provided in this section. The Mississippi River channel downstream from the hypothetical release location is characterized by low gradient and relatively flat water. The flood diversion channel with its dam and spill way has the potential to result in localized turbulence that could entrain crude oil, should it be released and transported downstream that far. Unlike OILMAP Land, the SIMAP fate and transport modeling software can quantify the amount of crude oil that is likely to become entrained into or dissolved in the water column, or deposited to sediments as a result of the turbulent conditions (Chapter 4 and 5). To shed additional light on this potential, SIMAP was used to simulate hypothetical releases of CLB and Bakken crude oils into the Mississippi River downstream of Palisade, Minnesota (and also at Little Falls, Minnesota). Like the OILMAP Land model, SIMAP also provides an indication of the downstream extent of oiling and mass balance of oil within the 24 hour modeled period. A longer time period was not modeled as it was assumed that emergency response measures to prevent or reduce further downstream transport of released oil would be in place within the 24 hour period.

The two crude oil types used in this analysis provide bounding cases for oils that range from light (e.g., Bakken crude oil having low viscosity and density) to heavy (CLB/CLWB, diluted bitumen crude oil types having higher viscosity and density). Seasonal variations in river flow velocity, temperature, wind speed, and snow and ice cover were all considered at the release location. A summary of key variables is provided in Table 7-79.

Table 7-79 Environmental and Hydrodynamic Conditions for the Three Modeled Periods at the Mississippi River at Palisade Crossing

Season	Month	Air Temperature (°C)	Wind Speed (m/s)	Average River Velocity (m/s)
Low Flow (Winter)	March	-3.19	4.78	0.33
Average Flow (Summer)	July	20.19	3.95	0.38
High Flow (Spring)	April	5.03	5.24	0.47
NOTE: A velocity of 1 m/s is equivalent to 2.25 miles per hour.				

The highest average flow rate of the Mississippi River downstream of Palisade coincides with the spring freshet (i.e., April-June), a result of rising temperatures and snowmelt. Average flow would typically occur in summer and fall seasons. July, the month with the warmest temperature, was selected to represent the maximum amount of evaporation. The lowest flow rate occurs in winter (March), and was typified by freezing conditions and probable ice cover on water.

The crude oil release volume was calculated as a full bore rupture, with a maximum time to response in the pipeline Control Center of 10 minutes, followed by a 3-minute period to allow for valve closure. The release volume therefore represents the volume of oil actively discharged in the period of time required to detect and respond to the event (taking into consideration the pipeline diameter, pipeline shutdown time, pipeline design flow velocity), followed by the volume of oil lost due to drain-down of the elevated segments of pipeline. The maximum 13-minute response time to valve closure is an Enbridge standard for safe operations and leak detection. This includes the combination of identification of the rupture, analysis of the pipeline condition, pipeline shutdown, and full valve closure in the affected pipeline section. While 13 minutes is the maximum time for valve closure, this is a conservative assumption, since a response through to valve closure is expected to occur in less than 13 minutes in a full bore rupture leak scenario. Based on these assumptions, the site-specific hypothetical release volume was estimated to be 11,840 bbl of Bakken, CLB, or CLWB.

7.7.5 Summary of Predicted Downstream Transport of Bakken and Cold Lake Crude Oils

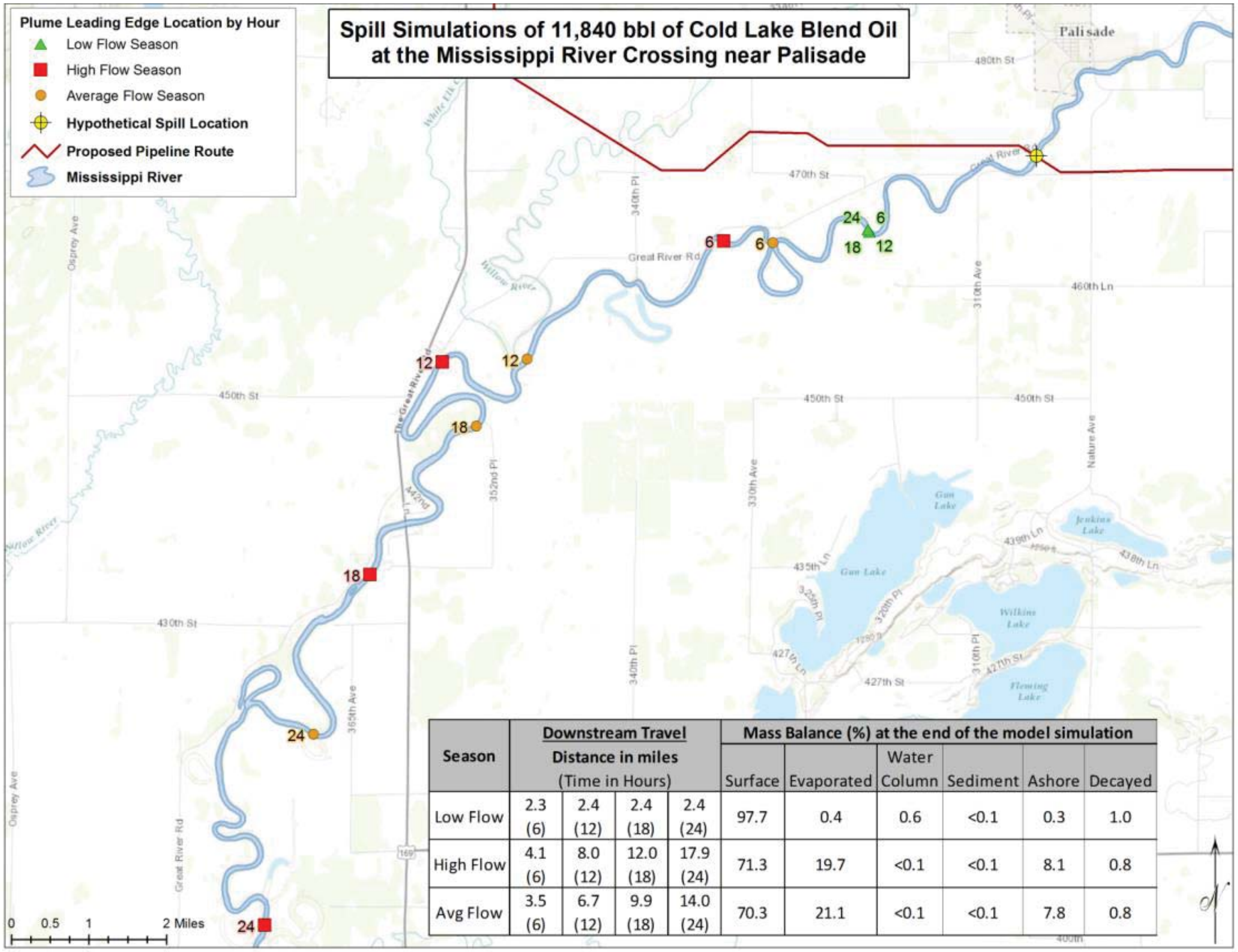
A summary of the predicted downstream trajectories and mass balance for Cold Lake and Bakken crude oils, under the three seasonal scenarios, is provided in Figure 7-37 and Figure 7-38. These simulations are assumed to provide bounding conditions for a release of heavy or light crude oil types, respectively. The fate of most types of crude oil, if released, would lie within the envelope of predictions for the Cold Lake and Bakken crude oil types. The Cold Lake crude oil was assumed to be CLB for the high flow and average flow scenarios, and to be CLWB for the low flow (winter) scenario. The maximum simulation duration using SIMAP was 24 hours, as it was assumed that emergency response measures to prevent or reduce further downstream transport of released oil would be in place within that length of time.

Symbols on the drawings indicate the river seasonal flow condition (high corresponding to spring freshet, average corresponding to summer-fall conditions, and low corresponding to winter flow under ice). Numbers associated with the symbols indicate the predicted location of the leading edge of the released oil in the river after 6, 12, 18 or 24 hours. Tables inserted within the Figures also provide information on the mass balance (i.e., oil remaining on the surface of the river, evaporated to the atmosphere, dissolved in the water column, deposited to sediment, adhering to river banks, or decaying through photo-oxidation and biodegradation) of the released oil at relevant points in time after the start of the release.

7.7.1.1 Mississippi River at Palisade Release During High Flow (Spring) Period

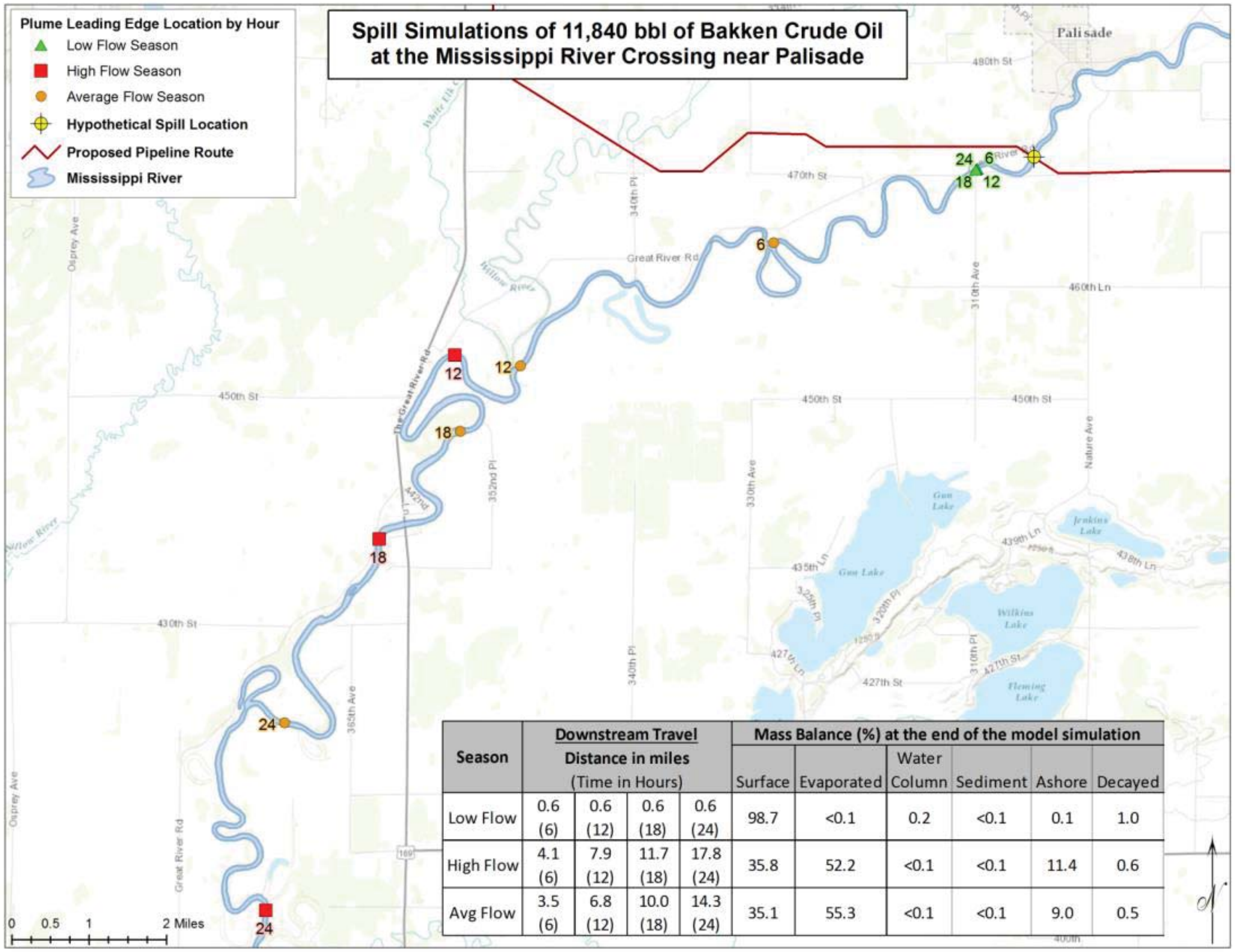
Under the high flow scenario CLB was predicted to travel downstream in the Mississippi River approximately 4, 8, and 18 miles after 6, 12, and 24 hours, respectively (Figure 7-44). By 24 hours after the hypothetical release, almost all of the released crude oil (71.3%) was predicted to remain on the surface of the Mississippi River, with 19.7% evaporating and 8.1% adhering to shorelines. Less than 1% was predicted to break down through photo-oxidation and biodegradation. Negligible amounts (less than 0.1%) of the heavy oil were predicted to mix in the water column, or deposit to sediment (Figure 7-44).

Bakken crude oil was predicted to follow a similar downstream transport pattern as CLB (Figure 7-45). By 24 hours after the hypothetical release, most (52.2%) of the Bakken crude oil was predicted to have evaporated, with 35.8% remaining on the river surface, approximately 11.4% adhering to shorelines, and less than 1% broken down through photo-oxidation and biodegradation. Negligible amounts (less than 0.1%) of the Bakken crude oil were predicted to mix within the water column or deposit to sediment (Figure 7-45).



Season	Downstream Travel Distance in miles (Time in Hours)				Mass Balance (%) at the end of the model simulation					
					Surface	Evaporated	Water Column	Sediment	Ashore	Decayed
Low Flow	2.3 (6)	2.4 (12)	2.4 (18)	2.4 (24)	97.7	0.4	0.6	<0.1	0.3	1.0
High Flow	4.1 (6)	8.0 (12)	12.0 (18)	17.9 (24)	71.3	19.7	<0.1	<0.1	8.1	0.8
Avg Flow	3.5 (6)	6.7 (12)	9.9 (18)	14.0 (24)	70.3	21.1	<0.1	<0.1	7.8	0.8

Figure 7-44 Predicted Downstream Transport of CLB Oil at the Mississippi River near Palisade, MN



Season	Downstream Travel Distance in miles (Time in Hours)				Mass Balance (%) at the end of the model simulation					
					Surface	Evaporated	Water Column	Sediment	Ashore	Decayed
Low Flow	0.6 (6)	0.6 (12)	0.6 (18)	0.6 (24)	98.7	<0.1	0.2	<0.1	0.1	1.0
High Flow	4.1 (6)	7.9 (12)	11.7 (18)	17.8 (24)	35.8	52.2	<0.1	<0.1	11.4	0.6
Avg Flow	3.5 (6)	6.8 (12)	10.0 (18)	14.3 (24)	35.1	55.3	<0.1	<0.1	9.0	0.5

Figure 7-45 Predicted Downstream Transport of Bakken Crude Oil at the Mississippi River near Palisade, MN

This pattern of mass balance for both oil types is the result of the oil properties and relatively calm waters (i.e., not a lot of surface breaking disturbances) of the Mississippi River during high and average river flow conditions. Both oil types were predicted to float on the water surface. Owing to the calm water conditions, negligible amounts of either crude oil type were predicted to entrain into the water column. These hypothetical releases were typified by large amounts of floating oil, which are predicted to form thick surface oil slicks downstream from the release. At the end of the 24-hour simulation, floating CLB and Bakken crude oil were predicted to have a thickness greater than 0.04 inches on the water surface, with none of the slick predicted to be less than 0.0004 inches. As a result of the extensive surface oil slicks, oil floating on the river was predicted to evaporate rapidly over the 24-hour simulation. If left unmitigated, both oil types remaining on the river surface after 24 hours could continue to move downstream, with weathering and oiling of shorelines continuing until all of the oil was removed from the water surface.

The potential for entrainment of CLB and Bakken crude oil into the water column was predicted to be low due to the low wind speeds which did not cause surface breaking waves, and the low water velocities, lack of rapids, riffles, and waterfalls in this area of the Mississippi river. Natural weathering resulted in increased viscosity of the CLB, which would further reduce the likelihood of potential entrainment into the water column. Because of this, THCs in the water column were predicted to be extremely low due to the oil remaining on the surface and not entraining within the water column.

Based on SIMAP simulations, most of the dissolved aromatic concentrations associated with the CLB and Bakken crude oil were predicted to be between 1 and 100 ppb. However, brief pulses of concentrations between 2,000 and 5,000 ppb, or greater than 5,000 ppb, were predicted to occur within 24 hours after the release in extremely limited spatial and temporal extents within the Mississippi River for CLB and Bakken crude oil, respectively.

Of the oil that made its way into the water column, a portion could interact with (i.e., become adsorbed to) suspended sediments. For CLB, THCs on the bed sediments were predicted to be generally less than 0.01 g/m^2, with small areas where deposition could be as high as 1 g/m^2. For Bakken crude oil, total hydrocarbon concentrations on the bed sediment were generally predicted to be less than 0.01 g/m^2, with small areas as high as 0.5 g/m^2 (Chapter 6.0).

For the hypothetical CLB release, retention of crude oil along shorelines resulted in predicted values that were generally greater than 500 g/m^2. In contrast, for the Bakken crude oil, shoreline retention values generally ranged from 100 to 500 g/m^2. This difference is due to the greater viscosity and adhesiveness of the CLB crude oil, which results in thicker oiling of shorelines as compared to the Bakken crude oil. Extensive shoreline oiling but limited sediment oiling was predicted for approximately 18 miles of the river, below the release location, under high river flow conditions. The highest sediment concentrations were predicted for the high river flow scenario due to the higher concentration of TSS in the water column. Less oil was expected to reach sediments in the Bakken releases, when compared to the CLB. In the longer term, if not recovered by emergency response personnel, crude oil that was initially deposited along shorelines could subsequently be deposited to bed sediments, in combination with silt and sand originating from the shoreline contact.

7.7.5.1 Mississippi River at Palisade Release During Average Flow (Summer–Fall) Period

Under the average flow scenario, CLB was predicted to travel downstream in the Mississippi River approximately 4, 7, and 14 miles after 6, 12, and 24 hours, respectively (Figure 7-44). By 24 hours after the hypothetical release, most of the released crude oil (70.3%) was predicted to remain on the surface of the Mississippi River, with 21.1% evaporating, 7.8% adhering to shorelines, and less 1% broken down through photo-oxidation and biodegradation (Figure 7-44). Negligible amounts (less than 0.1%) of the heavy oil were predicted to mix in the water column or deposit to sediment (Figure 7-44).

Bakken crude oil was predicted to follow a similar downstream transport pattern to CLB (Figure 7-45). Most of the Bakken crude oil (55.3%) was predicted to evaporate, with 35.1% remaining on the river's surface, 9% adhering to shorelines, and less than 1% broken down through photo-oxidation and biodegradation. Negligible amounts (less than 0.1%) of the lighter crude oil were predicted to mix within the water column or deposit to sediment (Figure 7-45).

This pattern of mass balance for both oil types is the result of the oil properties and relatively calm waters (i.e., not a lot of surface breaking disturbances) of the Mississippi River during high and average river flow conditions. Both oil types were predicted to float on the water surface. Owing to the calm water conditions, negligible amounts of either crude oil type were predicted to entrain into the water column. These hypothetical releases were typified by large amounts of floating oil, which formed thick surface oil slicks. At the end of the 24-hour simulation, floating CLB and Bakken crude oil were predicted to have a thickness greater than 0.04 inches on the water surface, with none of the slick predicted to be less than 0.0004 inches. As a result of the extensive surface oil slicks, oil floating on the river was predicted to evaporate rapidly over the 24-hour simulation. If left unmitigated, both oil types remaining on the river surface after 24 hours could continue to move downstream, with weathering and oiling of shorelines continuing until all of the oil was removed from the water surface.

The potential for entrainment of CLB and Bakken crude oil into the water column was predicted to be low due to the low wind speeds which did not cause surface breaking waves, and the low water velocities, lack of rapids, riffles, and waterfalls in this area of the Mississippi river. Natural weathering resulted in increased viscosity of the CLB, which would further reduce the likelihood of potential entrainment into the water column. Because of this, total hydrocarbon concentrations in the water column were predicted to be extremely low due to the oil remaining on the surface and not entraining within the water column.

Based on SIMAP simulations, most of the dissolved aromatic concentrations associated with the CLB and Bakken crude oil were predicted to be between 1 and 100 ppb. However, brief pulses of concentrations between 2,000 and 5,000 ppb, or 1,000 and 5,000 ppb, were predicted to occur within 24 hours after the release in extremely limited spatial and temporal extents within the Mississippi River for CLB and Bakken crude oil, respectively.

Of the oil that made its way into the water column, a portion could interact with suspended sediment. For CLB, total hydrocarbon concentrations on the bed sediment were generally less than 0.01 g/m^2, with small areas as high as 1 g/m^2. For Bakken crude oil, THCs on bed sediment were predicted to be generally less than 0.01 g/m^2, with small areas as high as 0.5 g/m^2.

For the hypothetical CLB release, retention of crude oil along shorelines resulted in predicted values that were generally greater than 500 g/m^2. However, overall the concentrations were predicted to be lower than under high flow conditions. In contrast, for the Bakken crude oil, shoreline retention values generally ranged from 100 to 500 g/m^2. This difference is due to the greater viscosity and adhesiveness of the CLB crude oil, which results in thicker oiling of shorelines as compared to the Bakken crude oil. Extensive shoreline oiling but limited sediment oiling was predicted for approximately 14.5 miles of the river, below the release location, under average river flow conditions. In the longer term, if not recovered by emergency response personnel, crude oil that was initially deposited along shorelines could subsequently be deposited to bed sediments, in combination with silt and sand originating from the shoreline contact.

7.7.1.2 Mississippi River at Palisade Release During Low Flow (Winter) Period

Under the low flow scenario CLWB was predicted to travel downstream in the Mississippi River approximately 2.5 miles within the 24 hour model simulation (Figure 7-44). By 24 hours after the hypothetical release, almost all of the released crude oil (97.7%) was predicted to remain on the surface of the Mississippi River (under ice), with approximately 1% broken down through biodegradation, and less than 1% evaporating, mixing in the water column, or adhering to shorelines (Figure 7-44). Negligible amounts (less than 0.1%) of the heavy oil were predicted to evaporate or deposit to sediment (Figure 7-44).

Under the low flow scenario Bakken crude oil was predicted to travel 0.5 miles downstream in the Mississippi River within the 24 hour model simulation (Figure 7-45). This distance is approximately one-fifth that of the CLWB and is the result of the difference in oil density: Bakken crude oil is less dense than CLWB and would be expected to rise through the water column more rapidly after a release than the CLWB. As a result, lighter oils would spend less time in the water column than heavier oils, travel a lesser distance downstream, and rise to the surface and adhere to the underside of the ice more quickly. By 24 hours after the hypothetical release, almost all of the released crude oil (98.7%) was predicted to remain on the surface of the Mississippi River (under ice), with approximately 1% broken down through biodegradation (Figure 7-45), 0.2% dispersed in the water column, and 0.1% adhering to shoreline. Negligible amounts (less than 0.1%) of the light oil were predicted to evaporate or deposit to sediment (Figure 7-45).

Where CLWB was predicted to adhere to the shoreline, concentrations were generally greater than 500 g/m^2, with some areas less than 1 g/m^2. The soluble portion of the CLWB was predicted to dissolve completely into the water column and be transported downstream. This was a conservative prediction reflecting the fact that ice cover would strongly limit or prevent the evaporation of volatile hydrocarbons, but also maximizing the potential release of soluble hydrocarbons to the water column.

Based on SIMAP simulations, most of the dissolved aromatic concentrations associated with the CLWB were predicted to be between 1 and 500 ppb. However, brief pulses of concentrations greater than 5,000 ppb were predicted to occur within 24 hours after the release in extremely limited spatial and temporal extents (generally within 1 mile of the release). At the end of the 24-hour simulation, floating oil greater than 0.04 inches thick was predicted to remain on the water surface (beneath the ice), with none of the slick predicted to be less than 0.0004 inches thick.

The soluble portion of the Bakken crude oil was also assumed to dissolve completely into the water column, and was predicted to be transported downstream resulting in elevated dissolved aromatic hydrocarbon concentrations in the water column in some areas. Maximum soluble hydrocarbon concentrations greater than 5,000 ppb were predicted to occur within 24 hours after the release in extremely limited spatial and temporal extents (the first 0.75 miles downstream of the hypothetical release). At the end of the 24-hour simulation, floating oil greater than 0.04 inches thick was predicted to remain on the water surface (beneath the ice), with none of the slick predicted to be less than 0.0004 inches thick.

Where sediment oiling was predicted occur, total hydrocarbon deposition to the bed sediment was generally predicted to be less than 0.01 g/m^2. Patchy oiling of Bakken crude oil was also predicted along shoreline of the Mississippi River near the release site, but most of the oil was predicted to remain trapped under the ice. Slightly lower amounts of Bakken crude oil were predicted along shorelines as compared to CLWB.

7.7.6 Qualitative EHHRA for the Mississippi River near Palisade

In this section the likely environmental effects of a crude oil release at the pipeline crossing location on the Mississippi River are described. A worst case crude oil release from a main-line pipeline, such as described here, would be an unlikely event (Chapter 4.0). The proposed pipeline could carry a variety of crude oil types, ranging from very light (e.g., Bakken crude oil) to heavy (e.g., diluted bitumen such as CLB). Therefore, the following discussion is based on the likely environmental effects of a crude oil release on relevant ecological and human environment receptors (identified in Section 7.7.3), using the predicted geographic extent of effects of released Bakken or CLB crude oil types over the 24 hour simulations as bounding conditions. Effects of season (including temperature, river flow conditions, and receptor presence/absence and sensitivity) were also considered in the analysis. The rationale supporting the effects analysis, based on case studies describing the effects of crude oil releases on the various ecological and human environment receptors, was provided in Section 7.1 and Table 7-78.

7.7.6.1 Terrestrial Receptors

For this modeling scenario, the hypothetical release of crude oil is assumed to enter the Mississippi River with no overland flow. Environmental effects on soils, terrestrial vegetation, and groundwater quality are assumed to be localized, limited in spatial extent, and readily remediated using conventional clean-up techniques. The environmental effects of a crude oil release on land cover receptors are not considered further for this release scenario.

7.7.6.2 Aquatic Receptors

The aquatic environmental and ecological receptors that are most closely associated with the Mississippi River at Palisade scenario are addressed in this section. These receptors include water and sediment quality in rivers, shoreline and riparian habitat, wetlands, aquatic plants, benthic invertebrates, and fish.

Crude oil released into the Mississippi River during the spring (high flow) or summer-fall (average flow) seasons is predicted to travel downstream, interacting with vegetation and seasonal shoreline areas. Based on SIMAP simulations, CLB crude oil and Bakken crude oil were predicted to follow the same downstream transport pattern (each predicted to reach approximately 18 miles downstream 24 hours after a release) and form slicks of similar thickness (generally between 0.0004 and 0.04 inches). However, a greater amount of CLB is predicted to remain on the surface of the Mississippi River after 24 hours as compared to Bakken crude oil (i.e., approximately 70% vs. 36%), while a greater amount of Bakken crude oil is predicted to evaporate as compared to CLB (i.e., approximately 55% vs. 20%). During spring (high flow) and summer-fall (average flow) seasons, both oil types are predicted to have similar amounts adhering to shorelines (i.e., between 8 and 11%), and negligible amounts of either oil type are predicted to mix into the water column or deposit to sediment (i.e., less than 0.1%).

The effects of a crude oil release on benthic invertebrates and fish would depend on the characteristics of the released oil, and environmental conditions at the time of the release. Acute toxicity to fish is commonly but not always observed in association with crude oil releases, and is an indicator that, at least briefly, concentrations of dissolved hydrocarbons (particularly mono-aromatic hydrocarbons, some low molecular weight PAHs, and short-chain aliphatic hydrocarbons) are sufficiently high to cause acute toxicity due to narcosis. The potential for entrainment of CLB and Bakken crude oil into the water column during high and average river flow conditions was predicted to be low due to the low wind speeds, which did not cause surface breaking waves, and the lack of rapids, riffles, and waterfalls in this area of the Mississippi River. Natural weathering resulted in increased viscosity of the CLB, which further reduced the likelihood of potential entrainment into the water column. Because of this, total hydrocarbon concentrations (i.e., whole oil in the water column) were extremely low due to the oil remaining on the surface and not entrained within the water column. Based on SIMAP simulations, most of the dissolved aromatic concentrations associated with the CLB and Bakken crude oil were predicted to be between 1 and 100 ppb. However, brief pulses of concentrations between

1,000 and greater than 5,000 ppb were predicted to occur within 24 hours after the release in extremely limited spatial and temporal extents within the Mississippi River. These areas of high concentration would be expected to move down the river with the flowing water, so that a transient pulse of relatively high exposure to dissolved aromatic hydrocarbon concentrations would be followed by exposure to much lower concentrations.

French McCay (2002) proposed a benchmark lethal concentration (LC50) value of 224 ppb (µg/L) for sensitive aquatic species exposed indefinitely to total aromatic hydrocarbons from crude oil. For species of average sensitivity, a threshold of 1,869 ppb was reported. Given exposure of shorter duration (i.e., less than one day), a considerably higher concentration (perhaps two to three times higher) would be required in order to result in the death of even sensitive species. Therefore, the predicted transient exposure concentrations for dissolved aromatic hydrocarbon compounds in the river water could result in acute lethality to fish that are sensitive or have average sensitivity to hydrocarbons. With these modeled concentrations, lethality could also be expected in isolated areas of the Mississippi within the release trajectory where high concentrations of dissolved aromatic hydrocarbon persist over a period of several days or longer. However, the majority of predicted dissolved aromatic concentrations were much less than 500 ppb.

Of the oil that made its way into the water column, a portion could interact with suspended particulate matter. Where oil is predicted to deposit to sediment, the highest sediment concentrations were predicted for the high river flow scenario due to the higher concentration of TSS in the water column. Slightly less oil was expected to reach sediments in the Bakken releases, when compared to the CLB. The highest sediment concentrations were predicted for the high river flow scenario due to the higher concentration of TSS in the water column. For CLB, total hydrocarbon concentrations in sediment were generally less than 0.01 g/m^2, with small segments as high as 1 g/m^2. For Bakken crude oil, THCs on the sediment were generally less than 0.01 g/m^2, with small segments as high as 0.5 g/m^2.

With limited mixing of crude oil into surface river bed sediments to a depth of less than 0.25 inch, crude oil deposition of less than 0.1 g/m^2 is likely to be undetectable, and without any ecological consequence. Crude oil deposition to sediment of less than 1 g/m^2 would result in sediment hydrocarbon concentrations that would be less than 100 ppm (mg/kg). These low concentrations would also be unlikely to result in significant environmental effects on fish, benthic invertebrates, or other aquatic life. As a result, based on the SIMAP model results, the potential for acute toxicity to fish and benthic invertebrates is expected to be low, and similar for both the Bakken and CLB crude oil types.

The potential for chronic effects of released crude during high and average river flow oil on fish eggs and embryos (i.e., induction of deformities or mortality collectively termed blue sac disease) is expected to be generally low. While the eggs and embryos of these species could be exposed to total PAH concentrations in the river water that could be sufficiently high to induce deformities or cause mortality, these areas of limited and transitory. The potential for blue sac disease would be greatest for a crude oil release in winter or during the spring freshet, as such crude oil could be dispersed into side-channel and oxbow habitat that is important for spawning fish such as northern pike. While local accumulations could result in adverse effects on developing fish eggs and embryos in the first season following an accidental crude oil release, it is not likely that such effects would persist beyond one year, and effects would occur in only a limited area of the river. Therefore, at the scale of the Mississippi River in Minnesota, it is not likely that such effects would be detectable at a population level.

The potential for phototoxicity caused by an interaction of UV light with PAHs accumulated in fish tissues would be greatest for a crude oil release in summer due to high light intensity and long day length. Small fish that are lightly pigmented or transparent (i.e., embryos, larval and juvenile fish) are most susceptible to phototoxicity. The risk of phototoxicity would be mitigated by high concentrations of suspended sediment and DOC present in the water of the Mississippi River, which would absorb and limit the penetration of UV light into the water column.

The Mississippi River supports emergent, floating and submerged aquatic plants. Where they occur, floating aquatic plants would be expected to be killed if contacted by an oil slick. Submerged aquatic plants would be less vulnerable, as they would be exposed primarily to dissolved hydrocarbons (which is limited in high and average flow conditions), and are not considered likely to be among the most sensitive groups of aquatic biota to such exposure. For a hypothetical release under spring freshet conditions, it is likely that most aquatic plants would still be dormant or submerged, and that environmental effects on this receptor type would be minimal. However, flooded riparian areas and wetland habitats in oxbows would also be exposed to the released oil, and if not properly remediated, crude oil residues could kill plants in these areas. This could affect the biological integrity and productivity of the habitat, and potentially lead to erosion and further damage to the habitat. A release of crude oil in winter would have little direct effect on aquatic plants, as they would be in a dormant state.

During low flow winter conditions, if the release was to occur directly to the river below the ice (as is assumed in the SIMAP model), or if there were openings in the ice that the released oil could penetrate, the oil could travel downstream under the ice, accumulating in the narrow gap between the ice and the river sediment, or accumulating in hollows under the ice as it moved. Results provided in Section 7.7.5.3 provide bounding cases for the products likely to be carried in the pipeline. The SIMAP simulations indicate that heavy crude oil could be carried 5 times farther downstream than light oil (i.e., 2.5 miles vs 0.5 miles from the point of release) under winter low-flow conditions, although this is due to the assumption that the heavy crude oil would only rise slowly through the water column. In reality, with the assumed failure mechanism of a full bore pipeline rupture, it is likely that both types of crude oil would well up from the river bed with a certain amount of momentum, along with entrained river bed muds. Both types of crude oil would probably behave more similarly, near the point of release, than the SIMAP simulation suggests. At the end of the 24-hour simulation, floating oil of both types is predicted to have a thickness between 0.0004 and 0.04 in. at the water surface (beneath the ice). For both oil types, the winter ice would effectively inhibit evaporation. The soluble portion of the CLWB was predicted to dissolve completely into the water column and be transported downstream. Maximum dissolved aromatic hydrocarbon concentrations greater than 500 ppb were predicted in limited regions within the release extent. However, brief pulses of concentrations greater than 5,000 ppb were predicted to occur 24 hours after the release in extremely limited spatial and temporal extents for CLWB (generally within 1 mile of the release) and Bakken crude oil (generally within 0.75 miles of the release). As noted above, short-term exposure to these concentrations of dissolved aromatic hydrocarbons from crude oil could result in mortality of fish species.

7.7.6.3 Semi-Aquatic Wildlife Receptors

Habitat along the Mississippi River downstream of the hypothetical release location supports amphibians (e.g., frogs, salamander), reptiles (e.g., turtles, snakes), birds (e.g., ducks, geese, shorebirds, raptors), and semi-aquatic mammals (e.g., muskrat, beaver, mink and otter). Details on predicted environmental effects for amphibians and reptiles, birds and mammals are provided below.

7.7.6.3.1 Amphibians and Reptiles

Crude oil released to the Mississippi River during the spring (high flow) or summer-fall (average flow) seasons would be predicted to travel downstream, interacting with vegetation and seasonal shoreline areas. Based on SIMAP simulations, CLB crude oil and Bakken crude oil were predicted to follow the same downstream transport pattern (each predicted to reach approximately 18 miles downstream 24 hours after a release) and form slicks of equal thickness between 0.0004 inches and greater than 0.04 inches. However, a greater amount of CLB is predicted to remain on the surface of the Mississippi River after 24 hours as compared to Bakken crude oil (e.g., approximately 70% vs. 36%), while a greater amount of Bakken crude oil is predicted to evaporate as compared to CLB (e.g., approximately 55% vs. 20%). During spring (high flow) and summer-fall (average flow) seasons, both oil types are predicted to have similar amounts adherence to shorelines (e.g., between 8 and 11%) and negligible amounts (less than 0.1%) of either oil type are predicted to mix within the water column or deposit to sediment.

Within the oil-exposed habitats along the river that support amphibians (adults, juveniles, and eggs), oiling effects including mortality would be observed. Turtles appear to be relatively tolerant of external crude oil exposure, and although these animals are likely to become oiled, mortality of turtles as a result of this exposure is less likely. Reptiles like lizards and snakes are primarily terrestrial species and are less intimately associated with aquatic environments. As a result, exposure of these animals to released crude oils would be limited. After the Kalamazoo River oil spill in 2010, snakes did not appear to be highly exposed to spilled oil. A release of light crude oil during the spring would likely have a greater effect than in summer due to the greater predicted downstream transport distance and interaction with greater areas of riparian and wetland habitats than later in the year.

Amphibians and reptiles undergo a winter dormancy period when temperatures drop below approximately 41 to 45°F. At this time, amphibians and turtles typically bury themselves in river bottom substrates or other similar habitats. Therefore, during the winter (and likely up until April or May when winter ice is gone), these organisms would have very little exposure to released oil moving on the water surface or within the water column.

7.7.6.3.2 Birds

Aquatic and semi-aquatic birds are those that use rivers, lakes, wetlands, and riparian areas as components of their habitat, particularly for nesting and feeding. These birds belong to a variety of guilds including but not limited to waterfowl, divers, gulls and terns, raptors, shorebirds, waders, and some songbirds. They have a variety of dietary preferences, including piscivory, insectivory, omnivory, and herbivory. If exposed to external oiling, the ability of birds to maintain body temperature may be compromised, leading to death as a result of hypothermia. Even if they survive their initial exposure to crude oil, the exposure may require an increase in metabolic rate to survive. In turn this may compromise other life functions such as reproduction or growth. Birds that survive external oiling may experience toxicological stresses as a result of ingesting crude oil residues while preening or attempting to clean and restore the normal properties and functions of feathers. Birds can also transfer potentially lethal quantities of crude oil residue from their feathers to the external surface of eggs, resulting in death of developing embryos.

Unlike many other vertebrate receptors, aquatic bird species in the northern temperate zone are nearly all seasonal migrant species which leave their summer (and often breeding) habitat in the fall for wintering areas farther south where they can find open-water habitat. However, some birds (e.g., Canada goose) will opportunistically remain in freezing conditions if there is reliable open water and a source of food available. Timely capture and rehabilitation of oiled birds may help to mitigate the environmental effects of a crude oil release. During the spring (high flow) season, many migratory birds would be returning to riverine and lacustrine habitats in Minnesota, or migrating through these areas on their way to breeding habitats farther north. With cold water temperatures prevailing, aquatic and semi-aquatic birds contacted by crude oil are likely to die as a result of hypothermia. Waterfowl and other semi-aquatic birds present in the affected river reach would be most affected. Animals upstream, farther downstream, or occupying other nearby habitats, would likely be less affected as it is assumed that emergency response measures to prevent or reduce further possible downstream transport of oil would be in place within 24 hours of the release.

The Mississippi River below Palisade, Minnesota would provide excellent habitat for a variety of waterfowl species, as well as fish-eating raptors, and other species such as kingfisher, herons and shorebirds. The environmental effects of a crude oil release in the summer-fall period are likely to be of similar or lesser magnitude. With rising water temperatures, mortality of lightly oiled adult birds due to hypothermia becomes less likely than in the spring, and the temporary presence of large numbers of migrating individuals is unlikely. However, in the early summer, environmental effects could include egg mortality due to transfer of oil from the feathers of lightly oiled adult birds in the nest, or mortality of young birds due to direct oil exposure or the loss of a parent bird.

Chronic adverse effects on the health of birds that survive their initial exposure to crude oil are also possible as a result of ingesting crude oil residues while preening, or while consuming food items. However, as in the spring, effects are expected to be limited to areas of oil exposure. Potential effects on aquatic and semi-aquatic birds in the fall would be similar to those in spring, although a smaller overall length of river habitat would be affected due to lower river flows. Mortality of waterfowl and other semi-aquatic bird species would occur, and would likely be similar to effects that were reported following the release of crude oil to the Kalamazoo River in 2010. While the death of these birds would be a serious environmental effect locally, given the length of the Mississippi River in Minnesota, and the abundance of other wetland, lake, river and riparian habitat in the region and state, longer-term population-level effects on semi-aquatic birds are not likely to be observed.

Under winter conditions (March), it was assumed that the Mississippi River would be frozen (100% ice cover). In addition, most waterfowl and other semi-aquatic bird species would migrate south in the winter. Therefore, a crude oil release in winter would be expected to have very limited effects on birds.

7.7.6.3.3 Semi-aquatic Mammals

While the semi-aquatic mammal species found in Minnesota include terrestrial species such as moose and raccoon, this assessment focuses particularly upon species that have a primary association with the aquatic environment such as muskrat and beaver (herbivores), American mink (carnivore-piscivore) and river otter (piscivore). These species are at greater risk of exposure to an oil release in water than more fully terrestrial mammals. The Mississippi River below Palisade, Minnesota, would provide excellent habitat for muskrat and beaver, as well as fish-eating mammals such as American mink and river otter, and incidental omnivorous mammals such as raccoon.

Effects to semi-aquatic mammals are typically described in terms of direct physical effects (e.g., hypothermia due to loss of insulation), direct toxicological effects (e.g., gastro-enteropathy caused by ingestion of crude oil residues while grooming oiled fur or ingesting food), and indirect effects caused by changes to habitat (e.g., land cover and food availability). The spatial extent along the Mississippi River where effects may occur, and the magnitude of effects, is related to the season and river flow rate, and the type of oil released. Effects to semi-aquatic mammals relate more to the amount of time spent in the water and oil-contaminated riparian habitat (and consequent exposure to physical oiling) than to dietary preferences. Timely capture and rehabilitation of oiled mammals may help to mitigate the environmental effects of a crude oil release.

During high and average flow conditions, and based on SIMAP simulations, CLB crude oil and Bakken crude oil were predicted to follow the same downstream transport pattern (each predicted to reach approximately 18 miles downstream 24 hours after a release) and form slicks of equal thickness between 0.0004 in. and greater than 0.04 in. Both oil types are predicted to have similar amounts of adherence to shorelines (e.g., between 8 and 11%) and only very little amounts of both types of oil are predicted to mix within the water column or deposit to sediment (e.g., less than 0.1%).

During the spring (high flow) season, with cold water temperatures prevailing, semi-aquatic mammals contacted by crude oil are likely to die as a result of hypothermia. Animals upstream, farther downstream where there is no exposure, or occupying other nearby habitats, would likely be unaffected. Therefore, although mortality of a considerable number of semi-aquatic mammals could be expected, large-scale (i.e., regional) population level effects are unlikely. Environmental effects of a crude oil release in the summer-fall period are likely to be of a magnitude similar to or lesser than those associated with a release during spring. With rising water temperatures, mortality of lightly oiled semi-aquatic mammals due to hypothermia is less likely than in the spring. Chronic adverse effects on the health of semi-aquatic mammals that survive their initial exposure to crude oil are possible as a result of ingesting crude oil residues while grooming, or while consuming food items. However, as in the spring, effects are expected to be limited to areas of oil exposure. While the death of these animals would be a serious environmental effect locally, given the length of the Mississippi River in Minnesota, and the abundance of other wetland, lake, river and riparian habitat in the region and state, longer-term population-level effects on semi-aquatic mammals are not likely to be observed.

In the winter months, muskrat and beaver are likely to reduce their activity levels, although American mink and river otter would remain active. Animals that became oiled in the winter would be likely to rapidly die as a result of hypothermia.

7.7.6.4 Human and Socio-Economic Receptors

Crude oils are complex mixtures of hydrocarbon compounds. Light crude oils typically contain more VOCs than heavier crude oils, although diluted bitumen may contain similar amounts of VOCs to light crude oils, depending upon the type and amount of diluent they contain. Air quality in the vicinity of a crude oil release, and along the downstream corridor, would be affected by the release of VOCs (such as benzene, which is often used as an indicator substance) primarily within the first 24 hours of an oil release. For the Mississippi River at Palisade scenario, the community of Palisade, Minnesota (population less than 200 as reported in the census of 2010) is located approximately one mile north of the hypothetical release location. Depending upon the wind direction at the time of a hypothetical crude oil release, receptors in Palisade might or might not be exposed to odor in the first few hours and days. A small number of human receptors would likely also be present in closer proximity to the river, between the hypothetical release location and the downstream extent of the oil trajectory. These individuals would have variable exposure to VOCs and odor, depending upon their location and prevailing wind speed and direction in the event of a crude oil release.

Based on SIMAP simulations, CLB crude oil and Bakken crude oil were predicted to follow similar downstream transport patterns (each predicted to reach approximately 18 miles downstream within 24 hours of a release), and to form slicks of similar thickness during the spring (high flow) or summer-fall (average flow) seasons. However, a greater amount of Bakken crude oil (greater than 50%) is predicted to evaporate within 24 hours as compared to CLB crude oil (approximately 20%). Therefore, the effects of a release of Bakken crude oil on air quality would be greater than the effects of a release of CLB.

If a crude oil release was to occur in winter, and to be confined below ice on the river, very little of the volatile hydrocarbon present in the oil would be released to the atmosphere as VOCs. Most would be forced to dissolve into the river water, moving downstream, or remain associated with the liquid crude oil at locations where this oil accumulated until spring breakup. At that time, it is likely that the remaining crude oil would be dispersed downstream along the river, although the residual volatile hydrocarbon content and effects on air quality would be lower than the effects described here for a release during the spring freshet.

Typical human health effects associated with short-term (acute) inhalation of volatiles from crude oil include headache, dizziness, nausea, vomiting, cough, respiratory distress, and chest pain. Short-term or repeated skin contact with crude oil may result in dermatitis. The case studies (Section 7.1) do not reveal any instances of human fatality as a result of inhalation of crude oil vapor. Similarly, ATSDR (1995) report that there are no known instances of human fatality as a result of inhalation of vapor from fuel oils, which would be comparable to light crude oils.

The potential for VOC inhalation exposures to the public would be greatest near and downwind from the release site while the released oil is on the water surface. In the unlikely event of a crude oil release, residents in close proximity would become aware of a strong hydrocarbon odor. Most of the volatile hydrocarbons would be lost within the first 24 hours following a release of crude oil. It is also expected that emergency response personnel would contact such residents and advise them to evacuate. Actual or potential exposure to crude oil vapor may result in residents leaving, or being advised to leave their homes for a period of time while the emergency response takes place.

The drinking water intake for Palisade, Minnesota is upstream of the hypothetical release location so effects on water quality for residences in the area are not expected. In addition, no drinking water HCAs were identified along the path of the release. However, in the event of a crude oil release, people would be notified and testing would be completed to confirm the safety of the water supply. Based upon case studies involving crude oil releases elsewhere, this process could take a few days to two weeks, but reports of crude oil releases affecting private wells are rare, making this an unlikely effect.

Relatively little has been published regarding the long-term effects of human exposure to a crude oil release. Health effects observed in residents and clean-up workers in the months following such releases generally do not persist over the long term (Eykelbosh 2014). The International Agency for Research on Cancer (IARC 1989) has determined there is "limited evidence of carcinogenicity" of crude oil in experimental animals and "inadequate evidence of carcinogenicity" of crude oil in humans. Although toxicological effects from short-term exposure to volatile hydrocarbons are reversible when exposure is reduced, other health effects such as anxiety and depression may occur, and may persist, regardless of whether the individual was physically exposed to hydrocarbons.

No overland transport of released crude oil was modelled for this hypothetical release location. Infiltration of crude oil into soil and subsequently into groundwater is assumed to be negligible.

The Mississippi River downstream from the hypothetical release location crosses through patches of the Waukenabo State Forest and sections of land owned by the BLM. This section of the Mississippi River is also frequented by recreational users for canoeing, fishing and other purposes. Effects on air and water quality, or the presence of crude oil residues in the sediment, riparian or wetland habitat, could potentially disrupt public use of natural resources (e.g., drinking water supplies, hunting, fishing, recreation). Emergency response workers, in cooperation with public health and safety officials, would be active in isolating, containing and recovering released crude oil, as well as notifying the public about the release. Recreational activities would be disrupted following a release of crude oil along the predicted downstream migration route. Fisheries regulators and public health officials typically close fisheries until it is confirmed through monitoring that fish consumption is not a threat to public health. This standard approach is an effective mitigation strategy to protect human receptors for contact with constituents in the oil.

7.7.6.5 Summary and Conclusions

Expected environmental effects to key ecological and human environment receptors after a hypothetical large crude oil release to the Mississippi River near Palisade, Minnesota have been assessed. The proposed pipeline could carry a variety of crude oil types (ranging from very light [e.g., Bakken crude oil] to heavy [e.g., diluted bitumen such as CLB], and the discussion of expected environmental effects on receptors is based on these crude oil types as bounding conditions. Potential terrestrial receptors, aquatic receptors, semi-aquatic wildlife receptors and human and socio-economic receptors were screened to identify those with the most likely interactions with released oil. The results of this assessment are summarized in Table 7-7-6.

Table 7-80 Environmental Effects Summary Table for Pipeline Crude Oil Releases to the Mississippi River at Palisade

Receptor	Expected Environmental Effects of Released Crude Oil to the Mississippi River at Palisade	Relative Effect	
		Light Crude Oil	Diluted Bitumen
Terrestrial Receptors			
Soils	It is assumed in the model that crude oil would enter directly into the Mississippi River with no holdup of oil on land. In the event of an actual oil release, any oil on land would undergo prompt and effective remediation. Residual effects on plant communities, soil or groundwater quality are unlikely.	SAME	SAME
Groundwater		SAME	SAME
Terrestrial Vegetation		SAME	SAME
Aquatic Receptors			
Rivers (Mississippi River)	Both light and heavy oil would travel downstream from the release location, affecting the Mississippi River. Lighter crude oils and heavier crude oils are predicted to follow the same downstream transport pattern (each predicted to reach approximately 18 miles downstream within 24 hours after a release), and form slicks of similar thickness (between 0.0004 inches and greater than 0.04 inches). During spring (high flow) and summer-fall (average flow) seasons, a greater amount of CLB is predicted to remain on the surface of the Mississippi River after 24 hours as compared to Bakken crude oil (e.g., approximately 70% vs. 36%). However, both oil types are predicted to have similar amounts adherence to shorelines (e.g., approximately 8% for the CLB and 9-11% for the Bakken). Negligible amounts of either crude oil type are predicted to mix within the water column or deposit to sediment. In winter, simulations indicate that heavy crude oil could be carried farther downstream than lighter oil (i.e., 2.5 miles vs. 0.5 miles from the point of release), but this may be due to assumptions in the model. Overall, the SIMAP simulations indicate similar effects of both crude oil types on the aquatic habitat of the Mississippi River at Palisade, Minnesota.	SAME	SAME
Sediment	In all three seasons, both oil types are predicted to have very little mixing within the water column or deposition to sediment (e.g., less than 0.1%). Neither the light nor the heavy oil type is likely to reach a density greater than that of the water and sink directly to the sediment within the first few days following release. Where deposition is predicted, a slightly higher concentration of CLB is predicted in sediment than for Bakken crude oil. However, neither is predicted to be deposited to sediments at concentrations that would seriously affect aquatic life.	SAME	SAME

Table 7-80 Environmental Effects Summary Table for Pipeline Crude Oil Releases to the Mississippi River at Palisade

Receptor	Expected Environmental Effects of Released Crude Oil to the Mississippi River at Palisade	Relative Effect	
		Light Crude Oil	Diluted Bitumen
Shoreline and Riparian Areas	Both light and heavy oil would travel downstream from the release location, affecting the Mississippi River. Lighter crude oils and heavier crude oils are predicted to follow the same downstream transport pattern (each predicted to reach approximately 18 miles downstream within 24 hours after a release), and form slicks of similar thickness (between 0.0004 inches and greater than 0.04 inches). During spring (high flow) and summer-fall (average flow) seasons, both oil types are predicted to have similar amounts adherence to shorelines (e.g., approximately 8% for the CLB and 9-11% for the Bakken). Flooding of riparian and wetland habitats in spring could lead to stranding of crude oils in these habitats, with heavy crude oil likely to be deposited as patties or tar balls, which would be persistent. This is in contrast to light crude oil which would be deposited as a thin layer or sheen. In winter, simulations indicate that heavy crude oil could be carried farther downstream than lighter oil (i.e., 2.5 miles vs. 0.5 miles from the point of release), but this may be a function of assumptions inherent in the model, and these distances are expected to be more similar should a release occur. Overall, the SIMAP simulations indicate that slightly more of the Bakken crude oil might strand on shorelines or in riparian areas (9-11%) than would be the case for CLB (approximately 8%), although the CLB crude oil type would tend to be more persistent in such areas.	SAME	SAME
Aquatic Plants	The Mississippi River supports emergent, floating and submerged aquatic plants. Based on SIMAP simulations for spring and summer-fall conditions, CLB crude oil and Bakken crude oil were predicted to exhibit similar downstream transport patterns, and to form slicks of similar thickness. Where they occur, floating aquatic plants would be expected to be killed if contacted by a floating oil slick. Submerged aquatic plants would be less vulnerable. Emergent aquatic plants are generally quite tolerant of moderate exposure to floating oil (such that a portion of the stem was oiled).	SAME	SAME
Benthic Invertebrates	Environmental effects on benthic invertebrates would be limited to areas affected by the released oil. In all three seasons, both oil types are predicted to have very little mixing within the water column or deposition to sediment (e.g., less than 0.1%). Neither the light nor the heavy oil type is likely to reach a density greater than that of the water and sink directly to the sediment within the first few days following release. Where deposition is predicted, a slightly higher concentration of CLB is predicted in sediment than for Bakken crude oil. However, neither is predicted to be deposited to sediments at concentrations that would seriously affect aquatic life such as benthic invertebrates.	SAME	SAME

Table 7-80 Environmental Effects Summary Table for Pipeline Crude Oil Releases to the Mississippi River at Palisade

Receptor	Expected Environmental Effects of Released Crude Oil to the Mississippi River at Palisade	Relative Effect	
		Light Crude Oil	Diluted Bitumen
Fish	Environmental effects on fish would be limited to areas affected by the released oil. In spring and summer-fall conditions, both light and heavy oil are predicted to follow the same downstream transport pattern (i.e., reach approximately 18 miles downstream within 24 hours after a release). The potential for entrainment of CLB and Bakken crude oil types into the water column during high and average river flow conditions was predicted to be low. Because of this, predicted total aromatic hydrocarbon concentrations in the water column were generally low due to the oil remaining on the surface and not entrained within the water column. The maximum concentration of dissolved aromatics from both oil types was locally greater than 1,000 to 5,000 ppb, but suggested a transient exposure of less than 24 hours duration. This concentration range and duration of exposure could result in acute lethality to sensitive aquatic species, and species with average sensitivity to hydrocarbons. In winter, Bakken Crude oil is predicted to travel 0.5 miles downstream in the Mississippi River within the 24 hour model simulation, a distance that is approximately one-fifth that of the distance traveled by CLWB. The predicted maximum soluble hydrocarbon concentration of both oil types is greater than 5,000 ppb in limited areas (within 1 mile of the release location) and transient exposures would be expected within their release extent.	SAME	SAME
Semi-Aquatic Wildlife Receptors			
Amphibians and Reptiles	Environmental effects on fish would be limited to areas affected by the released oil. In spring and summer-fall conditions, both light and heavy oil are predicted to follow the same downstream transport pattern (i.e., reach approximately 18 miles downstream within 24 hours after a release). During spring (high flow) and summer-fall (average flow) seasons, both oil types are predicted to have similar amounts of adherence to shorelines (e.g., approximately 8% for the CLB and 9-11% for the Bakken). Flooding of riparian and wetland habitats in spring could lead to stranding of crude oils in these habitats, with heavy crude oil likely to be deposited as patties or tar balls, which would be persistent. This is in contrast to light crude oil which would be deposited as a thin layer or sheen. Within these habitats, oiling effects on adults, juveniles, and eggs could potentially be observed. Higher potential would exist for effects on amphibians than for turtles, which appear to be somewhat tolerant of external oiling. Dormancy of amphibians and reptiles in winter and early spring means exposure to oil released at this time of year could be negligible, and adverse environmental effects unlikely.	SAME	SAME

Table 7-80 Environmental Effects Summary Table for Pipeline Crude Oil Releases to the Mississippi River at Palisade

Receptor	Expected Environmental Effects of Released Crude Oil to the Mississippi River at Palisade	Relative Effect	
		Light Crude Oil	Diluted Bitumen
Birds	Mortality of oiled aquatic and semi-aquatic birds would be limited to areas affected by the released oil. Both light and heavy crude oil types are predicted to travel similar distances, and both would form slicks of similar thickness. During the spring high flow season, many migratory birds would be returning to riverine and lacustrine habitats in Minnesota, or migrating through these areas on their way to breeding habitats farther north. Few birds are present in winter, so effects would be minimal in that season.	SAME	SAME
Semi-aquatic Mammals	Mortality of oiled semi-aquatic mammals would be limited to areas affected by the released oil. Both light and heavy crude oil types are predicted to travel similar distances, and both would form slicks of similar thickness. Adverse effects on mink and otter would be particularly severe in winter, due to the effects of oil in the insulating properties of fur, in combination with cold water temperatures. However, muskrat and beaver might be spared due to their lower activity levels in winter.	SAME	SAME
Human and Socio-Economic Receptors			
Air Quality	Effects on air quality have the potential to temporarily disrupt human use and occupancy patterns. Light crude oils typically contain more VOCs than heavier crude oils, although the VOC content of diluted bitumen may be similar to that of light crude oil, depending on the type and quantity of diluent used in its manufacture. Air quality in the vicinity of the oil release would be most affected within the first 24 hours of an oil release. Light crude oil is expected to travel a similar distance downstream under spring and summer conditions as heavy crude oil. As a result, environmental effects on air quality are predicted to be spatially similar for light crude oil types. Under winter conditions, cold temperatures, ice cover and absorption of crude oil into snow pack would strongly limit emissions of VOCs, in addition to constraining the area of effects.	MORE	LESS

Table 7-80 Environmental Effects Summary Table for Pipeline Crude Oil Releases to the Mississippi River at Palisade

Receptor	Expected Environmental Effects of Released Crude Oil to the Mississippi River at Palisade	Relative Effect	
		Light Crude Oil	Diluted Bitumen
Human Receptors	Typical human health effects associated with short-term inhalation of VOCs from crude oil releases include headache, dizziness, nausea, vomiting, cough, respiratory distress, and chest pain; fatality is unlikely. Residents in close proximity would become aware of a strong hydrocarbon odor. Most volatile hydrocarbons would be lost within 24 hours following a release. The human receptors most likely to be exposed to VOCs under this hypothetical crude oil release scenario would be located in homes located close to the Mississippi River, within about 18 miles of the release point. Under winter conditions, cold temperatures, ice cover and absorption of crude oil into snow pack would strongly limit emissions of VOCs, in addition to constraining the area of effects.	SAME	SAME
Public Use of Natural Resources	Emergency response workers, in cooperation with public health and safety officials, would be active in isolating, containing and recovering released crude oil, as well as notifying the public about the release. Both light and heavy crude oil types are predicted to travel similar distances, and both would form slicks of similar thickness, potentially interrupting public use of natural resources over a similar area. No drinking water HCAs were identified along the path of the release. However, some homes are located along the trajectory of a predicted release and could rely on groundwater as a drinking water source. In the event of a crude oil release, people would be notified and testing would be completed to confirm the safety of the water supply. It is unlikely that a crude oil release to the Mississippi River would result in adverse health effects to consumers of drinking water. Recreational activities would be disrupted following a release of crude oil along the predicted downstream migration route.	SAME	SAME

7.8 EXPECTED ENVIRONMENTAL EFFECTS OF LARGE RELEASES OF CRUDE OIL TO THE MISSISSIPPI RIVER AT LITTLE FALLS

The proposed pipeline would cross underneath the Mississippi River five miles north of Little Falls, Minnesota. As the Mississippi River flows south from the hypothetical release site, it passes through Little Falls, through the Little Falls electric generation dam, through Zebulon Pike Lake (an 8 mile long reservoir) and through another electric generation dam (Blanchard Dam). A number of islands and riparian habitats are part of this reach of the Mississippi River. This scenario captures a release of crude oil directly to the Mississippi River, with downstream transport from the hypothetical release point to the south through a large population center, as well as a high energy physical environment with several waterfalls. The average gradient of the Mississippi River in this section is greater than at other assessed locations, including both the effects of dams, and relatively narrow sections of the river where flow is confined and faster than in wider reaches. As identified in Chapter 3, the Mississippi River forms the western boundary of the Anoka Sand Plain Subsection of the Minnesota and Northeast Iowa Morainal Section of the Eastern Broadleaf Forest Province (MN DNR 2006).

7.8.1 Description of the Freshwater Environment

The Mississippi River near Little Falls flows south along a broad channel (approximately 800 ft across) with numerous islands (MN DNR 2016o). The river banks are typically steep and well defined. Immediately downstream of the hypothetical release site, the Mississippi River flows by Belle Prairie County Park and an island called Island 48. From here the Mississippi River passes Roscoe Island, Island 50, the confluence of Little Elk River, and then narrows and becomes turbulent prior to flowing over the Little Falls electrical generation dam. Directly south of this dam the Mississippi River bends sharply around Mill Island and flows south where it is fed by the Swan River.

The Zebulon Pike Lake reservoir begins downstream of Little Falls dam, and terminates at the Blanchard electrical generation dam about 8 miles south. Numerous parks (i.e., Le Bourget Park, James Green Park, Maple Island Park, Mill Park and the much larger Charles A. Lindbergh State Park) are associated with the reservoir. The McDougall WMA and the Charles A. Lindbergh State Park provide recreational opportunities such as hunting, trapping, hiking, cross-country skiing, snow shoeing, and wildlife watching (MN DNR 2016p; MN DNR 2016q). The banks of the Mississippi River are mainly forested, with residences and agricultural lands on either side. Below the Blanchard dam, the river channel continues to wind, with occasional islands and narrow sections, as it continues generally south toward the cities of Sartell, Sauk Rapids and St. Cloud, Minnesota.

Excellent fishing opportunities for smallmouth bass, walleye, northern pike, and muskellunge are available along this stretch of the Mississippi River (MN DNR 2016o). This section of the Mississippi River and surrounding riparian areas also provide habitat for mallard, teal, wood duck, mergansers, goldeneye, and Canada goose (MN DNR 2016r). The Anoka Sand Plain Subsection also provides open grasslands for sandpiper, nesting songbirds and grazing ungulates (elk, deer) and is home to 97 SGCN (MN DNR 2006; MN DNR 2016p; MN DNR 2016r). These include amphibians (1 species), birds (56 species), fish (3 species), insects (9 species), mammals (8 species), mollusks (9 species), reptiles (8 species), and spiders (3 species) (MN DNR 2006). Of these species, 37 are afforded federal or state endangered, threatened, or of special concern status (MN DNR 2006; MN DNR 2016d). It is foreseeable that some of these SGCN could utilize aquatic habitats along the Mississippi River.

Several access points downstream from the proposed pipeline crossing location were visited in May 2016, to provide additional insight into baseline environmental conditions for the Mississippi River near Little Falls. Representative site photographs are provided in Figure 7-46 through Figure 7-49. Field observations are summarized in Table 7-81.

Figure 7-46 Mississippi River and Riparian Habitat Approximately 5 Miles Downstream of Pipeline Crossing, Above the Little Falls Dam

Figure 7-47 Mississippi River and Riparian Habitat Approximately 5 Miles Downstream of Pipeline Crossing, Above the Little Falls Dam

Figure 7-48 Mississippi River and Riparian Habitat Approximately 28.75 Miles Downstream of Pipeline Crossing

Figure 7-49 Mississippi River and Riparian Habitat Approximately 53.1 Miles Downstream of Pipeline Crossing, at Clearwater, Minnesota

Table 7-81 Environmental Characteristics Observed at Selected Access Points on the Mississippi River in May 2016

Access Point	Latitude Longitude	Notes
4th Avenue Landing State Water Access Site 5 miles downstream of proposed pipeline crossing	45.9811 -94.3624	<u>Habitat Description:</u> site is upstream of dam in Little Falls. Shoreline is well-defined due to relatively stable water levels behind dam. Shoreline is gradual to abrupt, with most banks being less than 10 ft high. Terrace forest trees (Elm - green ash) are most common in vicinity of this site. The non-native, invasive Siberian elm is occasional in area. <u>Wildlife observed:</u> mallard
Mississippi Co Park State Water Access Site 28.75 miles downstream of proposed pipeline crossing	45.7266 -94.2231	<u>Habitat Description:</u> river banks are approximately 5-10 ft high in this area with silver maple floodplain forest on the lowest areas and islands. Terrace forest (elm-ash) begins approximately 15-20 ft above river level. Plant communities are generally moderate to good quality in areas observed. <u>Wildlife observed:</u> catbird, Canada goose, yellowthroat <u>Fish & Wildlife likely to occur in vicinity:</u> walleye, smallmouth bass, wood duck

Table 7-81 Environmental Characteristics Observed at Selected Access Points on the Mississippi River in May 2016

Access Point	Latitude Longitude	Notes
Clearwater State Water Access Site 53.1 miles downstream of proposed pipeline crossing	45.4195 -94.0424	Habitat Description: river banks are generally about 15-20 ft high in this area with the river banks being relatively steep-sided, but stable and vegetated. Terrace forest on first terrace above river is dominated by hackberry, silver maple, green ash, and American elm. The shrub layer and herbaceous vegetation is composed of a mix of native and nonnative species. Fish & Wildlife likely to occur in vicinity: walleye, smallmouth bass, wood duck

7.8.2 High Consequence Area Assessment for the Mississippi River near Little Falls Crossing Location

As defined in Section 7.0, HCAs include populated areas, drinking water source areas, ecologically sensitive areas, and commercially navigable waterways. Sensitive AOIs include Minnesota drinking water management areas, native plant communities, sensitive lake shores, recreational areas, tribal lands, and protected areas of several types (e.g., national forests, military lands, state parks).

Under low, average and high flow conditions, the stretch of the Mississippi River downstream from the hypothetical release location passes through several HCAs, as well as protected areas and drinking water AOIs (Table 7-82 and Table 7-83, respectively). The locations of the HCAs and AOIs are shown in Figure 7-50.

Table 7-82 HCAs Potentially Affected by a Release of CLB and Bakken Crude Oil at the Mississippi River near Little Falls Crossing Location

HCA Type	HCA Subtype	Description / Locations
Environmentally Sensitive Area	N/A	N/A
Population Area	Other	Little Falls, MN Rice, MN
Drinking Water	Wellhead Protection Area	Little Falls, MN
NOTE: Data for the HCA analysis were obtained from the USDOT PHMSA HCA datasets plus additional HCAs compiled by Enbridge during 2010 and 2013.		

Table 7-83 Table 7-8-3: AOIs Potentially Affected by a Release of CLB and Bakken Crude Oil at the Mississippi River near Little Falls Crossing Location

AOI Type	AOI Subtype	Description / Locations
Drinking Water	Surface Water Supply Management Area	Saint Cloud, MN
	Water Supply Management Area	Little Falls, MN
Protected Area	Bureau of Land Management	BLM Land
	Private Conservation Land	Sensitive Ground Water - Limit
	State Park	Charles A. Lindbergh State Park
	State Wildlife Management Area	McDougall WMA, Michaelson Farm WMA
	The Nature Conservancy	McDougall Homestead

NOTE:
Data for the AOI analysis were derived from multiple datasets provided on the Minnesota Geospatial Commons website, USGS Protected Areas Database of the United States and the Minnesota Department of Transportation.

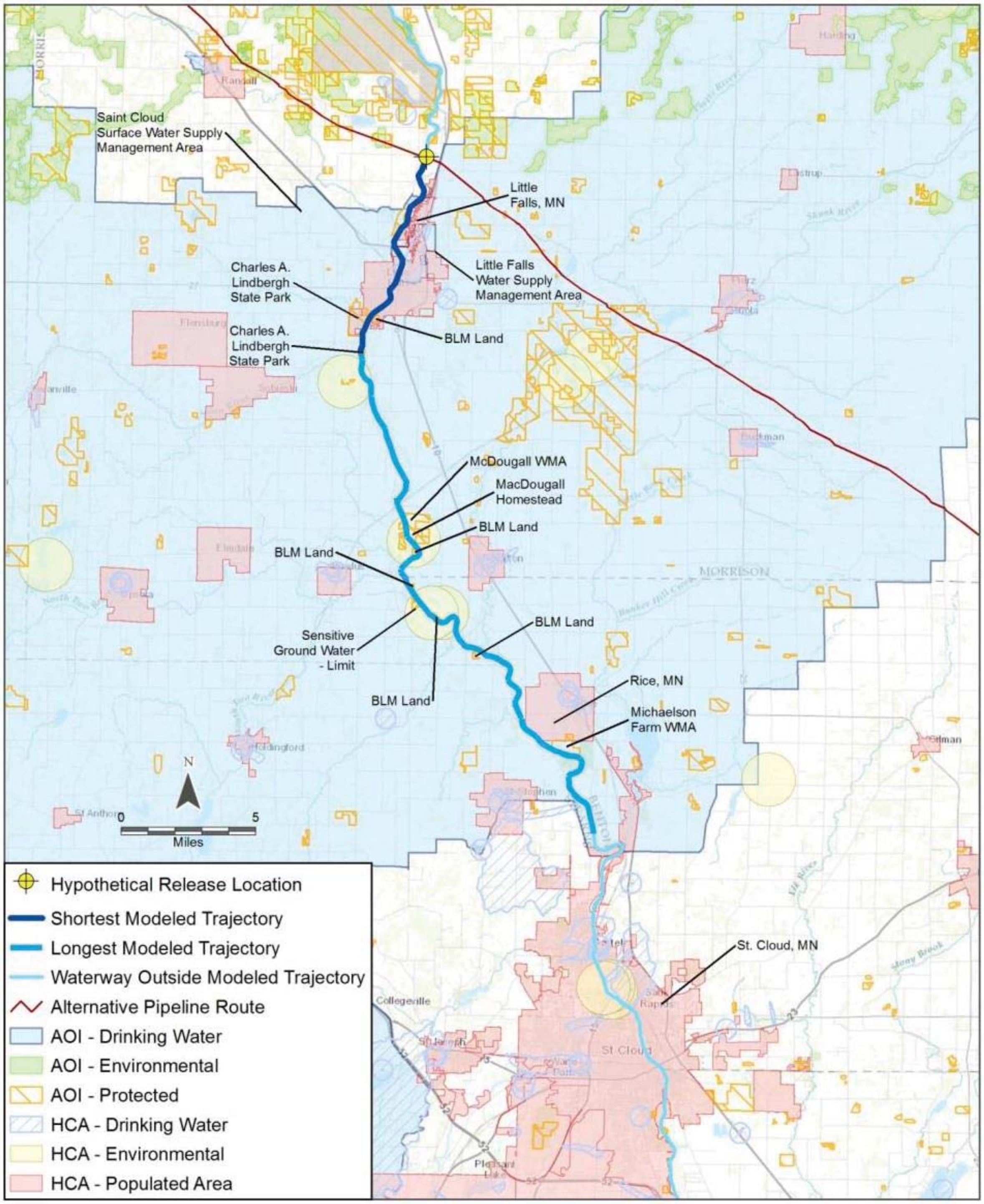


Figure 7-50 HCAs and AOIs Potentially Affected by a Crude Oil Release at the Mississippi River near Little Falls Crossing Location

7.8.3 Selection of Key Ecological and Human Environment Receptors for Mississippi River near Little Falls Crossing Location

Taking into account environmental characteristics of the Mississippi River near Little Falls, the potential interactions of released crude oil with key ecological and human environment receptors were screened to identify key receptors for the subsequent environmental effects analysis. The rationale and results of this screening step are provided in Table 7-84.

Table 7-84 Key Ecological and Human Environment Receptors for the Mississippi River near Little Falls Crossing Location

Receptor	Relevance for Inclusion as an Environmental Receptor for the Mississippi River near Little Falls Scenario	Selected (Y/N)
Terrestrial Receptors		
Soils	Low. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Mississippi River with no holdup of oil on land. Any oil that reaches soil would be physically remediated to established standards.	N
Groundwater	Low. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Mississippi River with no holdup of oil on land. In the event of an actual oil release, effects on groundwater quality would be localized and/or negligible.	N
Terrestrial Vegetation	Low. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Mississippi River with no holdup of oil on land. Any oil that reaches soil would be physically remediated and vegetative cover would be restored as part of the clean-up process.	N
Aquatic Receptors		
Rivers (Mississippi River)	High. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Mississippi River with subsequent physical transport downriver.	Y
Lakes (Zebulon Pike Lake)	Low. Zebulon Pike Lake is a reservoir approximately 8 miles south of Little Falls and bounded by the Little Falls Dam on the north and the Blanchard Dam on the south. While considered a lake, there is no relevant lacustrine habitat. This stretch of the Mississippi River is similar to other stretches.	N
Sediment	High. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Mississippi River with subsequent physical transport downriver. This allows potential interaction and/or deposition of crude oil residues to sediments.	Y
Shoreline and Riparian Areas	High. An assumption made in the fate modeling for this scenario is that released oil would enter directly into the Mississippi River with subsequent physical transport downriver. This allows potential interaction with shoreline and riparian habitat, especially associated with the many islands within the river.	Y
Wetlands	Low. An assumption made in the fate modeling for this scenario is that released oil would enter directly into Mississippi River with subsequent physical transport downriver. There is little to negligible wetland habitat in the vicinity of the predicted release trajectory.	N

Table 7-84 Key Ecological and Human Environment Receptors for the Mississippi River near Little Falls Crossing Location

Receptor	Relevance for Inclusion as an Environmental Receptor for the Mississippi River near Little Falls Scenario	Selected (Y/N)
Aquatic Plants	Low. Substantial aquatic plant community development is unlikely in the high energy environments of this stretch of the Mississippi River.	N
Benthic Invertebrates	High. The Mississippi River supports benthic invertebrate communities.	Y
Fish	High. The Mississippi River supports fish communities.	Y
Semi-Aquatic Wildlife Receptors		
Amphibians and Reptiles	High. Mississippi River supports amphibians and reptiles.	Y
Birds	High. Mississippi River supports waterfowl and other birds.	Y
Semi-aquatic Mammals	High. Mississippi River supports semi-aquatic mammals.	Y
Human and Socio-Economic Receptors		
Air Quality	High. From the hypothetical release site, the Mississippi River runs through the community of Little Falls, Minnesota (5 miles south) and is bordered by a number of homes. The Mississippi River also passes near the population center of Rice, Minnesota, which is along the downstream flow path for released crude oil. Effects on air quality have the potential to temporarily disrupt human use and occupancy patterns.	Y
Human Receptors	High. Effects on air quality or the presence of crude oil residues in aquatic and riparian habitat have the potential to temporarily affect human health. Drinking water for the communities of Little Falls and Rice is drawn from groundwater sources by city owned and operated wells. Therefore, the water supplies for residents of Little Falls and Rice are not likely to be affected by a release.	Y
Public Use of Natural Resources	Downstream of the hypothetical release site the Mississippi River flows through the Zebulon Pike Lake reservoir, numerous parks (i.e., Le Bourget Park, James Green Park, Maple Island Park, Mill Park, and the much larger Charles A. Lindbergh State Park) and the McDougall and Michaelson Farms WMA. These locations provide a number of recreational opportunities. Effects on air and water quality, or the presence of crude oil residues in the sediment or habitat, could potentially disrupt public use of natural resources.	Y

7.8.4 Modeled Conditions at the Release Location

A description of key modeling assumptions for the environmental effects analysis for the Mississippi River near Little Falls, Minnesota scenario is provided in this section. The Mississippi channel in this area is characterized by a variety of slow moving to moderately flowing sections, with occasional riffle sections, and dams with potential overflow and tailrace sections. This high energy environment has the potential to result in localized turbulence that may entrain crude oil.

Unlike OILMAP Land, the SIMAP fate and transport modeling software can quantify the amount of crude oil that is likely to become entrained into or dissolved in the water column, or deposited to sediments as a result of the turbulent conditions (Chapter 4 and 5). To shed light on this potential entrainment or dissolution, SIMAP was used to simulate hypothetical releases of CLB and Bakken crude oils into the Mississippi River downstream of Little Falls, Minnesota. Like the OILMAP Land model, SIMAP provides an indication of the downstream extent of oiling and mass balance of oil within the 24 hour modeled period. A longer time period was not modeled as it was assumed that emergency response measures to prevent or reduce further downstream transport of released oil would be in place within the 24 hour period.

The two crude oil types provide bounding cases for oils that range from light (e.g., Bakken crude oil having low viscosity and density) to heavy (CLB/CLWB, heavy diluted bitumen crude oil types having higher viscosity and density). Seasonal variations in river flow velocity, temperature, wind speed, and snow and ice cover were all considered at the release location. A summary of key variables is provided in Table 7-85.

Table 7-85 Environmental and Hydrodynamic Conditions for the Three Modeled Periods at the Mississippi River near Little Falls Crossing

Season	Month	Air Temperature (°C)	Wind Speed (m/s)	Average River Velocity (m/s)
Low Flow (Winter)	February	-8.33	4.30	0.46
Average Flow (Summer-Fall)	July	22.06	3.47	0.60
High Flow (Spring)	April	7.06	4.85	0.74
NOTE: A velocity of 1 m/s is equivalent to 2.25 miles per hour.				

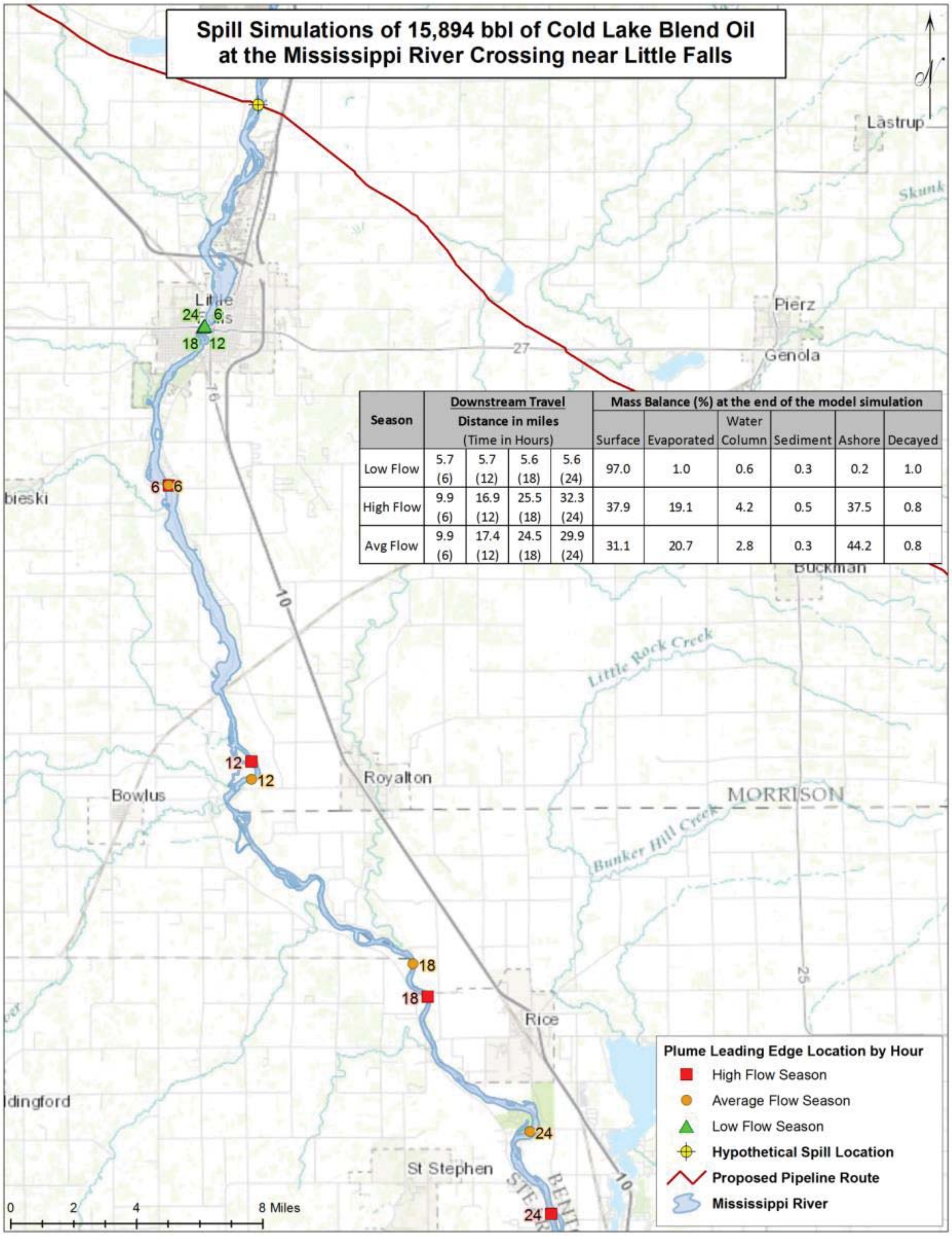
The highest average flow velocity of the Mississippi River near Little Falls coincides with the spring freshet (i.e., April), a result of rising temperatures and snowmelt. Average flow would typically occur in summer and fall seasons. July, the month with the warmest temperature, was selected to represent the maximum amount of evaporation. The lowest flow rate occurs in winter (February), and was typified by freezing conditions and probable ice cover on water.

The crude oil release volume was calculated as a full bore rupture, with a maximum time to response in the pipeline Control Center of 10 minutes, followed by a 3 minute period to allow for valve closure. Therefore, the release volume represents the volume of oil actively discharged in the period of time required to detect and respond to the event (taking into consideration the pipeline diameter, pipeline shutdown time, pipeline design flow velocity), followed by the volume of oil lost due to drain-down of the elevated segments of pipeline. The maximum 13 minute response time to valve closure is an Enbridge standard for safe operations and leak detection. This includes the combination of identification of the rupture, analysis of the pipeline condition, pipeline shutdown, and full valve closure in the affected pipeline section. While 13 minutes is the maximum time for valve closure, this is a conservative assumption, since a response through to valve closure is expected to occur in less than 13 minutes in a full bore rupture leak scenario. Based on these assumptions, the site-specific hypothetical release volume was estimated to be 15,894 bbl of Bakken, CLB, or CLWB crude oil.

7.8.5 Summary of Predicted Downstream Transport of Bakken and Cold Lake Crude Oils

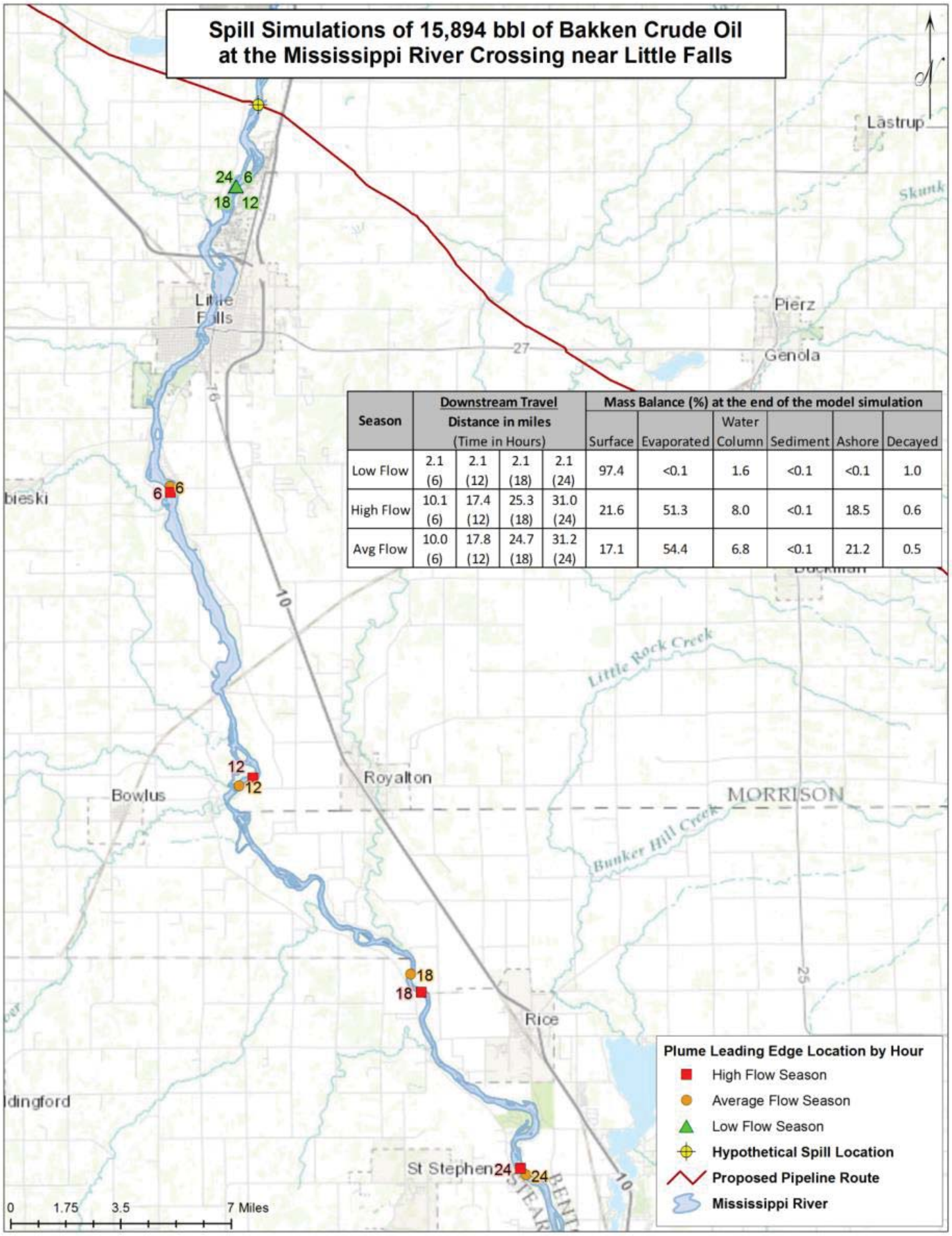
A summary of the predicted downstream trajectories and mass balance for Bakken and Cold Lake crude oils, under the three seasonal scenarios, is provided in Figure 7-51 and Figure 7-52. These simulations are assumed to provide bounding conditions for a release of light and heavy crude oil types, respectively. The fate of most types of crude oil, if released, would lie within the envelope of predictions for the Bakken and Cold Lake crude oil types. The Cold Lake crude oil was assumed to be CLB for the high flow and average flow scenarios, and to be CLWB for the low flow (winter) scenario. The maximum simulation duration using SIMAP was 24 hours, with intervals at 6 and 12 hours. These times were chosen for modeling purposes only as it was assumed that emergency response measures to prevent or reduce further downstream transport of released oil would be in place within that length of time.

Symbols on the drawings indicate the river seasonal flow condition (high corresponding to spring freshet, average corresponding to summer-fall conditions, and low corresponding to winter flow under ice). Numbers associated with the symbols indicate the predicted location of the leading edge of the released oil in the river after 6, 12, 18 or 24 hours. Tables inserted within the Figures also provide information on the mass balance (i.e., oil remaining on the surface of the river, evaporated to the atmosphere, dissolved in the water column, deposited to sediment, adhering to river banks, or decaying through photo-oxidation and biodegradation) of the released oil at relevant points in time after the start of the release.



Season	Downstream Travel Distance in miles (Time in Hours)				Mass Balance (%) at the end of the model simulation					
					Surface	Evaporated	Water Column	Sediment	Ashore	Decayed
Low Flow	5.7 (6)	5.7 (12)	5.6 (18)	5.6 (24)	97.0	1.0	0.6	0.3	0.2	1.0
High Flow	9.9 (6)	16.9 (12)	25.5 (18)	32.3 (24)	37.9	19.1	4.2	0.5	37.5	0.8
Avg Flow	9.9 (6)	17.4 (12)	24.5 (18)	29.9 (24)	31.1	20.7	2.8	0.3	44.2	0.8

Figure 7-51 Predicted Downstream Transport of CLB Oil at the Mississippi River near Little Falls



Season	Downstream Travel Distance in miles (Time in Hours)				Mass Balance (%) at the end of the model simulation: Surface	Evaporated	Water Column	Sediment	Ashore	Decayed
Low Flow	2.1 (6)	2.1 (12)	2.1 (18)	2.1 (24)	97.4	<0.1	1.6	<0.1	<0.1	1.0
High Flow	10.1 (6)	17.4 (12)	25.3 (18)	31.0 (24)	21.6	51.3	8.0	<0.1	18.5	0.6
Avg Flow	10.0 (6)	17.8 (12)	24.7 (18)	31.2 (24)	17.1	54.4	6.8	<0.1	21.2	0.5

Figure 7-52 Predicted Downstream Transport of Bakken Crude Oil at the Mississippi River near Little Falls

7.8.5.1 Mississippi River near Little Falls Release During High Flow (Spring) Period

Under the high flow scenario, CLB was predicted to travel 10, 17, 26, and 32 miles downstream in the Mississippi River after approximately 6, 12, 18 and 24 hours(Figure 7-51). By 24 hours after the hypothetical release, a portion of the released crude oil (37.9%) was predicted to remain on the surface of the Mississippi River, with 19.1% evaporating, 37.5% adhering to shorelines, and approximately 4.2% mixing in the water column. Less than 1% was predicted to deposit to sediment or be broken down through photo-oxidation and biodegradation (Figure 7-51).

Bakken crude oil was predicted to follow the same general downstream transport pattern as CLB (Figure 7-52). By 24 hours after the hypothetical release, most of the Bakken crude oil was predicted to evaporate (51.3%), with 21.6% remaining on the river surface, 18.5% adhering to shorelines, and 8% mixing in the water column. Negligible amounts (less than 0.1%) of the Bakken crude oil were predicted to deposit to sediment and less than 1% was predicted to be broken down through photo-oxidation and biodegradation (Figure 7-52).

Two key events were predicted to affect the mass balance of the crude oil approximately 4.8 and 14.4 hours (0.2 and 0.6 days) after the hypothetical release of CLB and Bakken crude. These events were predicted to occur as the releases passed over the Little Falls and Blanchard Dams, along with the associated rapids downstream (Chapter 6.0). At these locations, it was predicted that there would be substantial entrainment of crude oil into the river water. Entrained oil droplets in the water column are predicted to rise to the surface over subsequent quiescent reaches of the Mississippi River. Above the Little Falls dam, predicted total hydrocarbon concentrations in the river water were very low, as the oil would be floating on the surface, with volatile hydrocarbons mainly evaporating to the atmosphere. However, downstream of the Little Falls Dam, the dissolved aromatic hydrocarbon concentration in the water column is predicted to increase, as oil droplets forced into the water column enable the soluble portion to dissolve into the water. The total hydrocarbon concentration in the water column was predicted to decrease as the release moves downstream of the dam, due to the buoyant rise of whole oil droplets to the surface in the relatively quiescent waters downstream. This process was predicted to be repeated at the Blanchard Dam. More Bakken crude oil is predicted to be entrained than the CLB.

At the end of the 24 hour simulation, the thickness of the floating CLB was predicted to range from 0.004 to 0.04 in. on the water surface, with localized areas possibly exceeding 0.04 in. Slicks of Bakken crude oil were predicted to be generally thinner overall, but by the end of the 24-hour simulation, floating oil thicknesses between 0.004 and 0.04 in. could exist. Colorless and silver sheens and rainbow sheens that are less than 0.00004 in. could also remain in some areas. As a result of the predicted areal extent of the surface oil slicks, oil floating on the river was predicted to evaporate rapidly over the 24 hour simulation.

Based on SIMAP simulations, most of the dissolved aromatic concentrations associated with the CLB and Bakken crude oil were predicted to be between 1 and 100 ppb. However, brief pulses of concentrations between 1,000 and 5,000 ppb for CLB, or 1,000 and greater 5,000 ppb for Bakken crude oil, were predicted to occur within 24 hours after the release, but in extremely patchy and localized extents within the Mississippi River.

Extensive shoreline oiling was predicted for CLB and Bakken crude oil for approximately 29 or 30 miles of the river below the release location under high river flow conditions. The concentrations of CLB on the shore were predicted to be primarily greater than 500 g/m^2, with some segments between 100 and 500 g/m^2. In contrast, concentrations of Bakken crude oil on the shore were predicted to be generally lower, and range from 100-500 g/m^2 but with nearly equal lengths of shoreline exceeding 500 g/m^2. In general, Bakken resulted in less extensive shoreline oiling than the CLB.

When oil is mixed through the water column by turbulent mixing processes such as waterfalls at dams, there is a high potential for dissolved oil to interact with (i.e., to become adsorbed to) suspended sediments, or for suspended sediments to interact with small crude oil droplets suspended in the water (i.e., for oil-particle aggregates to form). Under the high flow scenario for CLB, substantial oiling of the bed sediment was predicted along approximately 24 miles of river bottom below Little Falls Dam, with concentrations between 0.01 and 0.5 g/m^2. In patchy and localized portions of the Mississippi River downstream of the waterfalls, sediment concentrations are predicted to exceed 500 g/m^2. However, over the larger area, the majority of sediment oiling is predicted to be much lower in concentration. In terms of Bakken crude oil, approximately 30 miles of river bottom were predicted to have sediment oiling less than 0.01 g/m^2, with some localized areas experiencing 0.01–0.5 g/m^2. Below Blanchard Dam, after the second waterfall, entrained oil and further mixing with suspended particulate matter, some patchy and localized portions of the river bottom may have sediment concentrations between 1 and 10 g/m^2 with values as high as 10–50 g/m^2 in very small areas. In general, Bakken was more easily entrained into the water column due to its lower viscosity. However, the overall quantity of oil interacting with suspended sediments was lower than the CLB.

7.8.5.2 Mississippi River near Little Falls Release During Average Flow (Summer–Fall) Period

Under the average flow scenario, CLB was predicted to travel approximately 10, 17, 25, and 30 miles downstream in the Mississippi River after 6, 12, 18 and 24 hours (Figure 7-51). By 24 hours after the hypothetical release, a portion of the released crude oil (31.1%) was predicted to remain on the surface of the Mississippi River, with 20.7% evaporating, 44.2% adhering to shorelines and 2.8% mixing in the water column. Less than 1% was predicted to deposit to sediment or be broken down through photo-oxidation and biodegradation (Figure 7-51). Bakken crude oil was predicted to follow the same general downstream transport pattern as CLB (Figure 7-52). By 24 hours after the hypothetical release, the majority of Bakken crude oil was predicted to evaporate (54.4%), with 17.1% remaining on the river surface, 21.2% adhering to shorelines and 6.8% mixing in the water column. A negligible amount (less than 0.1%) of the Bakken crude oil was predicted to deposit to sediment and less than 1% was predicted to be broken down through photo-oxidation and biodegradation (Figure 7-52).

As described for the spring freshet, as the hypothetical releases pass over the Little Falls and Blanchard Dams (4.8 and 14.4 hours after the hypothetical release), it was predicted that there would be substantial entrainment of crude oil into the river water. Entrained oil droplets in the water column are predicted to rise to the surface in subsequent quiescent reaches of the Mississippi River. Above the Little Falls Dam, predicted total hydrocarbon concentrations in the river water were very low, as the oil would be floating on the surface. However, downstream of the Little Falls Dam, the dissolved aromatic hydrocarbon concentration in the water column is predicted to increase, as oil droplets forced into the water column enable the soluble portion to dissolve into the water. The total hydrocarbon concentration in the water column was predicted to decrease as the release moves downstream of the dam, due to the buoyant rise of whole oil droplets to the surface in the relatively quiescent waters downstream. This process was predicted to be repeated at the Blanchard Dam. More Bakken crude oil is predicted to be entrained than the CLB.

During average river flow conditions, the relatively calm waters upstream and downstream of the Little Falls Dam and Blanchard Dam was predicted to result in large surface slicks over much of the river. At the end of the 24-hour simulation, floating CLB thicknesses ranged between 0.004 and 0.04 in. on the water surface, with localized areas exceeding 0.04 inches. Bakken crude oil slicks were generally thinner than CLB, and by the end of the 24-hour simulation, floating oil thicknesses between 0.004 and 0.04 in. (but in some areas less than 0.00004 in. representing colorless and silver sheens and rainbow sheens) could remain. As a result of the large surface oil slicks, oil floating on the river was predicted to evaporate rapidly over the 24 hour simulation.

Based on SIMAP simulations, most of the dissolved aromatic concentrations associated with the CLB and Bakken crude oil were predicted to be between 1 and 100 ppb. However, brief pulses of concentrations between 500 and 1,500 ppb for CLB, and between 500 and greater than 5,000 ppb for Bakken crude oil, were predicted to occur 24 hours after the release, and in extremely patchy and localized extents within the Mississippi River.

Extensive shoreline oiling was predicted for CLB and Bakken crude oil for approximately 29 or 30 miles of the river below the release location under high river flow conditions. The concentrations of CLB on the shore were predicted to be primarily greater than 500 g/m^2, with some segments between 100 and 500 g/m^2. In contrast concentrations of Bakken crude oil on the shore were predicted to be generally lower, and range from 100-500 g/m^2 but with nearly equal lengths of shoreline exceeding 500 g/m^2. In general, Bakken resulted in less extensive shoreline oiling than the CLB.

When oil is mixed through the water column by turbulent mixing processes such as waterfalls at dams, there is a high potential for dissolved oil to interact with (i.e., to become adsorbed to) suspended sediments, or for suspended sediments to interact with small crude oil droplets suspended in the water (i.e., for OPAs to form). Under the average flow scenario for CLB, substantial oiling of the bed sediment was predicted along approximately 30 miles of river bottom below Little Falls Dam, with concentrations between 0.01 and 0.5 g/m^2. In patchy and localized portions of the Mississippi River downstream of the waterfalls, sediment concentrations are predicted to exceed 500 g/m^2. However, the majority of sediment oiling is much lower in concentration over the larger area with any amount of potential oil on the sediments. In terms of Bakken crude oil, approximately 30 miles of river bottom were predicted to have sediment oiling less than 0.01 g/m^2, with some localized areas experiencing 0.01–0.5 g/m^2. Below Blanchard Dam the second waterfall is predicted to entrain and further mix the oil with suspended sediment; as a result, some patchy and localized portions of the river bottom may have sediment concentrations between 1 and 10 g/m^2 with values as high as 10–50 g/m^2 in very small areas. In general, Bakken was more easily entrained into the water column due to its lower viscosity. However, the overall quantity of oil interacting with suspended sediment was lower than the CLB.

7.8.5.3 Mississippi River near Little Falls Release During Low Flow (Winter) Period

Under the low flow scenario, CLWB was predicted to travel downstream in the Mississippi River approximately 5.5 miles at all four of the time points (6, 12, 18 and 24 hours) (Figure 7-51). As a result, the oil release would not encounter either of the waterfalls created by the two dams. By 24 hours after the hypothetical release, almost all of the released crude oil (97.0%) was predicted to remain on the surface of the Mississippi River (i.e., at the ice/water interface). Very little of the released crude oil was predicted to evaporate or undergo degradation within 24 hours. Less than 1% of the release was predicted to mix into the water column (i.e., little or no entrainment), adhere to shore lines, or deposit to sediment (Figure 7-51). Where CLWB was predicted on the shorelines, oiling was patchy between 1 and 2 miles downstream from the release point. Concentrations of CLWB on the shore were predicted to be predominantly in the range of 1 to 100 g/m^2, with some segments of the shoreline between 100 and 500 g/m^2, and others exceeding 500 g/m^2.

Under the low flow scenario Bakken crude oil was predicted to travel downstream in the Mississippi River approximately 2.1 miles at all four of the time points (6, 12, 18 and 24 hours) (Figure 7-52). This distance is less than that of the CLWB and is the result of the difference in oil density. Bakken crude oil is less dense than CLWB and would be expected to rise through the water column more rapidly after a release than the CLWB. As a result, lighter oils are predicted to spend less time in the water column than heavier oils, travel a lesser distance downstream, and rise to the surface and adhere to the underside of the ice more quickly. By 24 hours after the release, almost all of the released crude oil (97.4%) was predicted to remain on the surface of the Mississippi River (i.e., at the ice/water interface). Very little of the released crude oil was predicted to evaporate or undergo degradation within 24 hours. Approximately 1.6% of the release was predicted to mix into the water column (Figure 7-52). Negligible amounts (less than 0.1%) of the Bakken crude oil are predicted to deposit to sediment, evaporate, or adhere to shoreline (Figure 7-52). Under low flow conditions the 100% surface coverage was with ice was predicted to keep the entrained oil in the water column at the ice/water interface. Extremely patchy oiling along river banks was predicted downstream from the release point, with concentrations on the shoreline less than 1 g/m^2. Extremely small amounts of oil could be found on the sediments, with most concentrations falling less than 0.01 g/m^2. The soluble portion of the CLWB was predicted to dissolve into the water column and be transported downstream, resulting in elevated dissolved aromatic concentrations within the water column. By 24 hours after the hypothetical release, dissolved aromatic components were predicted to travel downstream from the initial release location with maximum concentrations greater than 5,000 ppb in the region between 1 and 3 miles of release location. Bakken crude oil was predicted to have maximum concentrations of dissolved components greater than 5,000 ppb directly under the oil trapped under the ice. Much larger portions of the river are predicted to experience dissolved aromatic concentrations in excess of 5,000 ppb, when compared to average or high flow scenarios.

At the end of the 24-hour simulation, both types of floating oil under the ice had a predicted thickness greater than 0.04 in. THCs on the bed sediment were generally less than 0.01 g/m^2 for both CLWB and Bakken crude oil due to the small amount of suspended sediment in the water column.

7.8.6 Qualitative EHHRA for the Mississippi River near Little Falls

In this section, the likely environmental effects of a crude oil release at the pipeline crossing location on the Mississippi River are described. A worst case crude oil release from a main-line pipeline, such as described here, would be an unlikely event (Chapter 4.0). The proposed pipeline could carry a variety of crude oil types, ranging from very light (e.g., Bakken crude oil) to heavy (e.g., diluted bitumen such as CLB). Therefore, the following discussion is based on the likely environmental effects of a crude oil release on relevant ecological and human environment receptors (identified in Section 7.8.3), using the predicted geographic extent of effects of released Bakken or CLB crude oil types over the 24 hour simulations as bounding conditions. Effects of season (including temperature, river flow conditions, and receptor presence/absence and sensitivity) were also considered in the analysis. The rationale supporting the effects analysis, based on case studies describing the effects of crude oil releases on the various ecological and human environment receptors, was provided in Section 7.1 and Table 7-84.

7.8.6.1 Terrestrial Receptors

For this modeling scenario, the hypothetical release of crude oil is assumed to enter into the Mississippi River with no overland flow. Environmental effects on soils, terrestrial vegetation and groundwater quality are assumed to be localized, limited in spatial extent, and readily remediated using conventional clean-up techniques. The environmental effects of a crude oil release on land cover receptors are not considered further for this release scenario.

7.8.6.2 Aquatic Receptors

The aquatic environmental and ecological receptors that are most closely associated with the Mississippi River at Little Falls scenario are addressed in this section. These receptors include water and sediment quality in the river, shoreline and riparian habitat, benthic invertebrates, and fish.

Crude oil released into the Mississippi River during the spring (high flow) or summer-fall (average flow) seasons is predicted to travel downstream, interacting with vegetation and seasonal shoreline areas. Based on SIMAP simulations, CLB and Bakken crude oil were predicted to follow the same downstream transport pattern. Each oil type is predicted to reach approximately 30 miles downstream within 24 hours after a release. In sections of the river above and below the Little Falls Dam and Blanchard Dam, large amounts of floating oil are predicted. CLB thickness was predicted to range from 0.004 to 0.04 in. on the water surface, with localized areas possibly exceeding 0.04 inch Bakken crude oil slicks were predicted to have the same thicknesses (between 0.004 and 0.04 inch), although in some areas less than 0.00004 inch could remain.

The effects of a crude oil release on benthic invertebrates and fish would depend on the characteristics of the released oil, and environmental conditions at the time of the release. Acute toxicity to fish is commonly, but not always observed in association with crude oil releases, and is an indicator that, at least briefly, concentrations of dissolved hydrocarbons (particularly mono-aromatic hydrocarbons, some low molecular weight PAHs, and short-chain aliphatic hydrocarbons) are sufficiently high to cause acute toxicity due to narcosis. The potential for entrainment of CLB and Bakken crude oil into the water column during high and average river flow conditions was predicted to be high, particularly as the crude oil passes the Little Falls Dam, and then the Blanchard Dam, along with the associated rapids downstream. Based on SIMAP simulations, most of the dissolved aromatic concentrations associated with the Cold Lake Blend and Bakken crude oil under spring and summer conditions were predicted to be between 1 and 100 ppb. However, brief pulses of concentrations between 500 and 1,500 ppb for CLB, and between 500 and greater than 5,000 ppb for Bakken crude oil, were predicted to occur 24 hours after the release, but in extremely patchy and localized extents of the Mississippi River.

French McCay (2002) proposed a benchmark lethal concentration (LC50) value of 224 ppb (µg/L) for sensitive aquatic species exposed indefinitely to total aromatic hydrocarbons from crude oil. For species of average sensitivity, a threshold of 1,869 ppb was reported. Given exposure of shorter duration (i.e., less than one day), a considerably higher concentration (perhaps two to three times higher) would be required to result in the death of even sensitive species. Therefore, the predicted transient exposure concentrations for dissolved aromatic hydrocarbon compounds in the river water could result in acute lethality to sensitive fish species, or to species that have average sensitivity to hydrocarbons. However, the majority of predicted dissolved aromatic concentrations were less than 500 ppb. Therefore, the potential for toxicity to fish would be greatest in the areas downstream of the two dams, with lower potential elsewhere.

Some of the entrained crude oil in the water column could interact with suspended particulate matter leading to the deposition of crude oil to sediment. Under the average flow scenario for CLB, substantial oiling of the bed sediment was predicted along approximately 30 miles of river bottom below Little Falls Dam, with concentrations between 0.01 and 0.5 g/m^2 with concentrations of Bakken crude oil less than 0.01 g/m^2, but with some localized areas experiencing 0.01-0.5 g/m^2. In patchy and localized portions of the Mississippi River downstream of the waterfalls, sediment concentrations are predicted to exceed 500 g/m^2 for CLB (but with limited spatial and temporal extent) and between 1 and 10 g/m^2 (but as high as 10–50 g/m^2 in very small areas) for Bakken crude oil.

With limited mixing of crude oil into river bed sediments to a depth of less than 0.5 in., crude oil deposition of less than 0.1 g/m^2 is likely to be undetectable and without any ecological consequence. Crude oil deposition to sediment of less than 1 g/m^2 would result in sediment hydrocarbon concentrations that would be less than 100 ppm (mg/kg). These low concentrations would also be unlikely to result in significant environmental effects on fish, benthic invertebrates, or other aquatic life. Crude oil deposition to sediment of greater than 50 g/m^2 would be expected to cause reduced community diversity, biomass and productivity. As a result, based on the SIMAP model results, the predicted crude oil deposition to sediments is not expected to be toxic to benthic invertebrates. Any such effects would be of short duration and limited to patchy areas within the trajectory of the oil release. Adverse environmental effects on benthic communities are more likely for CLB crude oil types rather than Bakken crude oil.

The potential for chronic effects of released crude oil on fish eggs and embryos (i.e., induction of deformities or mortality collectively termed blue sac disease) under high and average river flow conditions is expected to be low. While the eggs and embryos of these species could be exposed to total PAH concentrations in the river water that could be sufficiently high to induce deformities or cause mortality, these areas are of limited spatial extent and transitory. The potential for blue sac disease would be greatest for a crude oil release in winter or during the spring freshet, as crude oil could be dispersed into side-channel and oxbow habitat that is important for spawning fish. While local accumulations could result in adverse effects on developing fish eggs and embryos in the first season following an accidental crude oil release, it is not likely that such effects would persist beyond one year, and effects would occur in only a limited area of the river. Therefore, at the scale of the Mississippi River in Minnesota, it is not likely that such effects would be detectable at a population level.

The potential for phototoxicity caused by an interaction of UV light with PAHs accumulated in fish tissues would be greatest for a crude oil release in summer due to high light intensity and long day length. Small fish that are lightly pigmented or transparent (i.e., embryos, larval and juvenile fish) are most susceptible to phototoxicity. The risk of phototoxicity would be partially mitigated by high concentrations of suspended sediment and DOC present in the water of the Mississippi River, which would absorb and limit the penetration of UV light into the water column.

During low flow winter conditions, if the release was to occur directly to the river below the ice (as is assumed in the SIMAP model), or if there were openings in the ice that the released oil could penetrate, the oil could travel downstream under the ice, accumulating in the narrow gap between the ice and the river sediment, or accumulating in hollows under the ice as it moved. Results provided in Section 7.8.5.3 provide bounding cases for the products likely to be carried in the pipeline. The SIMAP simulations indicate that heavy crude oil could be carried farther downstream than light oil (i.e., 5.5 miles vs. 2.1 miles from the point of release) under winter low-flow conditions. At the end of the 24 hour simulation, floating oil of both types is predicted to have a general thickness greater than 0.04 inches beneath the ice. For both oil types, the winter ice would effectively inhibit evaporation. Bakken crude oil is less dense than CLWB and would be expected to rise through the water column more rapidly after a release than the CLWB. As a result, light oil would spend less time in the water column than heavier oil, and is predicted to have less dissolution into the water column during the period of lowest dilution flow than heavier oil.

Based on SIMAP simulations run for 24 hours, most of the dissolved aromatic concentrations associated with the CLWB were predicted to be between 1 and 500 ppb and within the first 1 to 3 miles downstream of the hypothetical release site. However, areas having dissolved aromatic hydrocarbon concentrations greater than 5,000 ppb were predicted to occur within this 24 hour period for both crude oil types. Short-term exposure to these concentrations of dissolved aromatic hydrocarbons from crude oil could result in mortality of fish species, particularly under the winter, low flow condition.

7.8.6.3 Semi-Aquatic Wildlife Receptors

Habitat along the Mississippi River downstream of the hypothetical release location supports amphibians (e.g., frogs, salamander), reptiles (e.g., turtles, snakes), birds (e.g., ducks, geese, shorebirds, raptors), and semi-aquatic mammals (e.g., muskrat, beaver, mink and otter). Details on predicted environmental effects for amphibians and reptiles, birds and mammals are provided below.

7.8.6.3.1 Amphibians and Reptiles

Crude oil released to the Mississippi River during the spring (high flow) or summer-fall (average flow) seasons would be predicted to travel downstream, interacting with vegetation and seasonal shoreline areas. Based on SIMAP simulations, CLB crude oil and Bakken crude oil were predicted to follow the same downstream transport pattern (each predicted to reach approximately 30 miles downstream 24 hours after a release). In sections of the river above and below the Little Falls and Blanchard dams, large amounts of floating oil are predicted with slicks between 0.004 and 0.04 in. on the water surface. A greater amount of CLB is predicted to remain on the surface of the Mississippi River after 24 hours compared to Bakken crude oil (e.g., approximately 31 to 38% vs. 17 to 22%).

Within the oil-exposed habitats along the river that support amphibians (adults, juveniles, and eggs), oiling effects including mortality would be observed. There is little or no relevant wetland habitat in the vicinity of the predicted release trajectory, so exposures would likely be limited to shorelines and riparian habitats. Turtles appear to be relatively tolerant of external crude oil exposure, and although these animals are likely to become oiled, mortality of turtles as a result of this exposure is not likely. Reptiles like lizards and snakes are primarily terrestrial species and are less intimately associated with aquatic environments. As a result, exposure of these animals to released crude oils would be limited.

Amphibians and reptiles undergo a winter dormancy period when temperatures drop below approximately 41 to 45°F. At this time, amphibians and turtles typically bury themselves in river bottom substrates or other similar habitats. Therefore, during the winter (and likely up until April or May when winter ice is gone), these organisms would have very little exposure to released oil moving on the water surface or within the water column.

7.8.6.3.2 Birds

Aquatic and semi-aquatic birds are those that use rivers, lakes, wetlands, and riparian areas as components of their habitat, particularly for nesting and feeding. These birds belong to a variety of guilds including but not limited to waterfowl, divers, gulls and terns, raptors, shorebirds, waders, and some songbirds. They have a variety of dietary preferences, including piscivory, insectivory, omnivory and herbivory. If exposed to external oiling, the ability of birds to maintain body temperature may be compromised, leading to death as a result of hypothermia. Even if they survive their initial exposure to crude oil, the exposure may require an increase in metabolic rate to survive. In turn, this may compromise other life functions such as reproduction or growth. Birds that survive external oiling may experience toxicological stresses as a result of ingesting crude oil residues while preening or attempting to clean and restore the normal properties and functions of feathers. Birds can also transfer potentially lethal quantities of crude oil residue from their feathers to the external surface of eggs, resulting in death of developing embryos.

Unlike many other vertebrate receptors, aquatic bird species in the northern temperate zone are nearly all seasonal migrant species which leave their summer (and often breeding) habitat in the fall for wintering areas farther south where they can find open-water habitat. However, some birds (e.g., Canada goose) will opportunistically remain in freezing conditions if there is reliable open water (e.g., immediately downstream of the two dams) and a source of food available). Timely capture and rehabilitation of oiled birds may help to mitigate the environmental effects of a crude oil release. During the spring (high flow) season, many migratory birds would be returning to riverine and lacustrine habitats in Minnesota, or migrating through these areas on their way to breeding habitats farther north. With cold water temperatures prevailing, aquatic and semi-aquatic birds contacted by crude oil are likely to die as a result of hypothermia. Waterfowl and other semi-aquatic birds present in the affected river reach would be most affected. Animals upstream, farther downstream, or occupying other nearby habitats, would likely be less affected as it is assumed that emergency response measures to prevent or reduce further possible downstream transport of oil would be in place within 24 hours of the release.

Some areas of the Mississippi River below Little Falls, Minnesota would provide excellent habitat for a variety of waterfowl species, as well as fish-eating raptors, and other species such as kingfisher, herons and shorebirds. The environmental effects of a crude oil release in the spring and the summer-fall period are likely to be of similar magnitude. With rising water temperatures, mortality of lightly oiled adult birds due to hypothermia becomes less likely than in the spring, and the temporary presence of large numbers of migrating individuals is unlikely. However, in the early summer, environmental effects could include egg mortality due to transfer of oil from the feathers of lightly oiled adult birds in the nest, or mortality of young birds due to direct oil exposure or the loss of a parent bird. Chronic adverse effects on the health of birds that survive their initial exposure to crude oil are also possible as a result of ingesting crude oil residues while preening, or while consuming food items. However, as in the spring, effects are expected to be limited to areas of oil exposure. Potential effects on aquatic and semi-aquatic birds in the fall would be similar to those in spring, although a smaller overall length of river habitat would be affected due to lower river flows. While the death of these birds would be a serious environmental effect locally, longer-term population-level effects on semi-aquatic birds are not likely to be observed given the length of the Mississippi River in Minnesota, and the abundance of other wetland, lake, river and riparian habitat in the region and state.

Under winter conditions (March), it was assumed that the Mississippi River would be frozen (100% ice cover). In addition, most waterfowl and other semi-aquatic bird species would migrate south in the winter. However, some birds (e.g., Canada goose, eagles) will opportunistically remain in freezing conditions if there is reliable open water and a source of food available. Areas of the Mississippi near the Little Falls and Blanchard Dam could provide these areas of open water. Timely capture and rehabilitation of oiled birds may help to mitigate the environmental effects of a crude oil release. A crude oil release in winter would be expected to have very limited effects on birds.

7.8.6.3.3 Semi-aquatic Mammals

While the semi-aquatic mammal species found in Minnesota include terrestrial species such as moose and raccoon, this assessment focuses particularly on species that have a primary association with the aquatic environment such as muskrat and beaver (herbivores), American mink (carnivore-piscivore), and river otter (piscivore). These species are at greater risk of exposure to an oil release in water than more fully terrestrial mammals.

Effects to semi-aquatic mammals are typically described in terms of direct physical effects (e.g., hypothermia due to loss of insulation), direct toxicological effects (e.g., gastro-enteropathy caused by ingestion of crude oil residues while grooming oiled fur or ingesting food), and indirect effects caused by changes to habitat (e.g., land cover and food availability). The spatial extent along the Mississippi River where effects may occur, and the magnitude of effects, is related to the season and river flow rate, and the type of oil released. Effects to semi-aquatic mammals relate more to the amount of time spent in the water and oil-contaminated riparian habitat (and consequent exposure to physical oiling) than to dietary preferences. Timely capture and rehabilitation of oiled mammals may help to mitigate the environmental effects of a crude oil release.

During the spring (high flow) season, with cold water temperatures prevailing, semi-aquatic mammals contacted by crude oil are likely to die as a result of hypothermia. Animals upstream, farther downstream where there is no exposure, or occupying other nearby habitats, would likely be unaffected. Therefore, although mortality of a considerable number of semi-aquatic mammals could be expected at a local scale, large-scale (i.e., regional) population level effects are unlikely. Environmental effects of a crude oil release in the summer-fall period are likely to be of a magnitude similar to or lesser than those associated with a release during spring. With rising water temperatures, mortality of lightly oiled semi-aquatic mammals due to hypothermia is less likely than in the spring. Chronic adverse effects on the health of semi-aquatic mammals that survive their initial exposure to crude oil are possible as a result of ingesting crude oil residues while grooming, or while consuming food items. However, as in the spring, effects are expected to be limited to areas of oil exposure. While the death of these animals would be a serious environmental effect locally, longer-term population-level effects on semi-aquatic mammals are not likely to be observed given the length of the Mississippi River in Minnesota, and the abundance of other wetland, lake, river and riparian habitat in the region and state.

In the winter months, muskrat and beaver are likely to reduce their activity levels, although American mink and river otter would remain active. Animals that became oiled in the winter would be likely to rapidly die as a result of hypothermia.

7.8.6.4 Human and Socio-Economic Receptors

Crude oils are complex mixtures of hydrocarbon compounds. Light crude oils typically contain more VOCs than heavier crude oils, although diluted bitumen may contain similar amounts of VOCs to light crude oils, depending upon the type and amount of diluent they contain. Air quality in the vicinity of a crude oil release, and along the downstream corridor, would be affected by the release of VOCs (such as benzene, which is often used as an indicator substance) primarily within the first 24 hours of an oil release.

Based on SIMAP simulations, CLB and Bakken crude oil were predicted to follow the same downstream transport pattern, with each predicted to reach approximately 30 miles downstream 24 hours after a release. As a result, both oil types are predicted to pass through the community of Little Falls, Minnesota (population of approximately 8,500 people) and pass along the western border of the community of Rice, Minnesota (population of approximately 1,275 based on 2010 census).

Typical human health effects associated with short-term (acute) inhalation of volatiles from crude oil include headache, dizziness, nausea, vomiting, cough, respiratory distress, and chest pain. Short-term or repeated skin contact with crude oil may result in dermatitis. The case studies (Section 7.1) do not reveal any instances of human fatality as a result of inhalation of crude oil vapor. Similarly, ATSDR (1995) report that there are no known instances of human fatality as a result of inhalation of vapor from fuel oils, which would be comparable to light crude oils.

If a crude oil release was to occur in winter, and to be confined below ice on the river, very little of the volatile hydrocarbon present in the oil would be released to the atmosphere as VOCs. The potential for VOC inhalation exposures to the public would be greatest in the spring and summer-fall seasons, near and downwind from the release site, while the released oil is on the water surface. In the unlikely event of a crude oil release, nearby residents would become aware of a strong hydrocarbon odor that would alert them to the presence of a hazard. Most of the volatile hydrocarbons would be lost within the first 24 hours following a release of crude oil. It is also expected that emergency response personnel would contact such residents and advise them to evacuate. Actual or potential exposure to crude oil vapor may result in residents leaving, or being advised to leave their homes for a period of time while the emergency response takes place.

Drinking water for the communities of Little Falls and Rice is drawn from groundwater sources by city owned and operated wells. Therefore, the water supplies for residents of Little Falls and Rice are not likely to be affected by a release. In addition, no drinking water HCAs were identified along the path of the release. However, in the event of a crude oil release, people would be notified and testing would be completed to confirm the safety of the water supply. Based upon case studies involving crude oil releases elsewhere, this process could take a few days to two weeks, but reports of crude oil releases affecting private wells are rare, making this an unlikely effect.

Relatively little has been published regarding the long-term effects of human exposure to a crude oil release. Health effects observed in residents and clean-up workers in the months following such releases generally do not persist over the long term (Eykelbosh 2014). The International Agency for Research on Cancer (IARC 1989) has determined there is "limited evidence of carcinogenicity" of crude oil in experimental animals and "inadequate evidence of carcinogenicity" of crude oil in humans. Although toxicological effects from short-term exposure to volatile hydrocarbons are reversible when exposure is reduced, other health effects such as anxiety and depression may occur, and may persist, regardless of whether the individual was physically exposed to hydrocarbons.

No overland transport of released crude oil was modelled for this hypothetical release location. Infiltration of crude oil into soil and subsequently into groundwater is assumed to be negligible.

Downstream of the hypothetical release site, the Mississippi River flows through the Zebulon Pike Lake (reservoir), and past several parks (e.g., Le Bourget Park, James Green Park, Maple Island Park, Mill Park, and Charles A. Lindbergh State Park), as well as the McDougall and Michaelson Farms WMAs. These locations provide a number of recreational opportunities. Effects on air and water quality, or the presence of crude oil residues in the sediment or habitat, could potentially disrupt public use of natural resources (e.g., drinking water supplies, hunting, fishing, recreation).

Emergency response workers, in cooperation with public health and safety officials, would be active in isolating, containing and recovering released crude oil, as well as notifying the public about the release. Recreational activities would be disrupted following a release of crude oil along the predicted downstream trajectory of the release. Fisheries regulators and public health officials typically close fisheries until it is confirmed through monitoring that fish consumption is not a threat to public health. This standard approach is an effective mitigation strategy to protect human receptors for contact with constituents in the oil.

7.8.6.5 Summary and Conclusions

Expected environmental effects to key ecological and human environment receptors after a hypothetical large crude oil release to the Mississippi River near Little Falls, Minnesota have been assessed. The proposed pipeline could carry a variety of crude oil types, ranging from very light (e.g., Bakken crude oil) to heavy (e.g., diluted bitumen such as CLB). The discussion of expected environmental effects on receptors is based on these crude oil types as bounding conditions. Potential terrestrial receptors, aquatic receptors, semi-aquatic wildlife receptors and human and socio-economic receptors were screened to identify those with the most likely interactions with released oil. The results of this assessment are summarized in Table 7-86.

Table 7-86 Environmental Effects Summary Table for Pipeline Crude Oil Releases to the Mississippi River at Little Falls

Receptor	Expected Environmental Effects of Released Crude Oil to the Mississippi River at Little Falls	Relative Effect	
		Light Crude Oil	Diluted Bitumen
Terrestrial Receptors			
Soils	It is assumed in the model that crude oil would enter directly into the Mississippi River with no holdup of oil on land. In the event of an actual oil release, any oil on land would undergo prompt and effective remediation. Residual effects on plant communities, soil or groundwater quality are unlikely.	SAME	SAME
Groundwater		SAME	SAME
Terrestrial Vegetation		SAME	SAME
Aquatic Receptors			
Rivers (Mississippi River)	Both light and heavy oil would travel downstream from the release location, affecting the Mississippi River. In spring and summer, both light (Bakken) and heavy (CLB) crude oil types are predicted to display similar downstream transport patterns. Both are predicted to reach approximately 30 miles downstream within 24 hours after a release, and to form slicks of similar thickness (between 0.004 inches and greater than 0.04 inches). During spring (high flow) and summer-fall (average flow) seasons, relatively more of the CLB is predicted to remain on the surface of the Mississippi River after 24 hours (31 to 38% vs. 17 to 22%), adhere to shorelines (37.5 to 44.2% vs 18.5 to 21.2%) and deposit to sediment (0.5% vs <0.1%). However, slightly more of the less viscous Bakken crude oil is predicted to mix and dissolve into the water column as compared to the CLB (e.g., approximately 6.8 to 8% vs 2.8 to 4.2%). In winter, simulations indicate that CLWB could be carried slightly farther downstream than the Bakken oil (i.e., 5.5 miles vs. 2.1 miles from the point of release), but the area affected by the highest dissolved aromatic hydrocarbon concentrations in water would be slightly larger for the Bakken oil than for the CLWB.	MORE	LESS
Sediment	In all three seasons, slightly more of the CLB is predicted to deposit to sediment than Bakken crude oil (e.g., approximately 0.5% vs <0.1%). In patchy and localized portions of the Mississippi River downstream of the waterfalls, sediment concentrations are predicted to exceed 500 g/m^2 for CLB (but with limited extent) and between 1-10 g/m^2 (but as high as 10-50 g/m^2 in very small areas) for Bakken crude oil. Contact between the weathered diluted bitumen and shorelines is also likely to result in mixing of mineral particles into the crude oil, which could then be deposited to sediments as aggregates of oil and mineral in larger droplets or globules. If not recovered, these aggregates could move downstream with bedload until a stable depositional environment was reached.	LESS	MORE

Table 7-86 Environmental Effects Summary Table for Pipeline Crude Oil Releases to the Mississippi River at Little Falls

Receptor	Expected Environmental Effects of Released Crude Oil to the Mississippi River at Little Falls	Relative Effect	
		Light Crude Oil	Diluted Bitumen
Shoreline and Riparian Areas	Both light and heavy oil would travel downstream from the release location, affecting the Mississippi River. Both Bakken and CLB crude oil types are predicted to exhibit similar downstream transport patterns (each predicted to reach approximately 30 miles downstream within 24 hours after a release). During spring (high flow) and summer-fall (average flow) seasons, a greater amount of CLB is predicted to adhere to shorelines (i.e., 37.5 to 44.2% for CLB vs. 18.5 to 21.2% for Bakken) 24 hours following the hypothetical release. Flooding of riparian habitats in spring could lead to stranding of crude oils in these habitats, with heavy crude oil likely to be deposited as patties or tar balls, which would be persistent, in contrast to light crude oil which would be deposited as a thin layer or sheen.	LESS	MORE
Benthic Invertebrates	In all three seasons, slightly more of the CLB is predicted to deposit to sediment than Bakken crude oil (e.g., approximately 0.5% vs <0.1%). In patchy and localized portions of the Mississippi River downstream of the two waterfalls, sediment concentrations are predicted to exceed 500 g/m^2 for CLB (but with limited extent) and between 1-10 g/m^2 (but as high as 10-50 g/m^2 in very small areas) for Bakken crude oil. Crude oil deposition to sediment of >50 g/m^2 would be expected to cause reduced community diversity, biomass and productivity. As a result, based on the SIMAP model results, the potential for crude oil deposition to sediments that would be toxic to benthic invertebrates is expected to be low. However, adverse environmental effects on the benthic community could be seen in patchy and localized areas of the Mississippi River, albeit briefly. Contact between the weathered diluted bitumen and shorelines is also likely to result in mixing of mineral particles into the crude oil, which could then be deposited to sediments as aggregates of oil and minerals in larger droplets or globules. If not recovered, these aggregates could move downstream with bedload until a stable depositional environment was reached. However, neither of the bounding oil types is predicted to be deposited to sediments at concentrations that would seriously affect aquatic life.	SAME	SAME

Table 7-86 Environmental Effects Summary Table for Pipeline Crude Oil Releases to the Mississippi River at Little Falls

Receptor	Expected Environmental Effects of Released Crude Oil to the Mississippi River at Little Falls	Relative Effect	
		Light Crude Oil	Diluted Bitumen
Fish	Environmental effects on fish would be limited to areas affected by the released oil. In spring and summer-fall conditions, both light and heavy oil are predicted to reach approximately 30 miles downstream within 24 hours after a release. On average, about twice as much of the Bakken crude oil type was predicted to dissolve into the water than was predicted for the CLB. The maximum concentration of dissolved aromatics from both oil types was locally greater than 1,000-5,000 ppb, but suggested a transient exposure of less than 24 hours duration. This concentration range and duration of exposure could result in acute lethality to sensitive aquatic species and species with average sensitivity to hydrocarbons. In winter, the effects of the Bakken crude oil on fish were also predicted to be slightly more severe than was the case for CLB.	MORE	LESS
Semi-Aquatic Wildlife Receptors			
Amphibians and Reptiles	Both light and heavy oil would travel downstream from the release location, affecting the Mississippi River. Lighter crude oils and heavier crude oils are predicted to follow the same downstream transport pattern (each predicted to reach approximately 30 miles downstream within 24 hours after a release), and form slicks of similar thickness (between 0.004 inches and greater than 0.04 inches). Flooding of riparian habitats in spring could lead to stranding of crude oils in these habitats, with heavy crude oil likely to be deposited as patties or tar balls, which would be persistent, in contrast to light crude oil which would be deposited as a thin layer or sheen. Within these habitats, oiling effects on adults, juveniles, and eggs could potentially be observed. Higher potential would exist for effects on amphibians than for turtles, which appear to be somewhat tolerant of external oiling. Dormancy of amphibians and reptiles in winter and early spring means exposure to oil released at this time of year could be negligible, and adverse environmental effects unlikely.	SAME	SAME
Birds	Mortality of oiled aquatic and semi-aquatic birds would occur in areas affected by the released oil. Both light and heavy crude oil types are predicted to travel similar distances, and both would form slicks of similar thickness. During the spring high flow season, many migratory birds would be returning to riverine and lacustrine habitats in Minnesota, or migrating through these areas on their way to breeding habitats farther north. Few birds are present in winter, so effects would be lower in that season.	SAME	SAME

Table 7-86 Environmental Effects Summary Table for Pipeline Crude Oil Releases to the Mississippi River at Little Falls

Receptor	Expected Environmental Effects of Released Crude Oil to the Mississippi River at Little Falls	Relative Effect	
		Light Crude Oil	Diluted Bitumen
Semi-aquatic Mammals	Mortality of oiled semi-aquatic mammals would be limited to areas affected by the released oil. Both light and heavy crude oil types are predicted to travel similar distances, and both would form slicks of similar thickness. Adverse effects on mink and otter would be particularly severe in winter, due to the effects of oil in the insulating properties of fur, in combination with cold water temperatures. However, muskrat and beaver might be spared due to their lower activity levels in winter.	SAME	SAME
Human and Socio-Economic Receptors			
Air Quality	Effects on air quality have the potential to temporarily disrupt human use and occupancy patterns. Light crude oils typically contain more VOCs than heavier crude oils, although the VOC content of diluted bitumen may be similar to that of light crude oil, depending on the type and quantity of diluent used in its manufacture. Air quality in the vicinity of the oil release would be most affected within the first 24 hours of an oil release. CLB crude oil and Bakken crude oil were predicted to follow the same downstream transport pattern, with each predicted to reach approximately 30 miles downstream 24 hours after a release. However, considerably more of the Bakken crude oil is predicted to evaporate to the atmosphere within 24 hours than is the case for the CLB. Both oil types are predicted to pass through the community of Little Falls, Minnesota and pass along the western border of the community of Rice, Minnesota. As a result, environmental effects on air quality are predicted to be spatially similar for both crude oil types, although slightly more severe for the Bakken crude oil. Under winter conditions, cold temperatures, ice cover and absorption of crude oil into snow pack would strongly limit emissions of VOCs, in addition to constraining the area of effects.	MORE	LESS
Human Receptors	Typical human health effects associated with short-term inhalation of VOCs from crude oil releases include headache, dizziness, nausea, vomiting, cough, respiratory distress, and chest pain; fatality is unlikely. Nearby residents would become aware of a strong hydrocarbon odor that would alert them to the presence of a hazard. Most volatile hydrocarbons would be lost within 24 hours following a release. The human receptors most likely to be exposed to VOCs under this hypothetical crude oil release scenario would be located in homes located close to the Mississippi River about 30 miles downstream from the release point (e.g., Little Falls, Minnesota). Under winter conditions, cold temperatures, ice cover and absorption of crude oil into snow pack would strongly limit emissions of VOCs, in addition to constraining the area of effects.	SAME	SAME

Table 7-86 Environmental Effects Summary Table for Pipeline Crude Oil Releases to the Mississippi River at Little Falls

Receptor	Expected Environmental Effects of Released Crude Oil to the Mississippi River at Little Falls	Relative Effect	
		Light Crude Oil	Diluted Bitumen
Public Use of Natural Resources	Both light and heavy crude oil types are predicted to travel similar distances, and both would form slicks of similar thickness, potentially interrupting public use of natural resources over a similar area. Downstream of the hypothetical release site the Mississippi River flows through the Zebulon Pike Lake reservoir and past several (i.e., Le Bourget Park, James Green Park, Maple Island Park, Mill Park, and the much larger Charles A. Lindbergh State Park) and the McDougall and Michaelson Farms WMA. The leading edge of both oil types is predicted to extend beyond these locations. Effects on air and water quality, or the presence of crude oil residues in the sediment or habitat, could potentially disrupt public use of natural resources. Emergency response workers, in cooperation with public health and safety officials, would be active in isolating, containing and recovering released crude oil, as well as notifying the public about the release. Drinking water for the communities of Little Falls and Rice is drawn from groundwater sources by city owned and operated wells. Therefore, the water supplies for residents of Little Falls and Rice are not likely to be affected by a release. In addition, no drinking water HCAs were identified along the path of the release. In the event of a crude oil release, people would be notified and testing would be completed to confirm the safety of the water supply. It is unlikely that a crude oil release to the Mississippi River would result in adverse health effects to consumers of drinking water. Recreational activities would be disrupted following a release of crude oil along the predicted downstream migration route.	SAME	SAME

7.9 SUMMARY

The assessment of environmental effects of oil releases began with a description of the observed and expected effects of oil on key ecological and human receptors, including how oil behaves (i.e., its fate) in terrestrial, atmospheric and freshwater environments and associated biological resources (Section 7.1). This section was followed by a detailed assessment of expected environmental effects for each of seven sites that are representative of most of the predominant ecological units, major hydrological features, watercourse widths, and watercourse features along the preferred and alternative routes in Minnesota (Sections 7.2 to 7.8). These sections were informed by detailed fate and transport modeling of hypothetical releases of very light (e.g., Bakken crude oil) and heavy (e.g., diluted bitumen such as CLB) crude oils (Chapter 6.0), as well as the information provided in Section 7.1. A brief summary of these components is provided below.

7.9.1 Summary of Predicted Fate and Downstream Transport of Bakken and Cold Lake Crude Oils

The OILMAP Land software was used to simulate hypothetical releases at five of the seven hypothetical release sites: Site 1—Mosquito Creek to Lower Rice Lake; Site 2—Mississippi River at Ball Club; Site 3—Sandy River; Site 4—Shell River to Twin Lakes; and Site 5—Red River. While OILMAP Land does provide an indication of the downstream extent of oiling and mass balance of oil within the 24 hour modeled period, it does not quantify the amounts of oil components dissolved into the water column. However, the SIMAP fate and transport modeling software can quantify the amount of crude oil entrained into or dissolved in the water column, as well as deposited to sediments. Due to the possibly turbulent nature of the Mississippi River near at Palisade, Minnesota (Site 6) and near Little Falls, Minnesota (Site 7) that would promote dissolution and deposition of released oil, SIMAP was used to simulate hypothetical releases of Bakken crude oils and CLB into the Mississippi River at these two hypothetical release sites. Like the OILMAP Land model, SIMAP also provides an indication of the downstream extent of oiling and mass balance of oil within the 24 hour modeled period. A longer time period was not modeled with either software as it was assumed that emergency response measures to prevent or reduce further downstream transport of released oil would be in place within the 24 hour period.

The fate and downstream transport of released oil in each scenario was largely determined by flow conditions (i.e., high flow coinciding with the spring freshet; average flow during summer or fall; low flow in winter typified by freezing conditions and probable ice cover on water) and oil type. At the end of the 24 hour simulation and under high flow conditions, Bakken crude oil as compared to CLB was predicted to evaporate more, have a greater or equal proportion remaining on the river surface (or lake), and to travel farther downstream. However, in the event of an actual release, the downstream extents of Bakken crude oil and CLB may be more similar. Bakken crude oil as compared to CLB was also predicted to spread more thinly on the water surface and to adhere less to river banks. Similar fate and transport of these two oils were typically predicted under average flow conditions, but evaporative losses could be greater in summer due to hotter ambient temperatures. Under low flow conditions, the downstream extents of Bakken crude oil and CLB were predicted to be similar, but shorter, than under average and high river flow conditions. Ice cover on rivers and lakes during winter would strongly limit or prevent evaporation to the atmosphere of both oil types.

A more detailed summary of the fate and downstream transport of released oil at the seven sites is provided in Section 6.

7.9.2 Summary of Expected Environmental Effects

For all seven sites, expected environmental effects to terrestrial receptors, aquatic receptors, semi-aquatic wildlife receptors and human and socio-economic receptors were screened to identify those most likely to have interactions with released crude oil. The proposed pipeline could carry a variety of crude oil types ranging from very light (e.g., Bakken crude oil) to heavy (e.g., diluted bitumen such as CLB). The discussion of expected environmental effects on receptors considers these crude oil types as bounding conditions.

A comparative summary by site and receptor in terms of which crude oil type is predicted to have more severe effects is shown in Table 7-87. Further details for the receptor groups (i.e., aquatic receptors, semi-aquatic wildlife, human and socio-economic receptors) are provided in sections below. Overall, the effects of a release of light crude oil compared to heavy crude oil are expected to be more or equal. In some cases, a similar magnitude of effect is expected. For sediment and shoreline and riparian areas, lighter oil is expected to have less of an effect than heavier oil. For the other receptors (river and lakes, quality, aquatic plants, benthic invertebrates, fish, amphibians and reptiles, birds and semi-aquatic mammals, and air quality, human receptors and public use of natural resources), lighter oil is expected to have a more of an effect, or an equal effect, when compared to heavier oil. Similarities in the magnitude of effects were more apparent when fate and trajectory were modeled using SIMAP.

Table 7-87 Comparative Analysis of Which Crude Oil Type is Predicted to Have More Severe Effects by Site and Receptor

Receptor	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Aquatic Receptors							
Rivers	Bakken	Bakken	Bakken	Bakken	Bakken	Same	Bakken
Lakes	CLB	Bakken	Bakken	Bakken	N/A	Same	N/A
Sediment	CLB	CLB	CLB	CLB	CLB	Same	CLB
Shoreline and Riparian Areas	CLB	CLB	CLB	CLB	CLB	Same	CLB
Aquatic Plants	Same	Bakken	Bakken	Bakken	Same	Same	N/A
Benthic Invertebrates	Bakken	Bakken	CLB	Same	Bakken	Same	Same
Fish	Bakken	Bakken	Same	Bakken	Bakken	Same	Bakken
Semi-Aquatic Wildlife Receptors							
Amphibians and Reptiles	Bakken	Bakken	Bakken	Bakken	Bakken	Same	Same
Birds	Bakken	Bakken	Bakken	Same	Bakken	Same	Same
Semi-aquatic Mammals	Bakken	Bakken	Bakken	Bakken	Bakken	Same	Same
Human and Socio-Economic Receptors							
Air Quality	Bakken	Bakken	Bakken	Bakken	Bakken	Bakken	Bakken
Human Receptors	Bakken	Bakken	Same	Bakken	Bakken	Same	Same
Public Use of Natural Resources	Same	Bakken	Bakken	Bakken	Same	Same	Same

NOTES:

Site 1—Mosquito Creek to Lower Rice Lake; Site 2—Mississippi River at Ball Club; Site 3—Sandy River; Site 4—Shell River to Twin Lakes; Site 5—Red River; Site 6—Mississippi River at Palisade; Site 7—Mississippi River at Little Falls

7.9.2.1 Terrestrial Receptors

With the exception of the Mosquito Creek to Lower Rice Lake scenario, where overland flow was predicted between the point of release and the point of oil entry to a water body, it was assumed in the other six scenarios that crude oil would enter directly into a water body (i.e., Mississippi River, Sandy River, Shell River, Red River) with no holdup of oil on land. In all scenarios and with both types of modeled oil, in the event of an actual oil release any oil on land would undergo prompt and effective remediation. Residual effects on plant communities, soil or groundwater quality are unlikely.

7.9.2.2 Aquatic Receptors

The effects of a crude oil release on benthic invertebrates and fish depends on the characteristics of the released oil and environmental conditions at the time of the release. Acute toxicity to fish is commonly but not always observed in association with crude oil releases, and is an indicator that, at least briefly, concentrations of dissolved hydrocarbons are sufficiently high to cause acute toxicity due to narcosis. Turbulence in river/lake waters could potentially disperse light oil as small droplets in the water column, increasing the potential for toxic fractions of the light oil to dissolve into the water column. During the spring freshet, areas of water flow in rivers could be sufficiently rapid and turbulent for such droplet formation to occur for the light crude oil, although heavy crude oil is less likely to be affected. As a result, the potential for acute toxicity to fish and benthic invertebrates could be greater for the light oil than for heavier oils. In lakes, rapid evaporation of volatile (and potentially water soluble) hydrocarbon constituents from the Bakken crude oil would be expected. Rapid evaporation could limit potential toxicity to fish within the lake.

Chronic effects of released crude oil on fish eggs and embryos could also result from the release of crude oils. The eggs and embryos of these species could be exposed to total PAH concentrations in river and lake water that could be sufficiently high to induce deformities or cause mortality. In addition the potential for phototoxicity would be greatest for a crude oil release in summer due to high light intensity and long day length, especially for small fish that are lightly pigmented or transparent (i.e., embryos, larval and juvenile fish).

Entrainment of small crude oil droplets in the water column during the spring freshet could also enhance the potential for light crude oils to interact with suspended sediment particles in the water column resulting in the formation of oil-particle aggregates. Such aggregates may subsequently be preferentially deposited in areas of still or slowly moving water. Heavy oils too can contact sediment particles along the shoreline, and some accumulation of both light and heavy oils in depositional areas is likely, although the precise mechanisms of deposition may vary. Neither crude oil type is likely to reach a density greater than that of the water and sink directly to the sediment within the first few days following release.

Where they occur, floating aquatic plants would be expected to be killed if contacted by an oil slick. Submerged aquatic plants would be less vulnerable, as they would be exposed primarily to dissolved hydrocarbons, and are not considered likely to be among the most sensitive groups of aquatic biota to such exposure. Emergent aquatic plants are generally quite tolerant of moderate exposure to floating oil (such that a portion of the stem could be oiled). For a hypothetical release under spring freshet conditions, it is likely that most aquatic plants would still be dormant or submerged, and that environmental effects on this receptor type would be minimal. However, flooded riparian areas and wetland habitats would also be exposed to the released oil, and if not properly remediated, crude oil residues could kill plants in these areas. This could affect the biological integrity and productivity of the habitat, and potentially lead to erosion and further damage to the habitat.

During the winter (low flow) period if the release was to occur directly to the river below the ice (as is assumed in the OILMAP Land and SIMAP model), or if there were openings in the ice that the released oil could penetrate, the oil could travel downstream under the ice accumulating in the narrow gap between the ice and the river sediment, or accumulating in hollows under the ice as it moved. For both oil types, the winter ice would effectively inhibit evaporation, while providing greater potential for dissolution into the water column during the period of lowest dilution flow. Therefore, a release in winter could cause fish mortality due to narcosis. This result would be more likely for the light crude oil, which would spread out over a larger area, facilitating release of more water soluble constituents. The heavy crude oil would tend to remain in thicker localized accumulations, and rapid release of more water soluble constituents from a thick layer of crude oil is unlikely. Fish eggs and larvae would generally not be present during the winter, so effects on these life stages are not likely, although crude oil residues in water and sediment could, if not adequately remediated, affect fish eggs and larvae in the following spawning season. Both crude oil types could be accumulated in sediment after a release in winter, and both crude oil types would be subject to re-mobilization with spring breakup of the ice, and increasing water flow rates.

7.9.2.3 Semi-Aquatic Wildlife Receptors

Habitat at the seven hypothetical release sites supports amphibians (e.g., frogs, salamander), reptiles (e.g., turtles, snakes), birds (e.g., ducks, geese, shorebirds, raptors) and semi-aquatic mammals (e.g., muskrat, beaver, mink and otter). Within the oil-exposed habitats along rivers and lakes that support amphibians (adults, juveniles, and eggs), oiling effects including mortality would be observed. Turtles appear to be relatively tolerant of external crude oil exposure, and although these animals are likely to become oiled, mortality of turtles as a result of this exposure is less likely. Reptiles like lizards and snakes are primarily terrestrial species and are less intimately associated with aquatic environments. Amphibians and reptiles undergo a winter dormancy period when temperatures drop below approximately 41 to 45°F. At this time, amphibians and turtles typically bury themselves in river bottom substrates or other similar habitats. Therefore, during the winter (and likely up until April or May when winter ice is gone), these organisms would have very little exposure to released oil moving on the water surface or within the water column.

If exposed to external oiling, the ability of birds and mammals to maintain body temperature may be compromised, leading to death as a result of hypothermia. Birds and mammals that survive external oiling may experience toxicological stresses as a result of ingesting crude oil residues during preening/grooming or ingesting food, and birds can also transfer potentially lethal quantities of crude oil residue from their feathers to the external surface of eggs. Waterfowl and other semi-aquatic birds and mammals present in the affected rivers and lakes would be most affected. Animals upstream, farther downstream, or occupying other nearby habitats, would likely be less affected as it is assumed that emergency response measures to prevent or reduce further possible downstream transport of oil would be in place within 24 hours of the release. Timely capture and rehabilitation of oiled birds and mammals may help to mitigate the environmental effects of a crude oil release.

7.9.2.4 Human and Socio-Economic Receptors

Effects on air quality from a release of crude oil have the potential to temporarily disrupt human use and occupancy patterns. Light crude oils typically contain more VOCs than heavier crude oils, although the VOC content of diluted bitumen may be similar to that of light crude oil, depending on the type and quantity of diluent used in its manufacture. Air quality and subsequent human exposure to VOCs in the vicinity of the oil release would be most affected within the first 24 hours. Light crude oil is expected to travel a similar distance downstream under spring and summer conditions as heavy crude oil. As a result, environmental effects on air quality are predicted to be spatially similar for light and heavy crude oil types. Under winter conditions, cold temperatures, ice cover and absorption of crude oil into snow pack would strongly limit emissions of VOCs and human exposure, in addition to constraining the area of effects.

Emergency response workers, in cooperation with public health and safety officials, would be active in isolating, containing and recovering released crude oil, as well as notifying the public about the release. Some homes located along the trajectory of a predicted release could rely on groundwater as a drinking water source. In the event of a crude oil release, people would be notified and testing would be completed to confirm the safety of the water supply. It is unlikely that a crude oil release to the any of the modeled rivers/creeks/lakes would result in adverse health effects to consumers of drinking water. Recreational activities would be disrupted following a release of crude oil along the predicted downstream migration route. Fisheries regulators and public health officials typically close fisheries until it is confirmed through monitoring that fish consumption is not a threat to public health. This standard approach is an effective mitigation strategy to protect human receptors for contact with constituents in the oil.

8.0 REVIEW OF ENVIRONMENTAL RECOVERY FOLLOWING RELEASES OF OIL

8.1 INTRODUCTION

Ecosystem and human environments experience numerous types of disturbances, including natural phenomena such as fire and flooding, and anthropogenic disturbances, including chemical and crude oil releases, mining, and industrial and urban development. The ability of a system to recover from disturbance is a complex phenomenon, dependent upon numerous intrinsic and extrinsic factors including the condition of the initial system, resistance and resiliency of the initial system prior to disturbance, and its inherent variability. The rate of recovery is largely dependent on the severity of the disturbance, its areal extent, and its duration.

Since various components of a system will recover at different rates, the selection of recovery endpoints and length of time can yield different results. It is therefore recommended that recovery endpoints be reflective of critical ecological function or important human relevance. Timeframes to determine if recovery from human disturbances has occurred need to be considered in the same context as natural recovery rates. Otherwise, it may be incorrectly determined that recovery from human disturbances has not occurred when, in fact, it is occurring but requires more time.

EERA requested that Stantec conduct a review of existing literature, supported with case studies, to evaluate the process of recovery from a crude oil release in a variety of environments and ecosystems. The review was prepared in support of the permitting process for the L3RP. Specifically, the Commission has requested information concerning the effects of potential crude oil releases along the preferred and alternate pipeline routes on the natural and human environment (Chapter 7.0), as well as the ability of these systems to recover from the effects of a crude oil release.

This chapter reviews current information on the recovery of natural and human environments from effects of crude oil releases. For biophysical environments, the ability of key groups of biota and key receptors to recover, the timeframe for recovery, and the factors affecting recovery rates are addressed. For human environments, the processes by which human use and socio-economic conditions recover following crude oil releases and the factors influencing recovery are addressed.

The recovery of both natural and human environments is considered based on the climatic conditions, ecosystems, and communities that exist in Minnesota, through which the pipelines will pass. When information was available, case studies from Minnesota and similar environments are considered to supplement the review of historical oil releases. Although broad generalizations cannot be drawn from a single event, case studies provide significant data that, in combination with existing literature, can help regulators and operators gain a more comprehensive understanding of the effects of crude oil releases and recovery of various environmental media.

It is important to note that within this document, the term "recovery" refers to the recovery of the natural and human environments that occurs after emergency response and clean-up of a crude oil release. It does not refer to the collection and removal of crude oil from the environment, which is a common use of this term in the spill response literature.

8.2 APPROACH

8.2.1 Goals and Objectives

The overall goal of this recovery review is to provide an overview of the current science and information related to the recovery of the natural (i.e., biophysical) and human environments following crude oil releases. This report focuses on terrestrial and freshwater habitats in continental and temperate North American climates, as well as on recovery of human uses and socio-economic conditions pertinent to the region. An extensive literature review was conducted for this report, and case studies in the upper Midwest and portions of Canada were identified to address the ability of both human and natural environments to recover from severe release events. Additional case studies from other areas are cited when recovery details are relevant.

While the majority of pipeline incidents[10] tend to be relatively small with a median release volume of three barrels, these smaller releases also tend to cause few effects and almost half (47%) are contained completely on the operator's property (PHMSA 2016). Most have limited effects on the environment; therefore, very little information about recovery is publicly documented for the majority of pipeline releases. Most of the available literature is based the recovery from very large releases with severe, and sometimes widespread, effects. While these types of releases are uncommon, they do tend to be documented for regulatory purposes and, in certain instances, have resulted in scientific research that has been published in peer-reviewed journals.

Specific objectives of the recovery section are to:

- Provide a recovery assessment specific to freshwater and terrestrial releases from ecoregions similar to Minnesota
- Update the recovery assessment with information not available at the time of previous reviews
- Address specific recovery topics, including:

[10] Incidents must be reported to PHMSA if the incident results in one or more of the following consequences: 1) a release of 5 gallons or more, 2) death or serious injury necessitating hospitalization, 3) fire or explosion not intentionally set by the operator, or 4) property damage of $50,000 or more (49 CFR 195.50).

- Those key receptors and groups for the natural environment for which ecological recovery was specifically studied and which may be present in the area of the two proposed projects
- How different approaches to emergency spill response, habitat restoration, and environmental rehabilitation can affect rates of recovery
- How biota respond and recover from crude oil releases
- Perspectives on how human socio-economic conditions recover following crude oil releases

8.2.2 Scope and Organization

To understand how systems recover from crude oil releases, an understanding of the physical and chemical properties of crude oil is needed (Section 8.2.3.1), as well as a general description of fate and behavior of crude oils in various environmental media (Section 8.2.3.2). Recovery from crude oil release effects is then examined for a variety of environmental receptors (Sections 8.3.1 to 8.3.7), as well as recovery of human communities from socio-economic effects (Section 8.3.8). Findings are summarized in Section 8.5.

8.2.3 Factors Affecting Recovery

8.2.3.1 Physical and Chemical Properties of Crude Oil

Crude oil is a complex mixture of petroleum hydrocarbons and its composition varies widely, depending on its origin and processing. Created from organic matter, crude oil is primarily composed of carbon and hydrogen, with smaller amount of other elements. These hydrocarbons vary in molecular weight, form, and length, and include paraffins, aromatics, cycloalkanes, alkenes, and other compounds. The differences in the structure of these compounds as well as their relative proportion within each crude oil account for the crude oil's physical and chemical characteristics.

From an environmental perspective, BTEX are of particular interest. These lightweight aromatic petroleum hydrocarbons are highly volatile and relatively water soluble, making them mobile within the environment but their environmental persistence is lower than many other petroleum hydrocarbons. Heavy molecular weight petroleum hydrocarbons, such as asphaltenes, have low volatility, are much less soluble, and are more environmentally persistent. Consequently, understanding how these hydrocarbons interact with the environment is important for understanding recovery.

Light crude oils are characterized by their high proportion of lightweight hydrocarbons, with few heavy constituents. Light crude oils typically have AP) gravities greater than 31.1, indicating that they will float on water[11] in the event of a release, which would facilitate clean-up (Lee et al. 2015). Light crude oils contain a smaller fraction of heavy molecular weight compounds than

[11] Fluids with API values greater than 10 float on the water's surface, while fluids with API gravities less than 10 will sink.

lower value API crude oils and have a low viscosity. As a result, they form a thin sheen across the surface of water that provides more surface area to the environment, thus enhancing weathering processes such as evaporation, dispersion, and photodegradation.

Medium crude oils generally have API gravities ranging from 22.3 to 31.1 (Lee et al. 2015). Environmental processes (e.g., spreading, evaporation and emulsification) will be intermediate in comparison to lighter and heavier crude oils.

Heavier crude oils have a higher proportion of heavy molecular weight compounds (e.g., asphaltenes) than light and medium crude oils. Heavy crude oils typically have API gravities less than 22.3 (Lee et al. 2015).

Diluted bitumen is one type of blended heavy crude oil[12]. Diluted bitumen crude oils from Canada generally have API gravities above 20 API, indicating that they will float on the surface of water (Crude Monitor 2016). Because diluted bitumens are heavy oils, they are more viscous than either medium or light crude oils and will spread over land and across the water's surface more slowly, reducing the affected area in a given period of time compared to lighter oils. Like other crude oils, diluted bitumen can form emulsions (i.e., water-in-oil mixtures). Due to the greater proportion of heavy molecular weight compounds and their affinity to organic materials, diluted bitumen emulsions tend to incorporate sediments. The resulting oil-water-sediment material tends to be more stable and has longer environmental persistence than light crude oil emulsions.

Several case studies presented in this report feature fuel oil and Bunker C Oil releases. These are extremely heavy oils that can have substantially different effects than crude oils transported by pipelines. However, these case studies are presented in this report where information to recovery is relevant.

8.2.3.2 Environmental Fate and Behavior of Crude Oil

Once released into the environment, crude oil is subject to a number of physical processes and chemical transformations, including evaporation, emulsification, dissolution, photodegradation, and biodegradation (Prince et al. 2003; Fingas 2015) (Section 7.1.2). These weathering processes are present regardless of release location. Additional details regarding environmental fate and behavior of crude oil are discussed in Section 7.1.

8.2.3.3 Species Resistance

Species differ in their ability to resist disturbance. For a crude oil release, species resistance depends on multiple factors including the species sensitivity to exposure to petroleum

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[12] Definitions of a "heavy oil" vary within the industry. For this report, heavy oils refer to those crude oils with API values less than 23 but more than 10. Raw bitumen is an extremely heavy crude oil with API value of 10 or less.

hydrocarbons, life stage, and behaviors that may increase or decrease the exposure of the organism. While effects of petroleum hydrocarbons were discussed in the previous chapter, the severity of effects and the areal extent of the effects can strongly influence the rate of recovery of the environment.

8.2.3.4 Species Resiliency

Numerous factors, such as life history strategies and the presence of nearby, unaffected populations that can recolonize an affected area, influence how quickly a species may recover from a crude oil release (i.e., the species' resiliency). While life history strategies for all species are not discretely divided into two independent groups, the "r" and "K" strategies are useful descriptors used by scientists to discuss population dynamics and characteristics.

Species that exhibit "r" strategies ("r strategists) produce a large quantity of offspring, resulting in an initial exponential growth in the local population. The success of these species relies on their biotic potential or maximum reproductive capacity (r) (Rafferty 2016a). Other characteristics of "r" strategists include short gestation periods, small body size, fast maturation rates, short life spans, and little individual parental investment. Some examples of "r" strategist species include certain annual grasses and forbes (including those that are often those considered invasive and noxious weeds); some insects (e.g., mosquitos, cockroaches); some bird species (e.g., house sparrows); and small mammals (e.g., mice).

The life history traits that characterize "r" strategists allow these species to exploit disturbed, less crowded, and sometimes unstable ecological niches (Rafferty 2016a). Therefore, they typically are not highly adapted to their environment since the environments they inhabit often change or are disrupted in some way. To succeed in these highly variable environments, it is crucial that "r" strategists are able to reproduce quickly and in great numbers to allow for the highest probability of continued future generations of offspring. Another advantage of large numbers of offspring in a temporary and unstable environment is the ability to respond opportunistically and to quickly claim untapped resources, such as nutrients and sunlight. However, after population booms, populations of "r" strategists begin to decline rapidly due to overcrowding or competition with more specialized species (Rafferty 2016a).

Species that exhibit "K" life history strategies ensure survival of their offspring by focusing on quality rather than quantity. Key characteristics of "K" strategists include fewer offspring, extended gestation periods, long life spans, large body size, and extensive parental investment. These species invest time in their individual offspring rather than relying on large numbers to increase the chance of survival and reproduction. "K" strategists utilize longer maturation periods and have the ability to transfer knowledge and skills to their young, which is needed to survive to adulthood and ultimately produce future generations (Rafferty 2016b). Populations that are "K" strategists fluctuate depending on the carrying capacity (K) of their local environment, resulting in stable biological communities and long term population growth (Rafferty 2016b). Because "K" strategists have evolved in relatively stable environments, "K" strategists may require longer periods to recover from disruptive changes to the environment, compared to "r" strategists. Examples of "K" strategists include many types of woody vegetation (e.g., redwood trees), certain birds (e.g., hawks, eagles), and large mammals (e.g., bears, humans).

8.2.4 Defining Recovery

Definitions of ecological recovery have evolved substantially over the last few decades within both regulatory and scientific contexts. Much of this evolution derives from advances in ecological knowledge based on the successes and failures of ecological remediation (Jackson and Hobbs 2009).

Historically, definitions of recovery include a central concept regarding a return of the ecosystem or a particular resource or human use to some desirable system state roughly equivalent to its pre-disturbance conditions. Since pre-disturbance (baseline) conditions often have not been quantitatively assessed prior to a release, definitive conclusions regarding recovery are difficult to achieve.

More recently, the definition of recovery has meant a return to the conditions that would have prevailed had the crude oil release not occurred, while recognizing the need to take into account spatial and temporal variability in natural ecosystems, as well as the influence of natural and man-made factors other than the release. Current perspectives from the scientific literature and regulatory context attempt to define appropriate and practical objectives of recovery and active remediation to re-establish the ecosystem functions that provide valuable ecological goods and services. This current perspective focuses less upon comparison with baseline conditions than identifying measures to assess recovery in terms of desired ecosystem function.

8.3 RECOVERY BY VALUED ECOSYSTEM COMPONENT

8.3.1 Groundwater

Groundwater often is an important resource for agriculture, public, industrial, and private water supplies. In Minnesota, groundwater supplies derived from aquifers account for about 75% of the drinking water and almost 90% of agricultural water supplies (MN DNR 2016).

Water beneath the land surface occurs in two principal zones: the unsaturated zone and the saturated zone beneath it. When the unsaturated zone is porous, consisting of materials such as sands and gravels, water from precipitation can percolate through the unsaturated zone and recharge the groundwater in the saturated zone. The top of the saturated zone is the water table. The saturated zone consists of groundwater filling the pores and crevices in soil, sand, gravel, or rock. Not all groundwater located within saturated zones is located within an aquifer.

Aquifers are defined as water-bearing porous soil or rock strata that yield water at rates sufficient to support human uses. Consequently, a saturated layer of clayey soil does not meet the definition of an aquifer. Well intakes are located below the water table and within saturated aquifer material where the water pressure is great enough to allow water to enter wells, thus permitting groundwater to be withdrawn for use (MN DNR 2016).

Aquifers are broadly classified into two categories, unconfined and confined. Unconfined aquifers are the saturated portions of the upper soil profile located above a confining layer. The upper surface of an unconfined aquifer is in direct contact with the atmosphere through porous materials. In contrast, confined aquifers are separated from the atmosphere by a confining layer, consisting of a very slowly permeable or rock layer (aquitard). Confining layers severely impede downward movement (percolation) of infiltrated water. Water in these aquifers is under pressure and, in a well, will rise above the top of the aquifer.

Aquifers differ in their susceptibility to surface contamination due to a variety of factors such as the depth to groundwater and the presence of a confining layer. Across the United States, the depth to the groundwater is highly variable. Groundwater depth can range from zero when it is immediately below the land surface to hundreds, even thousands of feet deep. In Minnesota, groundwater is generally close to the land surface, typically within a few tens of feet in much of the state (MN DNR 2016).

The presence or absence of a confining layer is a critical factor that affects an aquifer's vulnerability to surface contamination. Confined aquifers are protected by one or more relatively impermeable layers (such as clay) that limit the vertical movement of water and contamination. An unconfined aquifer has no overlying impervious layer to separate it from the surface contamination. Shallow, unconfined aquifers are considered to be vulnerable to surface contamination, whereas deep, confined aquifers have a comparatively low susceptibility to surface contamination.

Crude oil releases from pipelines do not commonly affect groundwater resources. The PHMSA maintains a pipeline incident database that contains detailed information on all reportable historical pipeline incidents[13]. On a national basis, PHMSA incident data indicate that only a small fraction (approximately 4%) of reportable incidents affected groundwater[14]. When groundwater resources were affected, approximately 77% of those releases required groundwater remediation activities (PHMSA 2016). For the State of Minnesota, PHMSA data

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[13] Incidents must be reported to PHMSA if the incident results in one or more of the following consequences: 1) a release of 5 gallons or more, 2) death or serious injury necessitating hospitalization, 3) fire or explosion not intentionally set by the operator, or 4) property damage of $50,000 or more (49 CFR 195.50).

[14] The majority of PHMSA reportable pipeline incidents since January 2002 are small (3 barrels or less) and almost half of the PHMSA-reported pipeline incidents occur completely within operator-owned facilities (47%). Of those releases that were not contained completely within the operator's property, the median release volume was 20 bbl, again indicating that small releases are the most common and very large releases are uncommon (PHMSA 2016).

indicate that groundwater is affected by 13% of the reported releases, with 50% of those releases requiring remediation (PHMSA 2016). Differences between the national and regional statistics appear to be related to a higher proportion of shallow, unconfined aquifers in the Minnesota region compared to other regions of the U.S. Nevertheless, only 0.4% of releases affected actual drinking water resources in states crossed by the SPP and L3RP (i.e., only a fraction of surface and groundwater resources are used as drinking water supplies) (PHMSA 2016).

8.3.1.1 Recovery of Groundwater Following a Crude Oil Release

8.3.1.1.1 Permeability of Soils to Crude Oil

Once crude oil is released into the environment, the attributes of the release site, including the groundwater characteristics, will determine how quickly the crude oil may penetrate into the soil; how far it may move vertically within the soil and subsoils; and the degree that the crude oil fills the interstitial spaces within the soil and between subsoil particles in the unsaturated layer. Effects to soil and groundwater generally are slow to develop, allowing time for emergency response and clean-up actions to mitigate potential effects. If clean-up activities do not completely remove the crude oil, the residual crude oil and constituents that dissolved from the crude oil may migrate downwards through the unsaturated layer to reach groundwater. Since petroleum hydrocarbons can adhere more strongly to soil particles with a higher organic carbon content, the mobility of the residual crude oil through the unsaturated layer is largely controlled by the composition of the unsaturated layer and the depth of the unsaturated layer (i.e., the distance between surface soil and groundwater). Factors such as the depth of the aquifer and presence of intervening layers of confining materials (e.g., horizontal layers of clay, silt, slate, granite) may reduce the potential for groundwater contamination. In general, the movement of crude oil in soils and subsoils is limited.

The surface area of crude oil in contact with groundwater, duration of contact with groundwater, and the concentration of water soluble constituents (e.g., benzene) within the crude oil are critical factors that determine if a plume of petroleum hydrocarbons may be formed in the groundwater and how large the plume becomes. In their examination of over 600 petroleum hydrocarbon releases, Newell and Connor (1998) found that residual oil acts as a source for groundwater contamination and that recovery occurred (e.g., groundwater plumes stabilized or decreased in size) when the residual petroleum hydrocarbons from the original release site were removed. Consequently, the timeliness and efficacy of clean-up activities in removing crude oil strongly affects the extent of impacts to groundwater and rates of recovery.

8.3.1.1.2 Chemical, Physical, and Biological Attenuation Factors

Groundwater recovery can be governed by a number of important natural environmental fate processes including chemical (adsorption), physical (volatilization, dilution, chemical attenuation), and biological (biodegradation) processes. Collectively, these environmental fate processes that stabilize or remove hydrocarbons from the environment are referred to as natural attenuation. *Biodegradation* is generally the most significant natural attenuation process and occurs when microbes digest petroleum hydrocarbons, converting hydrocarbons into small amounts of water and gases. Native microbial populations may bloom and biodegrade petroleum hydrocarbons in groundwater. *Sorption* causes contaminants to adhere to soil particles, but does not destroy the contaminants. Sorption reduces the rate that petroleum hydrocarbons can migrate through soils and subsoils. *Dilution* decreases contaminant concentrations as they migrate through the medium and mix with clean groundwater. *Evaporation* changes liquids to gas and can be a significant means of reducing release volume, as well as removing many of the most concerning compounds (i.e., BTEX) from the soil. However, evaporation rates are reduced when the exchange of gases is limited, so evaporation at the soil surface will be greater than evaporations at increasing depth within the soil horizon. *Chemical reactions*, including complexation and abiotic transformation, can stabilize and convert hydrocarbons into less harmful forms (USEPA 2016).

Because of natural attenuation, dissolved hydrocarbon plumes tend to stabilize within tens to hundreds of feet from the source release (Newell and Connor 1998; Connor et al. 2015). Although natural attenuation rates depend on site-specific physical, chemical, and biological subsurface environment characteristics, nationwide investigations of over 1,300 historical petroleum release sites found that the migration of dissolved constituents typically stabilizes within approximately 425 feet of the point of release. Furthermore, this analysis found that approximately 94% of BTEX plumes studied were either stable or shrinking (Connor et al. 2015). Natural attenuation stabilizes and reduces the concentrations of many petroleum hydrocarbons compounds, including BTEX (MN PCA 2005).

> ***Enbridge Crude Oil Pipeline, Bemidji, Minnesota:*** *The Bemidji release is the sentinel study that vastly increased the scientific understanding of natural attenuation processes. In 1979, a pipeline released approximately 10,700 barrels of crude oil near Bemidji, Minnesota. Initial clean-up efforts removed approximately 8,200 barrels (75% of the original volume) and an unquantified volume was lost to the atmosphere to volatilization. There was a substantial volume of crude oil that remained in the soils and subsoils after clean up. The release occurred in an area of very sandy soils with shallow groundwater. Since the release occurred within a state forest with few environmental receptors (e.g., drinking water intakes, populated areas) in close proximity to the release site, the State of Minnesota, the USGS, and Enbridge collectively agreed to monitor effects of crude oil and its dissolved constituents on groundwater. As part of this research initiative, these agencies and Enbridge agreed that further clean up and remediation of the site (i.e., treatment of contaminated soils and subsoils) would not be undertaken at that time. Seventeen years after the release, natural attenuation had limited the movement of the hydrocarbon plume to 650 ft in length, compared to groundwater movement of 1,640 ft (Delin et al. 1998).*

Natural attenuation is influenced by a number of factors including soil type, depth to groundwater, electron receptors, nutrient availability, and temperature. Rates of natural attenuation depend upon the subsurface temperature and presence of electron receptors that are utilized by the microbes to degrade petroleum hydrocarbons. Oxygen, used for aerobic respiration, can result in much higher reaction rates compared to anaerobic (anoxic) reactions that depend on electron acceptors, such as nitrate, ferric iron, sulfate, or carbon dioxide (listed from strongest to weakest). As the more preferred electron receptors are consumed (e.g., oxygen, nitrate), the oxidation-reduction (redox) potential of the groundwater decreases over time. Consequently, many remediation activities focus on supplementing oxygen and nitrogen to maintain and enhance rates of natural attenuation.

> ***Enbridge South Cass Lake Pumping Station, Minnesota****: A subgrade leaking flange at the Cass Lake pumping station in north-central Minnesota was discovered in 2002. An estimated 1,143 barrels of crude oil were present at the groundwater table, and the dissolved phase plume (>10 ppb benzene) extended 500 ft downgradient (Drennan et al. 2010). Because the oil resided under a gravel-covered yard at Cass Lake, enhanced surface recharge was suspected as a factor accelerating degradation (Drennan et al. 2010). To further accelerate groundwater recovery, a bioventing groundwater remediation system[15] was installed in 2014. Monitoring data following just three months of operation suggest biodegradation was being enhanced with increased oxygen, decreased carbon dioxide, and increased temperature in the unsaturated zone (AECOM 2015).*

8.3.1.1.3 Removal of Residual Crude Oil

If crude oil is allowed to remain in the soils and subsoils following a release, the residual oil can act as a source of dissolved constituents that contribute to the formation of a groundwater plume. Natural attenuation processes slow the movement of dissolved petroleum hydrocarbons in groundwater. Eventually, the petroleum hydrocarbon plumes stabilize when an equilibrium is reached between dissolved petroleum products entering the plume and the degradation of hydrocarbons along the groundwater's leading edge.

The movement of groundwater plumes has been studied extensively. Newell and Connor (1998) summarized data from petroleum hydrocarbons throughout the U.S. Their analysis concluded that the removal of the source of petroleum hydrocarbons was one of the most critical variables in groundwater recovery, allowing plumes to stabilize and eventually begin to shrink.

If crude oil remains in the environment, weathering and the natural attenuation process will continue to degrade the remaining crude oil. Concentrations of straight-chained hydrocarbons and simple aromatics will diminish with time, leaving a small volume of crude oil composed of complex, multi-ringed petroleum hydrocarbons that can be extremely persistent.

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[15] The purpose of the bioventing groundwater remediation system, consisting of three bioventing wells installed to depths of 24 ft below grade as well as eight total vapor monitoring points, was to oxygenate and degrade petroleum compounds in subsurface soils (AECOM 2015).

> ***Enbridge Crude Oil Pipeline, Bemidji, Minnesota***: *Bekins et al. (2005) analyzed soil cores 25 years after the Bemidji release and found substantial biodegradation of the n-alkane fraction had occurred through methanogenesis. While weathering of the crude oil has decreased the mobility and capacity of the residual oil to liberate soluble contaminants into the groundwater, weathering continues to remove light- and medium-weight petroleum hydrocarbons, leaving behind a crude oil that is increasingly persistent and less susceptible to natural attenuation.*

8.3.1.2 Factors Affecting Recovery

Rapid and effective emergency response containment and clean up can substantially accelerate recovery by limiting the amount of crude oil available to affect groundwater, and by reducing hydrocarbon concentrations to levels where natural attenuation processes can more readily complete the recovery.

Failure to remove residual oil at the release site is the most significant factor impeding the recovery of groundwater. If left in place, residual oil at the release site can represent an ongoing source for the dissolved plume, potentially for many decades. Vertical fluctuations in the water table also can impede recovery by increasing the amount of oiled substrate in the saturated and unsaturated layers (i.e., smear zone thickness).

When accelerated rates of recovery are desired, active remediation or enhanced bioremediation can be implemented. Selection of remediation technology depends on the remedial objectives, affected media (e.g., soil, saturated and unsaturated layers, groundwater characteristics), and the physical and chemical properties of the petroleum hydrocarbon (e.g., crude oil volatility, crude oil transmissivity [i.e., its mobility within the pores and interstitial spaces of the subsoils and underlying lithology], concentrations of soluble petroleum hydrocarbons with the crude oil).

Active remediation can involve the installation of a mechanical system where recovery wells are used to volatilize certain petroleum hydrocarbons and extract the resulting gases (e.g., soil vapor extraction), inject airflow to volatilize petroleum hydrocarbons below the water table (e.g., air sparging), or extract the affected groundwater and/or crude oil (e.g., skimming, pump-and-skim). A multi-phase extraction[16] system involves the simultaneous extraction of volatilized petroleum hydrocarbons from the unsaturated layer, groundwater, and crude oil where it has pooled on the surface of the water table.

Soil vapor extraction often is used to remediate contaminants that are within the saturated layer. The selection of a soil vapor extraction system must consider the volatility of the residual petroleum hydrocarbon (i.e., vapor pressure of the residual petroleum hydrocarbon), ability of the crude oil to desorb from the soil (i.e., Henry's Law), and soil type (course-grained versus fine-

[16] Multi-phase extraction—a generic term for technologies that extract VOCs from soil vapor and groundwater, simultaneously (USEPA 1999).

grained). Crude oil that is weathered and adsorbed to fine-grained soils (e.g., silt, clay) is not a good candidate for soil vapor extraction.

Extraction of crude oil from the unsaturated zone where the crude oil has filled the pores between subsoil particles is conducted through pumping, skimming, or multi-phase extraction techniques. Pumping extracts groundwater from a well and the water can be treated and disposed of, if contaminated from the crude oil. Since crude oil tends to float, groundwater is extracted by pumping and then oil is skimmed from the surface of the extracted groundwater. As described above, multi-phase extraction methods remove product from the unsaturated layer, the groundwater surface, and the saturated layer. Selection of these methods rely upon the ability of the crude oil and its dissolved constituents to move through the spaces within the soil and subsoil structure as the crude oil is conveyed to a recovery well (i.e., transmissivity).

Crude oil transmissivity is considered a better metric than measurements of in-well thickness of oil for assessing if oil is recoverable (i.e., mobile) (ITRC 2009). Crude oil transmissivity is dependent upon the soil type, crude oil physical properties (e.g., density, viscosity), crude oil saturation (i.e., percentage of pore space occupied by crude oil), and thickness of the mobile crude oil in the formation. In general, transmissivity is higher for light crude oils (e.g., Bakken crude oil) and lower for heavy crude oils (e.g., diluted bitumen). As crude oils weather, they become more viscous and dense and therefore have lower transmissivity. ITRC (2009) identified a practical minimum crude oil transmissivity range (0.1 to 0.8 square ft per day [ft^2/d]) to help determine if the oil can be feasibly recovered hydraulically.

As the extraction process progresses, the process becomes less efficient as the crude oil saturation reaches residual levels, the crude oil becomes hydraulically disconnected (i.e., present as disconnected globules within the pores), or is immobilized by capillary forces within the pore space.

> ***Enbridge Crude Oil Pipeline, Bemidji, Minnesota****: In 1999, the State of Minnesota mandated active remediation for the Bemidji release site with the objective of reducing crude oil in all monitoring wells to only a "sheen". A pump-and-skim extraction system was used from 1999 through 2003 and approximately 700 barrels of crude oil were removed during that time. Despite the removal of a substantial volume of residual crude oil, the regulatory agency requirement was not met because the residual oil continued to create a sheen from water extracted from certain monitoring wells. Further, the crude oil thickness decreased locally near the pumping wells during pumping, but there was little effect on surrounding monitoring wells as crude oil thickness rebounded following system shutdown (Delin and Herkelrath 2014).*

Enhancements of natural attenuation processes also can be considered to accelerate groundwater recovery. Typically, natural attenuation enhancements involve increasing the availability of electron acceptors, such as oxygen and nitrate. Bioventing, where ambient air is injected or extracted at low flow rates, is used to supplement and replenish oxygen for microbial respiration in the vadose zone. Biosparging (a process where compressed air is injected at low flow rates below the water table) is used to increase dissolved oxygen levels in the groundwater to enhance biodegradation. Sulfate amendments also have been used to enhance biodegradation rates in anaerobic environments.

8.3.1.3 Groundwater Summary

The vast majority of terrestrial crude oil releases do not affect groundwater resources. National statistics demonstrate that only 1.36% of releases required groundwater remediation, and 0.17% of the releases adversely affected drinking water, whether groundwater or surface water (PHMSA 2016). In the Upper Midwest, the presence of shallow unconfined aquifers increases groundwater vulnerability compared to other parts of the US. In Minnesota and surrounding states, PHMSA data indicate that groundwater is affected by 9.7% of the pipeline releases, with 71% of those same releases requiring remediation (PHMSA 2016).

Effects and the subsequent need for groundwater recovery can be substantially reduced by minimizing the duration that crude oil is in contact with the groundwater. Previous reviews of petroleum hydrocarbon releases concluded that the removal of the residual oil at the release site was the most important factor for initiating recovery (Newell and Connor 1998).

When a petroleum hydrocarbon plume is formed, recovery of groundwater can occur through natural attenuation, but may take decades to achieve. Petroleum hydrocarbon plumes move more slowly than the groundwater due to adhesion to soil particles and natural attenuation processes. As a result, the length of petroleum hydrocarbon plumes generally is tens to hundreds of feet. A compilation of studies evaluating 600 sites (Newell and Connor 1998) found most petroleum hydrocarbon plumes were stabilized or decreasing, indicating recovery (Newell and Connor 1998). Human intervention through enhanced natural attenuation or by active remediation procedures can accelerate rates of groundwater recovery from decades to years.

8.3.2 Soils

The Natural Resource Conservation Service (Soil Survey Staff 2003) defines soil as a natural body consisting of “solids (minerals and organic matter), liquid, and gases that occurs on the land surface, occupies space, and is characterized by one or both of the following: i) horizons or layers, that are distinguishable from the initial [bedrock] material as a result of additions, losses, transfers, and transformations of energy and matter; or ii) the ability to support rooted plants in a natural environment.”

Ecosystem functions provided by soils (Coleman et al. 1998; Doran and Parkin 1994) include:

- Accepting, storing, and releasing water to plants, streams and subsoils
- Accepting, storing, and processing nutrients, making them available to plants and other organisms

- Supporting and sustaining root growth
- Maintaining viable soil biotic habitat
- Responding to management and resisting degradation

The soils in the region crossed by the two proposed pipelines are generally characterized by glacial till and sandy soils. The materials deposited through direct and indirect glacial action provide the parent material for the soils in this region. Glacial till is an unsorted mixture of material ranging from very fine clay to stones and boulders. During glacial retreat (i.e., melt), large amounts of water were released, which washed the till, removing fine particles. The remaining sands and gravel materials were then sorted, forming glacial outwash sediments. These materials were collected in low-lying areas (sometimes for long time periods), forming lacustrine deposits that settled in lakes. Lacustrine deposits range from sand and gravel at beaches to clayey substrate near the center of a lake. During the glaciation and melting periods, wind transported soil particles (i.e., silt and clay) to other areas, where the particles were deposited on older till or bedrock (i.e., weathered and fresh) (Anderson et al. 2001).

A crude oil release on glacial till would not migrate quickly through soil media due to the low permeability of the material. Conversely, a crude oil release on sandy and gravelly soils consistent with glacial outwash, would migrate more quickly due to the higher porosity of the material. Similarly, crude oil released on clayey deposits (i.e., toward the center of the lacustrine deposits) would not migrate through the soil as quickly as crude oil released on sandy and gravelly deposits (i.e., on lake beaches). Migration of crude oil released on loess deposits would depend on the bulk density of the soil and whether the medium contained moisture (Wang and Shao 2009).

There are numerous types of surface soils, the distribution and characteristics of which are broadly controlled by parent material, climate, biota, and time. Although they are variable, soils typically include a common matrix of air, water, and organic and inorganic (mineral) particles that vary in size and shape. This soil matrix commonly supports an ecosystem of microbes and invertebrates. These organisms, in turn, provide a supporting foundation for an even larger ecosystem of plants and animals.

8.3.2.1.1 Soil Microorganisms

Soil microorganisms, an integral part of soil, primarily consist of bacteria, actinomycetes, fungi, algae, protozoa, and nematodes. This assemblage is responsible for cycling nutrients, such as nitrogen, phosphorous, potassium, calcium, magnesium, iron, and sulphur, through the decomposition of organic matter. Certain microorganisms (e.g., bacteria) also have the ability to use petroleum products as a food supply, decomposing crude oil to carbon dioxide and water (Jensen 1975; Rowell 1975; Watts et al. 1982).

However, the smaller soil organisms tend to contribute disproportionately more to the overall abundance of metabolic activity within the soil and often form symbiotic relationships with plants.

The abundance, diversity, and resiliency of soil organisms are dependent on the nature of the soil and the associated plant community. Reproduction rates and sensitivity to petroleum hydrocarbons can allow some species to proliferate more quickly and consume petroleum hydrocarbons compared to other species (Brezeszcz et al. 2016). These characteristics can determine how quickly the soil ecosystem can recover when exposed to crude oil. For example, Rowell (1975) found microbes began to degrade crude oil in several types of mineralized soils in Alberta within 1 to 3 days after application of crude oil at a concentration of 5% by weight. A key element regulating these characteristics is the availability of active organic matter that can readily be used as a source of energy and carbon. In addition, nutrients, moisture content, temperature, and other climatic factors play important roles (Rowell 1975; Dibble and Bartha 1979).

While an important component of the soil, soil invertebrates are not easily quantified in the field and, as a result, there is little information about their response to crude oil releases. Consequently, the following sections focus on the recovery of the soil ecosystem. Terrestrial plant recovery, which is closely related to soil recovery, is discussed in Section 8.3.3.

Review of recent national PHMSA pipeline incident data[17] shows that almost half of reportable pipeline incidents resulted in soil contamination (PHMSA 2016)[18]. The majority of releases include soil remediation involving 100 cubic yards of soil or less, and only 3% of releases reported to PHMSA require soil remediation of 10,000 cubic yards or more (PHMSA 2016).

8.3.2.2 Recovery of Soils and Soil Microorganisms following a Crude Oil Release

Recovery of soils and soil organisms is strongly influenced by the volume of the release, as well as by the type of crude oil. Large, concentrated releases tend to result in a larger initial effect on a localized area, which leads to slower recovery (Wang et al. 1998). Large volume releases also can create hydraulic head pressure that may allow crude oil to penetrate deeper into the soil, where crude oil degradation is generally slower and recovery can be prolonged, than a small volume of crude oil.

The physical and chemical characteristics of the crude oil determine how the oil moves through soils, its toxicity to soil organisms, and how readily the crude oil can be degraded by microbial organisms. Low viscosity crude oils do not flow easily and adhere to soil particles, limiting their ability to penetrate into the soil and subsoils (Rowell 1975; Raymond et al. 1976; Vanloocke et al. 1979). Crude oils that contain a greater portion of straight-chained hydrocarbons (paraffins) will

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[17] Incidents must be reported to PHMSA if the incident results in one or more of the following consequences: 1) a release of 5 gallons or more, 2) death or serious injury necessitating hospitalization, 3) fire or explosion not intentionally set by the operator, or 4) property damage of $50,000 or more (49 CFR 195.50).

[18] The majority of PHMSA reportable pipeline incidents since January 2002 are small (3 barrels or less) and almost half of the PHMSA-reported pipeline incidents occur completely within operator-owned facilities (47%). Of those releases that were not contained completely within the operator's property, the median release volume was 20 bbl, again indicating that small releases are the most common and very large releases are uncommon (PHMSA 2016).

degrade more quickly than branched hydrocarbon chains or aromatic hydrocarbons (Volk 1980). Soluble aromatics metabolize more quickly than non-soluble aromatic hydrocarbons (Volk 1980; Fedorak and Westlake 1981).

Evaporation of crude oil at or near the ground surface can quickly reduce the volume of crude oil, particularly with lighter crude oil products, but other weathering processes (e.g., photodegradation) tend to occur more slowly (Wein and Bliss 1973; Wang et al. 1998). Weathering processes occur more slowly in colder environments or in soils that are acidic, low in nutrients, or anoxic (Sparrow and Sparrow 1988; Wang et al. 1998).

The topography of a release site is also an important factor, along with release size. Flat and relatively flat terrain tends to confine the crude oil to a relatively small, contiguous, and easily defined area. In steep terrain, the same volume of crude oil may move farther from an initial release site, compared to relatively flat terrain. Similarly, a precipitation event or snow melt can result in a larger affected area, but can lessen effects and accelerate recovery (Collins et al. 1994).

Clean-up and remediation efforts, including removal of contaminated soil and efforts to enhance biodegradation rates, generally can accelerate site recovery, although some methods such as *in situ* burning can negatively affect soil recovery (De Jong 1980; SLR Consulting 2008a; Nieber 2013). Both bioremediation (using microorganisms) and phytoremediation (using plants) are appropriate remediation options, especially at sites where a short growing season and low temperatures prevent rapid degradation of petroleum products through other weathering processes. See Section 7.1 for further discussion regarding weathering processes.

> ***Unknown Operator, Nipisi Pipeline Release, Alberta**: In 1970, Nipisi Pipeline released approximately 60,000 barrels of crude oil and affected over 25 acres of predominantly bog/fen habitat (Wang et al. 1998). Initial treatments included burning, tilling, or fertilizer additions. After the initial remediation treatment, no further reclamation activities occurred and the site was designated a scientific research area to study subsequent recovery rates of peat bog/fen habitat. After 25 years, surface and subsurface soil core samples in affected areas were analyzed to determine which clean-up method was most effective, and document changes in residual oil after 25 years. Results found no differences between the initial treatments. Core samples revealed that crude oil near the soil surface (depth: 0–1.6 inches) had been significantly weathered, whereas subsurface samples (depth: 4–16 inches) showed very little weathering. There were limited petroleum hydrocarbons at depth (depth: 31–39 inches). Beyond the surface of the peat bog, soil conditions were anoxic and the bog experienced negligible flushing of groundwater through recharge. Water levels did fluctuate vertically within the bog with seasonal precipitation. Researchers believe that the limited amount of crude oil weathering that was observed in the 4–16 inch*

> *samples was attributable to restricted natural attenuation processes, including volatility, photodegradation, and dissolution. Since groundwater movement was quite slow, researchers hypothesized that vertical penetration was related to the amount of organic content, grain size, and "chromatographic" processes that allowed lighter hydrocarbons to migrate deeper into the peat than if the water levels had been stable (Wang et al. 1998). While recovery is occurring, the colder temperatures at this latitude also may be responsible for slow recovery at the site.*

Soil microorganism activity plays a role in the biodegradation of crude oil and promotes recovery of both the biological function and matrix of the soil (Ellis and Adams 1961). Historical efforts to reclaim agricultural soils contaminated with petroleum hydrocarbons included enhancing aerobic conditions by increasing the population of soil microorganisms through fertilization and cultivation, seeding with microorganisms, or removal of crude oil by burning (Schwendinger 1968). Subsequent research has shown that some of these practices can reduce rates of soil recovery, particularly if applied inappropriately. Fertilization and cultivation (when feasible) typically increase biodegradation rates, particularly when degradation has depleted oxygen and nutrient levels in the soil. When done improperly, soil tilling can severely disrupt the soil structure, leading to increased compaction, increased erosion, and lower productivity. Seeding with microorganisms has had mixed success but is becoming a more sophisticated science as scientists identify which microbes or microbial communities degrade petroleum hydrocarbons most efficiently (Brezeszcz et al. 2016).

> ***Unknown Operator, Crude Oil Pipeline, Moose Jaw, Saskatchewan**: In January 1974, a pipeline failure occurred north of Moose Jaw, Saskatchewan. The pipe was buried 3.3 ft below the soil surface and the diluted bitumen (API gravity 23) flowed underneath the frozen topsoil and into a ditch that was 2,289 ft from the pipeline break. Some surface pooling also occurred close to the release point, but the majority of the crude oil was present as a thin lens, a fraction of an inch thick (several millimeters), just below the frost line. Of the total 15,720 barrels that were released, an estimated 10,060 barrels were recovered. No exact estimate of the crude oil remaining could be made as an unknown amount of crude oil was removed from the site in the form of contaminated snow. Some crude oil was likely lost by volatilization (De Jong 1980). Further remediation of the affected soil was not conducted and, in the spring of 1974, crops were planted. Fertilizer was applied to enhance the rate of crude oil weathering but was limited to the maximum rate tolerated by the crops. From 1974 to 1978, monitoring demonstrated an appreciable decrease in crude oil content within the soil, particularly in the 1977 fallow year when higher levels of fertilizer were applied (De Jong 1980). The surface soil (0 to 1.2 inches) showed the greatest hydrocarbon reductions. The study provided further support for the role of microbes in reducing the concentration of crude oil, and the recovery of the environment. The addition of fertilizer helped compensate for the increased demand for nitrogen*

made by the microorganisms that were most active in the surface soil where there was more oxygen (De Jong 1980).

Burning can be counterproductive for recovery of soil productivity since burning can create anaerobic conditions and incomplete burning can create a hydrophobic (i.e., resisting or repelling water) soil surface, substantially slowing the biodegradation of crude oil (Chapelle 1999; Cozzarelli and Baehr 2003; Nieber 2013). In some cases, crude oil contaminated soils can become hydrophobic, so soil tilling can be an effective remediation strategy to break the surface tension, allowing water to penetrate, as well as oxygenating the soil. Current strategies to enhance biodegradation of petroleum hydrocarbons generally focus on providing sufficient oxygen and nutrients to enhance microbial growth, while minimizing effects on terrestrial vegetation.

***Enbridge Crude Oil Pipeline, Bemidji, Minnesota**: During this 10,700-barrel release in 1979, crude oil sprayed over an area of approximately 1.6 acres and collected in low-lying areas before infiltrating the sandy soil and contacting shallow groundwater. Initial clean-up efforts removed approximately 8,200 barrels (75% of the original volume). Much of the remaining oil was retained in the surface and subsurface soils. Although there were immediate effects of the oil release on terrestrial habitat, subsequent removal of topsoil, and burning of that topsoil had a greater effect. Fire affects the chemical properties of soil organic matter through heating of soil organic matter and associated rapid losses of nitrogen availability. Nitrogen availability is a limiting factor for growing plants and other vegetation. Hydrophobic compounds may also be formed from heating of the soil and contribute to soil hydrophobicity (the ability of soil to repel water), which is commonly observed following a fire. Intense fires (greater than 750°F) may reduce or consume soil organic matter which holds sand, silt, and clay particles together, reducing overall soil structure (Kennard et al. 2016).*

The area that was disturbed and burned has remained relatively barren for most of the last 30 years due to the combined effects of lack of topsoil and burning that have made the soil hydrophobic(Nieber 2013). Using the Water Drop Penetration Time test to assess the soil's water repellency, researchers found that the soil within the crude oil spray zone ranged from slightly water repellent to extremely water repellent. Where the soil was extremely water repellent, water drops tended to evaporate from the surface before they could be absorbed into the soil. Repellency within the crude oil spray zone extended to a depth of approximately 16 in. in some locations. Outside the crude oil spray zone, the soil was water "wettable" (Nieber 2013). While hydrophobic soils and topsoil stripping have limited recovery in certain areas, the vast majority of the soils affected by the crude oil and its overland flow have recovered to support vegetation comparable to surrounding areas, particularly in low lying wetland areas.

Within the crude oil release literature, recovery of the soil matrix is usually associated with the reduction in petroleum hydrocarbon concentrations and resulting increased capacity to support an abundance and diversity of microbes, plants, and invertebrates. From a regulatory perspective, soil has recovered when the concentration of crude oil has been reduced below an established soil quality standard or guideline. According to the MN PCA risk-based site evaluation guidance, the residential soil reference value for benzene is 6.0 ppm and the industrial soil reference value for benzene is 10.0 ppm (MN PCA 2009, 2012). Many soil-based organisms have a high tolerance to petroleum hydrocarbons. Therefore, the recovery of the soil-based organisms usually is complete long before petroleum hydrocarbon reduction in the soil is achieved (Borja et al. 2010).

***Enbridge Line 3 Glenavon, Saskatchewan**: On April 15, 2007, approximately 6,230 barrels of crude oil were released as a result of a rupture on Enbridge's Line 3. Spill response and clean-up efforts for Enbridge's Line 3 release included removal of crude oil from surface water and vegetation. Crude oil was removed from a slough where hydrocarbon concentrations were above applicable criteria (e.g., Canadian Council of Ministers of the Environment (CCME) Freshwater Aquatic Life Criteria, 1999, updated 2007). Water and crude oil were removed from the affected slough using skimmers and vacuum trucks. Approximately 5,740 barrels of crude oil were recovered by April 22, 2007 (Transportation Safety Board Canada 2008). Contaminated vegetation, sediment, and soil were transported to an off-site location for disposal (SLR Consulting 2008a).*

Soil samples were collected in association with four components of the response and clean-up efforts: site stratigraphy[19] boreholes; pipeline trench repair; irrigation sump lines; and remediation of the affected slough. Soil samples were analyzed for BTEX, certain petroleum hydrocarbons, total metals, detailed salinity, and CCME PAHs. For soil samples not associated with the affected slough, contaminant concentrations generally were below the remediation criteria set by Saskatchewan Environment and the CCME. Concentrations of metals for samples either were below CCME agricultural criteria or were consistent with background conditions (SLR Consulting 2008a).

After the initial remediation efforts in the affected slough, the effects on soil were largely limited to sediment in the slough and possibly the upper one foot of underlying native clay soil (SLR Consulting 2008b). Additional remediation efforts were undertaken to remove contaminated sediment and native clay soil under the affected slough where hydrocarbon concentrations exceeded applicable remedial criteria (SLR Consulting 2008b). Following this remedial action, PAH

[19] Stratigraphy refers to how geological materials are vertically layered, usually as observed through soil cores taken from bore holes. For example, the stratigraphy from a well bore might be: loamy soil (0 to 2 ft bgs); sand (2 to 10 ft bgs); clay (10 to 15 ft bgs); and gravel (15 to 30 ft bgs).

concentrations were below CCME criteria and BTEX and petroleum hydrocarbon concentrations from the base of the excavation were generally non-detectable. Metal concentrations also were generally below CCME criteria and/or were consistent with conditions in nearby sloughs.

***Enbridge Line 37 Fort McMurray, Alberta**: In the Line 37 pipeline release in 2013, synthetic crude oil (approximately 750 barrels) released from the pipeline rose to the surface in the saturated soils, flowed overland along the pipeline ROW to a fen, and then reached the shores of an unnamed lake. Initial remediation efforts involved targeted excavation (soil and sediment), crude oil skimming of surface water, treatment of surface water, groundwater soil flushing (fen), and installation of physical barriers (hard and soft booms). Excavation within the ROW included removing affected soil at the release site and soil beyond the release point that showed visual contamination. Depth of excavation ranged from approximately 1 to 2.5 ft below grade. Approximately 7,275 tons of contaminated soil was removed from the ROW. Remediation efforts removed a majority of the released crude oil (approximately 93%), and natural attenuation monitoring was employed to track the weathering and effects of the remaining product (Hemmings et al. 2015).*

Soils within the ROW are generally mineral soils with a minor organic component. In the fen, peat at the surface is underlain by mineral soils of various textures (e.g., silt, clay and sand). Soil samples were collected from the ROW, the fen, and the area surrounding the unnamed lake. These samples were analyzed for BTEX, straight-chained petroleum hydrocarbons, and PAHs. Concentrations of BTEX and straight-chained petroleum hydrocarbons were higher than acceptable guidelines in many of the samples. Following initial remediation efforts (excavation), residual oil was still detected within the soils of the right-of-way and fen (Hemmings et al. 2015).

A biotreatability study determined that hydrocarbon-degrading bacterial populations were present in the soil in sufficient quantities to allow biodegradation to occur in the presence of oxygen or under anoxic conditions. Further study of these bacterial populations indicated that they would be capable of degrading short-chain hydrocarbons, but less able to degrade long-chain hydrocarbons.

Ecotoxicological tests were then conducted to determine if residual hydrocarbons posed a risk to ecological receptors. These tests included survival and reproduction of Collembola (small wingless soft-bodied hexapods that live in soil) and avoidance response in earthworms. Tests also were conducted to assess emergence and growth of plants, the results of which are discussed in Section 8.3.3. Petroleum hydrocarbons did not affect adult Collembola survival or *reproduction in the ROW soils, but there was significant reduction in both survival and reproduction in the fen soils (Hemmings et al. 2015). Earthworms avoided the contaminated soils from both the ROW and fen and showed preferential selection for the uncontaminated reference soils. This avoidance was attributed in part to the petroleum hydrocarbons and to the low soil pH. Site-specific target levels for petroleum hydrocarbons that would be protective of terrestrial ecological receptors were calculated for right-of-way soils and fen soils. Soil concentrations were generally lower than the target levels, although up to 15% of the samples from the fen had petroleum hydrocarbon concentrations that exceeded the target levels. Overall conditions at the site were considered to be "improving," but specific statements regarding recovery status of soils were not made and monitoring at the site was still on-going (Hemmings et al. 2015).*

Petroleum hydrocarbon releases in wetlands (e.g., bogs and fens) in northern portions of North America exhibit slower remediation activity due to a decreased rate of biodegradation of subsurface crude oil in anaerobic environments, acidic conditions, and cooler temperatures, as well as a lack of nutrients in wetlands for petroleum hydrocarbon-degrading microbes and bacteria. Additionally, intense fire can limit nutrients in the soil (nitrogen); however, adding fertilizer can aid in soil nutrient and microbe recovery.

8.1.1.1 Factors Affecting Recovery

Spill response and remediation of crude oil-contaminated soils can minimize the effects of crude oil on soils, as well as accelerate recovery (Hemmings et al. 2015; SLR Consulting 2008b). Top soil stripping followed by topsoil replacement can quickly restore the productivity of affected areas. Bioremediation (using microorganisms) and phytoremediation (using plants) are appropriate remediation options, especially at sites where a short growing season and low temperatures prevent rapid degradation of petroleum products through other weathering processes. In contrast, in situ burning of oiled soil reduces the microbial community and can leave a water-repellent residue that further inhibits microbial recolonization and biodegradation (Essaid et al. 2011; Nieber 2013; Kennard et al. 2016).

Environmental conditions that affect the weathering of crude oil can impede or enhance recovery. Topography that promotes flushing of crude oil from a site following precipitation events or snow melt can accelerate recovery (Collins et al. 1994). Cold temperatures restrict evaporative losses, microbial activity, and biodegradation (Wein and Bliss 1973). Low nutrient availability restricts microbial activity and biodegradation (Sparrow and Sparrow 1988). Higher oxygen levels in the soil promote aerobic degradation, but degradation also occurs under anaerobic conditions (Essaid et al. 2011).

8.3.2.3 Soil and Soil Microorganism Summary

Effective clean up and remediation of crude oil-contaminated soils are important factors in accelerating recovery of soils and, in turn, soil biota and vegetation. Remediation of crude oil-contaminated soils can be accelerated by adding fertilizer to increase the nitrogen content of the environment, which increases microbial activity and aids the productivity of petroleum hydrocarbon-degrading microbes and bacteria. Although crude oil releases in the terrestrial environment have the potential to cause immediate effects to soil structure and microorganisms, the microbial community can readily adapt and decompose crude oil. This decomposition, along with evaporation and photodegradation, contributes to the weathering processes that reduce the concentration of oil and oil constituents and facilitates recovery.

Other factors also strongly influence initial effects to soil and subsequent recovery. In general, large volumes of released crude oil will cause more damage to the soil and greater changes to the abundance and diversity of microorganisms compared to small releases. The greater initial damage subsequently requires longer times for adaptation and recovery. Environmental conditions supporting weathering, such as warm temperatures and presence of oxygen, lead to more rapid soil recovery.

8.3.3 Vegetation

8.3.3.1 Terrestrial Vegetation

Plants tend to dominate the visible terrestrial landscape. Using photosynthesis, plants convert solar energy and carbon dioxide into carbohydrates and oxygen and form the primary food source for terrestrial life. Healthy plant communities provide numerous ecosystem services that include:

- Supporting: soil formation and stabilization, nutrient fixation and cycling, primary production
- Provisioning: food, fresh water, fuel wood, fiber, medicines, and biochemical
- Regulating: climate, soil temperature, and moisture
- Providing: cultural, spiritual and religious, recreation, aesthetic, and educational value (World Resource Institute 2003)

Terrestrial plant recovery is influenced by many of the same factors that determine the effects of a crude oil release on soils and their recovery. This section specifically addresses the recovery of terrestrial plants from effects of a crude oil release. While releases off the operator's property often may affect vegetation, only 2.5% of pipeline incidents reported to PHMSA[20] resulted in the need for active vegetation remediation[21] (PHMSA 2016).

8.3.3.1.1 Recovery of Terrestrial Plants following a Crude Oil Release

Many factors that influence the effects of released crude oil and associated recovery of terrestrial plants are closely related to the recovery of soils following a release (Section 8.3.2). In general, the recovery of oil-affected soils varies from a few weeks to decades. The rate of recovery for vegetation depends on the sensitivity of the affected species; the severity of the release and the amount of physical contact of vegetation with the crude oil; and the rate of reproduction and proximity of unaffected seed sources. Factors that impede or accelerate weathering processes of crude oil such as volatilization, photodegradation, or natural biodegradation affect the rate of both soil and plant recovery (Belsky 1982; Wang and Fingas 1997).

Recovery is expected to be slower under colder climatic conditions as lower temperatures affect the length of growing seasons, rate of crude oil weathering, and biological activity that supports biodegradation. Snow cover and shorter winter days also affect the rate of photodegradation.

An experiment was conducted on two areas of permafrost vegetation in central Alaska, which were sprayed with crude oil to determine recovery rates following the use of fertilizers and bacteria to aid reclamation processes (Racine 1994). Following the initial spraying, crude oil was located below the ground surface and on top of the permafrost. In areas where a low volume of crude oil was sprayed on the vegetation, the oil initially covered the ground, which caused initial damage to vegetation. Following 20 years of recovery, understory vegetation had almost recovered. However, in areas where a high volume of crude oil was sprayed, the release created small areas of oil-saturated ground surface, which exhibited little sign of recovery. While the crude oil spread below the ground surface, it had little or no apparent effect on the shallow-rooted vegetation above the migrating oil, even after 15 to 20 years. Both sites exhibited high, long-term mortality of black spruce after 15 years. Remediation efforts included in-situ application of fertilizers and bacteria to aid in recovery in place of excavation methods. Recovery was rapid for areas with less saturated crude oil where lichens, mosses, and shrubs all showed good recovery after 20 years.

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[20] Incidents must be reported to PHMSA if the incident results in one or more of the following consequences: 1) a release of 5 gallons or more, 2) death or serious injury necessitating hospitalization, 3) fire or explosion not intentionally set by the operator, or 4) property damage of $50,000 or more (49 CFR 195.50).

[21] The majority of PHMSA reportable pipeline incidents since January 2002 are small (3 barrels or less) and almost half of the PHMSA-reported pipeline incidents occur completely within operator-owned facilities (47%). Of those releases that were not contained completely within the operator's property, the median release volume was 20 bbl, again indicating that small releases are the most common and very large releases are uncommon (PHMSA 2016).

While this experiment demonstrated how severity of oiling affects vegetation recovery rates, the observed rates of recovery may be slower than expected in the Minnesota region. Racine's (1994) experiment was conducted in central Alaska where crude oil weathering processes would be slower and growing conditions harsher than in Minnesota due to latitude and the presence of permafrost. Permafrost is defined as locations where soil temperatures are continuously below 32 degrees Fahrenheit for two or more years. In addition to colder soil temperatures that would reduce the rate of vegetative growth, permafrost would reduce growth by limiting availability of soil moisture to vegetation within the root zone. Permafrost also would greatly reduce natural attenuation processes that are affected by temperature (e.g., volatilization, biodegradation). In Alaska, 80% of the state is affected by permafrost, including the study site. While Minnesota has soils that can freeze to depths of 60 inches or more, frozen soils are considered seasonal and therefore, are not considered permafrost (World Meteorological Organization 2016). Consequently, vegetation in Minnesota is likely to recover more quickly from crude oil exposure than that observed in central Alaska, even though the sites share many of the same species such as black spruce, lichens, and mosses.

Plants recover from crude oil exposure through both the regrowth of surviving structures, such as roots and buds, and recolonization from the surrounding unaffected areas. A study conducted in the Northwest Territories, Canada, cited by Racine (1994), indicated vegetation that was oiled during the summer exhibited greater damage than vegetation that was oiled in winter (Hutchinson and Freedman 1978).

The rate of recovery can be influenced by precipitation and runoff events that can remove crude oil from the affected area. In regions with high snowpack and good drainage, oil can be flushed out of the area by large volumes of snowmelt water. This effect can lead to rapid recovery of habitat and seed germination within a year (Collins et al. 1994; Belsky 1982).

Historical efforts to promote plant recovery on agricultural soils contaminated with petroleum hydrocarbons often have involved increasing the population of soil microorganisms. Efforts to increase soil microorganisms have included fertilization and cultivation to produce more aerobic conditions or seeding with microorganisms (Schwendinger 1968). Even in areas where soils support the natural weathering of the crude oil, the sudden availability of organic compounds from the crude oil may promote microbial growth. As discussed in Section 8.3.2, the addition of fertilizers, including oxygen-releasing compounds, and tilling of the soil can help maintain microbial activity and thus promote the biodegradation of the crude oil and the recovery of the plant community.

Like soil microbes, plants also can play an important role in promoting the degradation of soil contaminants. Phytoremediation is a technique that utilizes plants to biodegrade contaminants from the soil and improve soil structure. Plants infiltrate soil with their roots, releasing nutrients and supporting growth of indigenous microbes throughout the soil profile. Active revegetation through seeding and planting following remediation can be an important factor influencing terrestrial plant recovery.

At the community level, while plant communities that experience substantial effects may recover quickly, the recovery of a plant community may take an altered trajectory and regress to an earlier successional stage. Early successional plant communities are characterized by more disturbance-tolerant species, often including plants considered invasive and noxious weeds (Robson et al. 2004). While affected plant communities may recover quickly and regain their ecological function, productivity, and abundance, returning to a diversity state prior to the release without intervention can take years to decades.

Robson et al. (2004) examined the differences in terrestrial plant communities between uncontaminated sites and sites affected by crude oil releases located in Saskatchewan, Canada. Although this study did not focus specifically on recovery endpoints, it did examine some of the factors that influence the recovery process. Differences in total vegetative cover and species diversity between oiled and uncontaminated sites were attributed to the tolerance of different species to crude oil, soil disturbance, and low soil fertility. Oiled sites had substantially more early successional species that were self-pollinating or reproduced solely by seed (Robson et al. 2004). The authors noted that species composition and abundance were affected by distance to undisturbed habitat, which may serve as an important seed source.

The following case studies provide examples of terrestrial plant recovery from oil releases. Where the information is available, these examples describe the recovery status of the plant community, time to recovery, and influence of the release characteristics and the environment on the recovery. Although broad generalizations cannot be drawn from a single event, case studies provide important information that, in combination with existing literature, can help regulators and operators gain a more comprehensive understanding of the effects of oil releases on terrestrial plants and recovery.

> ***Unknown Operator, Mt. Baker, Washington**: In March and early April of 1972, 164 barrels of No. 2 Fuel Oil were released near Mt. Baker, Washington, inundating 2 subalpine meadow communities. Because subalpine communities have limited growing seasons and relatively thin soils compared to low elevation plant communities, subalpine plant communities may be particularly vulnerable to disturbance. Prior to the release, vegetative plant cover was 80 to 100%. Two growing seasons after the release, plant cover was reduced to only 1%. Recovery of the subalpine plant community was studied over the following nine years (Belsky 1975; Belsky 1982).*
>
> *Only one species of sedge and one species of heather survived the initial release. Seedlings of black alpine sedge (<u>Carex nigricans</u>) appeared on the bare soil after one growing season, and other subalpine species returned over the next two to four years although the plant community remained measurably affected. After 9 years, subalpine ground cover was between 5 and 20%, and plant abundance and diversity remained low. However, the researchers stated that the original disturbance was no longer discernable by a casual observer.*

Recovery of a subalpine plant community from the release can be facilitated by the type of fuel, the topography of the area, and the time of the release. Although diesel fuel is initially more toxic to plants (Walker et al. 1978;, Wein and Bliss 1973), it is predominantly composed of relatively small chain hydrocarbons, which weather more rapidly than complex ringed hydrocarbons found in higher concentrations in crude oils. The snow cover and frozen ground that was present at the time of the release prevented adsorption of the fuel by the soil, and much of the contact with the product was to dormant vegetation (Belsky 1982). In the spring, a large volume of snowmelt water and the steep terrain combined to flush much of the fuel out of the area, further limiting the subsequent exposure to the emerging vegetation.

***Unknown Operator, Crude Oil Pipeline, Moose Jaw, Saskatchewan**: In January 1974, approximately 39.5 acres of agricultural land were affected by a release of crude oil (API gravity 23) from a pipeline in Moose Jaw, Saskatchewan. Approximately 15,700 barrels were released, of which approximately 10,100 barrels were recovered from trenches dug around the contaminated area. Crops were planted to study their performance as a tool for delineating the contaminated areas. Fertilizer was applied to enhance the rate of biodegradation, but application rates were limited to the maximum levels tolerated by the crops. Oil was observed to have affected the soil both vertically (depth) and horizontally.*

The results of the study indicated that soils with an oil content greater than 1% were associated with zero growth during the first growing season in 1974 following the release. The correlation between low yields and oil concentrations may have been influenced by late seeding in 1974. The crop did not mature and total above ground yields were obtained (De Jong 1980). The study continued through 1978 with different crops planted each year. With the exception of 1977 in which the oil-contaminated area was left fallow, De Jong (1980) noted that areas of poor growth were correlated with areas of greater oil content.

De Jong (1980) also observed in areas unaffected by oil contamination, that poor germination and growth of vegetation were caused by soil disturbance from large equipment used during clean-up activities. Use of the equipment resulted in poorly-filled trenches and boreholes, subsoil on the surface, and soil compaction.

At the end of the study, some residual contamination remained in 7 of 9 soil borings at depths from soil surface to 47 inches and ranged between 0 and 5% of soil volume. Oil contamination greater than 0.5% soil volume affected soil water uptakes at deeper soil depths.

Crop yields in oil contaminated areas remained lower than those from non-contaminated areas. Grain yield and soil moisture data for contaminated soil cores during the 1978 growing season indicated yields decreased by approximately 161 pounds/acre (lbs./ac). For comparison, yields of non-contaminated soil cores indicated yields decreased approximately 71 lbs./ac for each centimeter decrease in soil water uptake. Decreased yields at the oil contaminated sites were influenced by reduced availability of nitrogen in the soil and reduced water uptake by the crops (De Jong 1980). Key factors discussed by the authors contributing to microbial degradation of oil included adequate soil moisture, nutrients (i.e., nitrogen), and subsurface soil temperature.

***Enbridge Crude Oil Pipeline, Bemidji, Minnesota**: This 1979 pipeline release sprayed 10,700 barrels of crude oil over an area of approximately 1.6 acres. The released oil collected in topographic depressions before infiltrating into the soil and groundwater.*

While there were immediate effects from the oil on the terrestrial vegetation (e.g., trees sprayed by oil), the long-term effects to vegetation were localized and were the result of topsoil stripping without replacement and in-situ burning of the oil. While these methods were considered appropriate at the time, the portions of cleared and burned area have remained relatively devoid of vegetation for most of the last 30 years due in part to the burning of the crude oil and the development of water repellent surface soil. The lack of revegetation also left the soil prone to surface erosion, and the remaining rocky substrate further inhibited the rate of revegetation. The majority of the site was not stripped of topsoil and soil was not burned in place, and the herbaceous vegetation appears to be relatively comparable to the surrounding ROW, particularly in the low-lying wetland areas (H. Tillquist, pers. comm.).

Fire can affect the chemical properties of soil organic matter through heating of soil organic matter and the associated rapid losses of nitrogen in the areas where the soil has been burned. Lack of nitrogen is a limiting factor for growing plants and other vegetation. Hydrophobic polymers formed during the soil heating/burning can result in soil hydrophobicity. Intense fires (greater than 750°F) also may reduce/consume soil organic matter that holds sand, silt, and clay particles together, reducing overall soil structure (Kennard et al. 2016).

Because the site was used as a research site to investigate the long-term effects of an oil release, remediation to hydrophobic soils has not been conducted. According to Delin (H. Tillquist, pers. comm.), the addition of fertilizers, shallow tilling, and where absent, topsoil replacement, would likely result in the reestablishment of the vegetative community.

> *Factors influencing recovery at this site included landscape position (topography and microtopography), as well as the degree of water repellency. Vegetation is relatively dense in topographic depressions where run-off has provided sufficient water to support growth, but quantitatively, it has not completely recovered outside of these depressions (Nieber 2013).*

8.3.3.1.2 Factors Affecting Recovery

Factors that contribute to accelerated weathering of crude oil and soil recovery also contribute to terrestrial plant recovery. These factors include warm temperatures, evaporation, photodegradation, flushing, and microbial activity (Wein and Bliss 1973; Belsky 1982; De Jong 1980). Cold temperatures and shorter growing seasons reduce the rate of microbial activity and evaporative losses, thus limiting the potential biodegradation of the crude oil and subsequent terrestrial plant recovery (Wein and Bliss 1973; De Jong 1980). Higher nutrient availability supports plant growth and can accelerate microbial activity stimulated by the crude oil, further promoting oil degradation and terrestrial plant recovery (De Jong 1980; Robson et al. 2004).

Crude oil in soils can reduce available nitrogen and affect water uptake, impeding terrestrial plant recovery (De Jong 1980). In some cases, the effect of crude oil and remediation on the plants renders the soil prone to erosion and other physical forces. Under these circumstances, the damage may be more permanent where the soil layer is significantly disturbed (Essaid et al. 2011; Nieber 2013).

Water from storm events or snow melt can act to transport the crude oil, especially on sloped ground, thus flushing oil out of the soil and naturally attenuating oil concentrations (Collins et al. 1994; Belsky 1982). Resulting decreased hydrocarbon concentrations in the soil can accelerate plant recovery.

Crude oil releases occurring at or near periods of plant dormancy can result in less severe effects and subsequently aid recovery (Belsky 1982).

Early successional species that are self-pollinating or reproduce solely by seed are important early colonizers following a crude oil release. Undisturbed habitat nearby can function as a seed source for these species and thus accelerate recovery (Robson et al. 2004).

Clean-up activities that compact and/or disturb soils can slow terrestrial plant recovery (De Jong 1980). Burning of oil after a release can damage both plant roots and buds, reduce the microbial community, and leave a water repellent residue on the soil surface that further inhibits crude oil weathering and terrestrial plant recovery (Essaid et al. 2011; Nieber 2013). Recovery can be prolonged for sites that do not undergo remediation and terrestrial plant restoration (Nieber 2013).

8.3.3.1.3 Summary of Terrestrial Vegetation

Terrestrial plants are an integral part of the soil food web and effects to and recovery of soils are closely related to terrestrial plant recovery. The case studies presented for both terrestrial plants and soils describe a recovery process and indicate that plant communities are able to recover from the effects of a crude oil release. Environmental conditions that enhance weathering of oil and/or bulk transport and attenuation in the soil are key factors to accelerating the recovery of the plant community. Factors that contribute to weathering, soil recovery, and subsequent terrestrial plant recovery include oil type, temperature, nutrient availability, soil moisture, evaporation, photodegradation, flushing, and microbial activity. The interaction of these variables can be complex and needs to be evaluated on a site-specific basis following a release. Disturbance related to remediation activities can result in additional effects to terrestrial vegetation, further delaying recovery. See Section 8.5 for further details. Therefore, remediation efforts should focus on minimizing soil disturbance, soil compaction, and disruption of root masses, if possible, allowing affected plant communities to recover naturally.

8.3.3.2 Wetland and Riparian Vegetation

Wetland and riparian vegetation is associated directly with or exists in the proximity of wetland or open water habitats. Wetland plants can range from fully aquatic species to those species such as red maple (*Acer rubrum*) that grow across a wider range of habitats, including seasonally inundated and seasonally saturated areas. Riparian vegetation grows along the banks of watercourses and waterbodies and can include both wetland and non-wetland communities.

Wetland and riparian communities provide a variety of functions that support both natural and human environments. These functions include, but are not limited to, wildlife and fisheries habitat, groundwater exchange, shoreline stabilization, flood and storm surge reduction, and water quality protection through the uptake of excess nutrient and toxins. Wetlands are distinguished from dry lands (uplands) by ground or surface water that is present for a sufficient period of time to saturate the soil and support a prevalence of vegetation adapted to these wet conditions. Wetlands can be closely associated with marine, riverine, or lentic (e.g., ponds and lakes) systems or they may form in isolated basins or on slopes away from obvious sources of surface water. In wetland classification systems such as the National Wetland Inventory (NWI) (Cowardin et al. 1979), vegetation, soils, and hydrology play key roles in defining the wetland type. Although hydrology, soils, and vegetation are intricately tied together, vegetation is often the wetland focal point because it is readily visible and changes in plant communities can be easily observed.

8.3.3.2.1 Recovery of Wetland and Riparian Vegetation Following a Crude Oil Release

Many of the same factors that influence the initial effects of a crude oil release also can influence the recovery of wetland and riparian vegetation. The type of oil, release volume, time of year, and environmental conditions at the time of the release will influence the rate of recovery (Hoff et al. 1993; Lin and Mendelssohn 1996). Because of its viscosity, crude oil can coat vegetation and inhibit respiration. Light, soluble, and highly volatile constituents within crude oils can be toxic to plants, particularly herbaceous vegetation (Michel and Rutherford 2013). Plants tend to be less sensitive to petroleum hydrocarbon toxicity compared to animals. Most release volumes from pipelines are small and contained entirely within an operator's property. Consequently, the effects on vegetation are often minimal with nominal periods for recovery. In the unlikely event of a very large, widespread release, effects on vegetation can be severe and recovery periods may be long.

Similar to terrestrial vegetation, the time of year when a release occurs can strongly influence the type and extent of effects of crude oil releases on vegetation, as well as the time it can take for plant communities to recover. A crude oil release that occurs during or just prior to senescence (i.e., seasonal quiescence of vegetation) will have less of an effect on vegetation and recovery should occur more quickly (Michel and Rutherford 2013; Pezeshki et al. 2000). Senescence, including leaf drop in many plants, occurs prior to the onset of dormancy when most, if not all, biological processes within a plant cease until the next growing season. If leaf drop has occurred, there is less surface area exposed to oiling and, under dormant conditions, the plant does not experience the same metabolic or reproductive effects that it does during the growing season.

Other aspects of the initial crude oil release and the environment in which the release occurs also can influence the recovery period. If a crude oil release only coats the aboveground portion of a plant, recovery can occur within a single growing season. In contrast, if the crude oil penetrates into the soil, recovery often takes three to five years, or potentially longer (Mendelssohn et al. 2012). Environmental influences such as the flow and movement of water, whether from natural or anthropogenic activities, can advance or potentially hinder recovery. The natural stream flow, tidal action, and wakes created by boat traffic were attributed to helping flush oil from a contaminated marsh along the Delaware River from the Panamanian Tank Vessel Grand Eagle release in 1984 (Michel and Rutherford 2013). Flood events that occur concurrently with an oil release, such as in the Enbridge Line 6B release near Marshall, Michigan, can result in oil becoming stranded in larger areas and areas beyond annual flood levels (USFWS et al. 2015a). Flooding can help to flush oil from affected areas, but oil stranded above typical flood stages can remain for longer periods if it is not cleaned up, and can slow vegetation recovery and reestablishment (Michel and Rutherford 2013).

Physiology and reproductive strategy of vegetation affect how readily plants can recover from a crude oil release or other environmental disturbances. For example, rhizomes, which store starches and proteins, provide plants with an energy source and, in some species, act as an alternate means of reproduction that allow plants to survive and more readily recover following a crude oil release (Lin and Mendelssohn 1996). Annual species tend to be particularly susceptible to the initial effects of an oil release but can be the first to reestablish if there is an available seed source near the release location (Michel and Rutherford 2013). Recovery time also is influenced by the wetland community type (e.g., forested, scrub-shrub, emergent). If the root zone is unaffected by crude oil or clean-up activities, vegetation can begin to rebound within a single growing season from the direct oiling effects (Rood and Hillman 2013).

Oil spill response methods on vegetation can either impede or accelerate recovery depending on how the methods are employed and the type of vegetation affected. The recovery period for historical wetland mitigation can take decades if the vegetation is removed during remediation efforts (USACE 2010), while current techniques avoid disturbing wetland vegetation to the extent practical. The potential for adverse effects was also observed in the Texaco (Anacortes Refinery) 1991 Fidalgo Bay release in Puget Sound, Washington. After the release of 5,000 barrels of North Slope crude oil in a salt marsh, researchers followed the recovery of woody saltwort (*Salicornia virginica* [*Salicornia depressa*]) to study the influences of the oil release and subsequent clean-up methods (Washington Department of Fish and Wildlife et al. 2004). The recovery of woody saltwort density in treatment areas that employed flushing with low-pressure, ambient temperature seawater lagged only slightly behind the control areas. The treatments that involved oil removal with a high-powered industrial vacuum and manual clean up and where the surface was trampled by foot traffic, took an additional three months to reach control densities. In addition, the below-ground biomass of woody saltwort was lower, possibly indicating that these plants were stressed and/or there was damage to the below-ground root system (Hoff et al. 1993).

When clean-up activities are not employed, recovery results can be highly variable. In the absence of clean up, recovery of wetland and riparian vegetation is influenced by the scale and severity of the release event, including the volume of released oil, the plant community involved, and other environmental factors. Following a release from a Plains Midstream pipeline into the Red Deer River, Alberta, recovery occurred quickly in a relatively exposed habitat along the riverbanks (AER 2014). Further details regarding this release and vegetative recovery are discussed below as a case study.

In contrast, prolonged recovery occurred at Buzzards Bay, Massachusetts, and Chalk Point, Maryland, which involved saltmarsh and brackish marsh communities, respectively. In September 1969 and October 1974, two separate No. 2 Fuel Oil releases from tank barges (*Florida* [4,500 barrels] and *Bouchard 65* [180 to 870 barrels], respectively) into Buzzards Bay caused extensive plant mortality (Costa 2013). Without clean up or remediation, salt marsh plants had not fully recovered after nearly 40 years based on stem density and biomass estimates. Factors contributing to persistent oil effects from these releases included the type of oil (No. 2 Fuel Oil), high tides that stranded the oil in the marsh where it penetrated into the organic soils, the sheltered setting of the affected marsh, a lack of oil clean up and remediation activities, and amount of oil that remained in the environment (Michel and Rutherford 2013). Similar to the Buzzard Bay releases, the Chalk Point release occurred on April 7, 2000 and involved the release of 3,330 barrels of a No. 6 and No. 2 fuel oil mixture into a brackish marsh along the Patuxent River from a pipeline going into nearby Chalk Point Power Generating Station (Michel and Rutherford 2013). The heavily oiled area in the interior of the marsh was left untreated (due to limited access) and seven years later, the oil showed little evidence of weathering due to the nature of the released products. No. 2 and No. 6 fuel oils consist largely of complex, heavy molecular weight hydrocarbons that are resistant to weathering and biodegradation. The slow weathering in the interior of the marsh was attributed to slow physical removal processes, oil type, and low oxygen availability (Michel et al. 2009). Although vegetation within the marsh exhibited some growth, plant density and height were less than what was observed in unaffected areas.

Although the literature is limited regarding the functional recovery of temperate wetland and riparian vegetation following a crude oil release, information from traditional wetland restoration provides insight into the recovery process. Herbaceous wetlands, especially freshwater emergent marshes and wet meadows, have successfully been created or restored (NRC 2001). Other wetland community types are more difficult to replicate or restore because of complex species assemblages (e.g., sedge meadows, fens) or specific requirements for groundwater or surface water flows (Minkin and Ladd 2003; NRC 2001). In these cases, wetlands and riparian areas may recover some ecological functions even though the area may revert to another state (Minkin and Ladd 2003).

The initial and potentially long-term effects of crude oil releases on wetland and riparian vegetation are influenced by a variety of environmental and biological conditions, as well as the amount of oil in a given location, the physical and chemical characteristics of the oil, and the methods used to clean up the release.

The following case studies from temperate North American environments provide examples of the effects these releases had on the vegetation and the vegetation's subsequent recovery. The following case studies describe several remediation approaches and environmental factors that can accelerate or impede recovery of wetland and riparian vegetation following an oil release.

> ***Enbridge Line 4 Cohasset, Minnesota***: *On July 4, 2002, an underground pipeline located west of Cohasset, Minnesota, ruptured and released approximately 6,000 barrels of crude oil in a large wetland complex (NTSB 2004). Approximately 2,574 barrels of crude oil were recovered. Because of concerns that the oil contamination would spread with forecasted rain, the decision was made to burn the oil in place (NTSB 2004). The in-situ burn was estimated to have consumed approximately 3,000 barrels of crude oil. The affected wetland was described as a peat wetland complex with naturally occurring forested and scrub-shrub components. The crude oil release occurred in the pipeline ROW, which was dominated by herbaceous vegetation, including devil's beggartick (Bidens frondosa), bluejoint reedgrass, and broad-leaf cattail (USFWS et al. 2005). After the vegetation in and adjacent to the release site was burned, temporary mat roads were constructed to allow access for heavy equipment. Burned trees were cut and removed, and oiled peat and debris were excavated to a depth of approximately three ft.*
>
> *In total, approximately 11 acres of wetlands were affected by the initial crude oil release and remediation activities. Following remediation, wetland restoration efforts included re-establishing site topography and vegetation. Disturbed*

surfaces within the wetland were re-contoured to create pit and mound microtopography and some seeding with native wildflowers and grasses was conducted. Emergent plants, unrooted cuttings (shrubs and trees), and tree seedlings were installed. As of 2005, the affected site was a mix of emergent vegetation and open water habitat. Although the site was dominated by cattails, other species such as broad-leaved arrowhead (Sagittaria latifolia), water plantain (Alisma subcordatus), duckweed (Lemna minor), sedges, and rushes also were becoming established. The presence of duckweed is often considered an indicator of good water quality since it is among the most sensitive of aquatic plants (Wang 1986). Because of changes to the site including the removal of the peat substrate from the affected area, it is unlikely that the peat wetland will fully revert to its previous condition, but instead will provide emergent wetland habitat (USFWS et al. 2005).

Canadian National Railway Company, Wabamun Lake Oil Release, Alberta: *On August 3, 2005, a Canadian National Railway Company railroad incident involving a release of 4,400 barrels of heated Bunker C Oil (a very high density oil) and 554 barrels of pole treating oil flowed across lawns adjacent to the railway and into Wabamun Lake. The Bunker C Oil was still warm when released due to being recently heated for loading into railcars and was therefore less viscous than the oil would have been at ambient temperature. As it flowed overland and into the lake, the Bunker C Oil picked up sediment, debris, and water that changed the behavior of the oil once it entered Wabamun Lake (Hollebone et al. 2011). Strong winds and wave action dispersed the oil-water-sediment mixture across the lake.*

These oil-water-sediment mixtures quickly formed neutrally-buoyant tarballs[22] *that were observed moving up and down through the water column. Not long after the release, the submerged and sunken tar balls were seen along the shoreline and in shallow water. Some of the submerged oil-water-sediment material also formed relatively large patties and logs. Even after initial clean-up efforts, tar balls were commonly observed along the vegetated shoreline (Hollebone et al. 2011). Tar balls on and around the vegetation continued to move laterally in the water column and release oil during the course of their movements. Those tar balls in contact with and adhering to shoreline vegetation also continued to release oil. In February 2007, tar balls were still observed within shoreline vegetation and adhering to roots of shoreline vegetation (Hollebone et al. 2011).*

The vegetated shoreline of Wabamun Lake is dominated by softstem bulrush (Schoenoplectus tabernaemontani) and broad-leaf cat-tail (Typha latifolia)

[22]Bunker C Oil is extremely heavy and viscous. Therefore, formation of neutrally and negatively buoyant tar balls and emulsions is more likely than with other crude oils.

(Wernick et al. 2009). Because of the location of the release and the wind direction at the time, much of the oil became trapped in the softstem bulrush beds along the lakeshore. During clean-up efforts, the oiled softstem bulrush was cut manually or with mechanical weed cutters, either just below the waterline or just above the sediment. The sediments were then flushed and/or vacuumed (Thormann and Bayley 2008; Wernick et al. 2009). The selected method of treatment was based on accessibility and the perceived sensitivity of the area to disturbance. In general, areas that were accessible from shore were cut manually. Those areas inaccessible from shore and considered to be particularly sensitive to disturbance were cut primarily using reed cutters (Thormann and Bayley 2008). Low-pressure flushing was used to remove oil from sediment and vegetation, and vacuuming was used to remove remaining tarballs.

Studies that followed the softstem bulrush beds recovery concluded that the Bunker C Oil itself had no long-term effects on the biomass, cover, height, or seedhead production of the softstem bulrush (Thormann and Bayley 2008). However, the clean-up efforts did have a substantial negative effect on rhizome density and biomass (Thormann and Bayley 2008). Researchers concluded that clean up treatment applied to some of the study site substantially disturbed or damaged plant rhizomes resulting in decreased biomass (Thormann and Bayley 2008). The same authors concluded that the richness and cover of submerged aquatic plants had not been affected by the release or subsequent clean-up treatments (Thormann and Bayley 2008).

When comparing two of the monitoring sites, researchers concluded that the difference in the aboveground biomass of softstem bulrush potentially could be attributed to water depth, wind and wave exposure, and the intensity of the clean-up treatment. In general, monitoring sites with shallower water depth, regardless of the degree of oiling or intensity of treatment, had a greater biomass of softstem bulrush. The difference in biomass in shallower water was attributed to increased rates of seed germination, seedling growth, and rhizome survival and re-growth (Thormann and Bayley 2008). Because the water level in Wabamun Lake rose approximately 1.3 ft from 2005–2007, it is uncertain whether some of the deeper areas will successfully recolonize.

***Plains Midstream, Red Deer River, Alberta**: On June 7, 2012, between approximately 1,000 and 3,000 barrels of light crude oil released into the Red Deer River in Alberta. The release was caused by high floodwaters that eroded the riverbed and banks, exposing the 12-inch Rangeland South Pipeline within the river, resulting in a rupture. The flood eroded the west bank of the river and exposed the line, thereby creating the break in the pipeline (AER 2014).*

Following the release, researchers identified three areas along the river floodplain to assess the release effects on vegetation and the potential for natural recovery (Rood and Hillman 2013). In consultation with Alberta Environment and Sustainable Resource Development, two of these areas received no remedial clean up, and the third only had limited vegetation removed during clean-up efforts in order to study vegetation recovery rates. Balsam poplar (Populus balsamifera), sandbar willow (Salix exigua), and wolf willow (Elaeagnus commutata) dominated the floodplain areas along the Red Deer River. Researchers tagged and measured hundreds of saplings of these three species in the study areas. The degree of crude oil coating on the saplings was variable. Initially, the coating was oily and readily transferable but, after two weeks, weathering of the oil made the coating tacky and more difficult to remove. After approximately four weeks, the coating was chalky and dark as a result of oxidation and heavily coated leaves fell off the saplings. Staining on the stems, as well as the surrounding rock and gravel substrate, gradually faded and by the end of the summer, some of the staining had almost completely disappeared.

During the course of the summer, stem measurements showed that those saplings that were heavily oiled grew more slowly, but did produce new shoots from the stems and suckers. Researchers also observed new seedlings sprouting from the roots in oil-coated river banks and on contaminated gravels and sands. In both of these instances, this new growth was characterized as "extensive." Researchers noted that because the saplings grew on raised surfaces, they were more exposed to wind and sun, where accelerated weathering of the released crude oil, specifically evaporation and oxidation, likely occurred. They also noted that the effects of oiling of these woody riparian species were temporary and that the plants rebounded by the end of the same growing season. Based on their observations, their recommendations for future releases would be to remove only heavily coated vegetation, limiting site disturbance and minimizing potential introduction and establishment of invasive species.

Enbridge Line 37 Fort McMurray, Alberta*: On June 22, 2013, during the Enbridge Line 37 release, 1,300 barrels of synthetic crude oil were released from the pipeline, rose to the surface in the saturated soils, and flowed overland along the pipeline ROW to a fen, eventually reaching the shores of an unnamed lake. The release site underwent integrated remediation that was completed in October 2013 and involved targeted excavation (soil and sediment), oil skimming of surface water, treatment of surface water and groundwater, soil flushing (fen), and installation of physical barriers (hard and soft booms). Activities specifically conducted in the fen included flushing, installation of a sand bag weir to assist with collection of the treatment water, and installation of an Aquadam to divert up gradient surface water. In addition, approximately 92.6 tons of affected surface vegetation was removed, though the root mats were left in place. Remediation efforts removed a* *majority of the released crude oil (approximately 93%), and natural attenuation monitoring was employed to track the weathering and effects of the remaining product (Hemmings et al. 2015).*

While monitoring of the wetland in 2014 identified additional areas of stressed and dead vegetation that was not observed in 2013, the overall vegetative cover of the release site had improved. In 2014, 10 to 20% of the vegetation within the sampled plots were showing signs of stress or were dead. Two wetland community vegetation plots were sampled. Stressed and dead vegetation generally was limited to leaves on individual plants and to a few dead young white birches (Betula papyrifera). There were no patches of dead vegetation observed. Because the vegetation beyond the release site did not show comparable signs of stress, it was presumed that the effects observed in the release area were attributable to the crude oil.

An ecotoxicological assessment was completed to determine if the remaining hydrocarbons posed a risk to ecological receptors, including vegetation. The assessment used sediment and soils that remained in place after initial remediation efforts and plant species, including black spruce (Picea mariana), bluejoint reedgrass (Calamagrostis canadensis), and northern wheatgrass (Elymus lanceolatus). Endpoints measured for plants were seedling emergence, shoot and root lengths, and dry mass. Seedling emergence and growth were unaffected in the tests with lake sediments. Bluejoint reedgrass shoot and root lengths showed a negative effect in tests using soils from the ROW and fen. Black spruce also showed a negative effect for shoot lengths, but seedlings showed an increase in emergence. Although bluejoint reedgrass seedling emergence was not affected in tests with the fen soils, there were statistically significant effects on the species' growth that were attributed to the residual petroleum hydrocarbons. Additional monitoring of stressed vegetation and soil contamination levels conducted in 2015 will be used to assess the health of the wetland and determine if additional remediation is necessary (Hemmings et al. 2015).

Analyses of the case studies indicate that vegetation recovery is affected by several factors: 1) amount and type of crude oil released; 2) ambient temperature that affects weathering and biodegradation rates; 3) remediation or treatment methods (e.g., flushing, excavation, in-situ burning); 4) type of ecosystem (e.g., wetland, lake, stream); and 5) water depth. Warmer temperatures can accelerate recovery, whereas releases that occur in colder environments can take longer to show recovery signs due to a shorter growing season. Remediation methods can differ depending on the environment (e.g., wetland, fen, stream) and can affect the recovery timeframe. Burning can decrease the amount of oil, but it also can create hydrophobic and sterilized soils, which decrease rates of vegetation recovery. Excavation of the released *crude oil can accelerate recovery, but soil disturbance may cause greater harm in some sensitive environments.*

8.3.3.2.2 Factors Affecting Recovery of Wetland and Riparian Vegetation

Environmental factors that increase the weathering process can benefit the recovery of vegetation. Weathering of oil-contaminated soils (and associated effects on vegetation) occurs slowly because of low flushing, high organic content, and lack of oxygen (Michel et al. 2009; Michel and Rutherford 2013). These include degree of exposure of the vegetative community, which influences evaporation and photodegradation, and natural flushing by stream flows, waves, or tides (ESRD 2012; Michel and Rutherford 2013). In lentic environments, wind and wave action can drive released crude oil into fringing wetland communities, increasing effects and impeding subsequent recovery of these areas (Thormann and Bayley 2008). In lotic environments, flood conditions can disperse released crude oil into riparian habitats over a wider area than during normal flows and, depending on the success of clean-up activities, can slow subsequent recovery of these areas (USFWS et al. 2015a). Consequently, properly employed use of low-pressure flushing and vacuuming of residual crude oil can remove oil from the environment and, therefore, can be effective remediation techniques.

Crude oil releases that occur during the dormant season can result in faster rates of vegetation recovery than plants affected during active growing seasons. Dormant plants are less biologically active and may have less leaf surface area potentially exposed to oiling (Michel and Rutherford 2013; Pezeshki et al. 2000). Emergent wetland community types dominated by herbaceous and annual vegetation generally recover faster than forested communities (USACE 2010; USFWS et al. 2005). Vegetation often can begin to reestablish quickly from undisturbed root masses and existing seed banks. Forested communities and other late successional vegetation communities may take longer to recover completely from a crude oil release or subsequent clean-up activities than emergent or early successional communities (USFWS et al. 2005; USACE 2010). For example, when mature forest stands are cut or burned following a release as part of remediation activities, it may take several decades for this community to recover to the forested successional stage.

High release volumes that smother or otherwise cause substantial dieback of large areas of vegetation can delay recovery (Michel and Rutherford 2013). Additionally, clean-up activities that damage root masses and remove surface soil can delay recovery (Thormann and Bayley 2008; Wernick et al. 2009; USFWS et al. 2005; Hoff et al. 1993). Lack of clean up in heavily oiled areas, especially when active growing portions of vegetation have been heavily coated and root masses are affected by crude oil, also can delay recovery (Michel and Rutherford 2013; Corn and Copeland 2010).

Natural attenuation of crude oil can be an effective approach in areas with light to moderate oiling or where clean-up activities have removed the bulk of the released product (ESRD 2012; Hemmings et al. 2015). Natural attenuation may be the preferred recovery choice compared to active clean up where removal of existing natural seed banks and root masses could delay reestablishment of vegetation or potentially expose a natural community to invasive species (Rood and Hillman 2013). The potential effects of leaving crude oil in place needs to account for potential effects to water quality, fisheries, and wildlife in the area. Localized remediation of heavily oiled vegetation that focuses on vegetation removal with minimal root disturbance can accelerate recovery (Hemmings et al. 2015; Hoff et al. 1993; Thormann and Bayley 2008). Remediation must be carefully implemented since surface soil removal and subsequent changes in hydrology can prevent reestablishment of the original wetland types (USFWS et al. 2005).

8.3.3.2.3 Summary of Wetland and Riparian Vegetation Recovery

Wetland and riparian vegetation support numerous functions and values for both the natural and human environment. Effects to these communities from a crude oil release can subsequently affect the functions they support, such as wildlife and fisheries habitat, shoreline stabilization, and water quality. Depending on the degree of oiling and species susceptibility, some species of vegetation show little or no response, while others may die back, at least temporarily, or may show other signs of stress. The effects to and recovery of vegetation following a crude oil release will vary depending on the type and amount of product released, type and intensity of response activities, time of year, weather conditions, soil characteristics, and vegetation type.

The information reviewed here demonstrates a relationship between the type and intensity of remediation efforts and the recovery of affected vegetation communities. In some instances, vegetation communities can recover naturally without active remedial efforts as was seen with the Red Deer River study in Alberta. With other releases, such as the Cohassett and Lake Wabamun releases, additional clean-up activities are needed to reduce further effects within the environment. The information from the case studies, other literature, and general wetland restoration literature suggests that the greater the magnitude and severity of disturbances resulting from a crude oil release, the longer it will take a wetland or riparian community to recover. This includes recovery of the vegetation and the functional capacity of the community. Nevertheless, the case studies and other literature demonstrate that wetland and riparian vegetation do recover from a crude oil release. Remediation techniques can strongly affect vegetation recovery so the effects of clean-up activities and the selection of remedial procedures should be appropriate to the site-specific circumstances.

8.3.4 Terrestrial and Semi-Aquatic Wildlife

Wildlife includes a wide range of terrestrial, semi-aquatic, and aquatic species—including birds, mammals, reptiles, and amphibians-that occupy nearly every type of natural, human-altered, or human-created environment. Semi-aquatic wildlife, such as amphibians and waterfowl, are closely associated with aquatic habitats for most or some portion of their life cycle. Terrestrial species are principally land-dwelling and may use aquatic habitats for limited purposes or periods. For example, North American species of the deer family (*Cervidae*) are terrestrial species, but visit aquatic habitats for water, food, and cover. Similarly, the bald eagle

(*Haliaeetus leucocephalus*) carries out most aspects of its life on or over land, but forages principally in or near aquatic habitats.

Wildlife species are valued as part of the natural environment, as well as for their cultural and economic importance. Federal and state laws place value on wildlife due to its aesthetic, ecological, educational, recreational, and scientific value. Wildlife-related recreational activities, including hunting, fishing, and wildlife watching (i.e., observing and photographing), involve millions of people and contribute upwards of several billion dollars annually to individual state economies (U.S. Department of the Interior, USFWS, and U.S. Department of Commerce, U.S. Census Bureau 2011).

Injury and mortality of wildlife from a crude oil release can stimulate public concern and sympathy. This is particularly true when larger charismatic species (e.g., eagles and otters) are affected or when releases with potential population-level effects occur. From the public's perspective, the protection and rescue of animals becomes the expected focal point of a release. Rehabilitation of oiled wildlife is a common element of modern crude oil spill response.

Notwithstanding the level of public concern, based on the PHMSA pipeline incident database[23], most releases are small[24], are often within the operator's facilities, and wildlife species may not be present at the time of the release. Small numbers of wildlife may be affected by releases and often their recovery is undocumented. Active wildlife remediation programs are generally associated with the large, widespread releases and, consequently, are only reported in 0.4% of releases (PHMSA 2016).

8.3.4.1 Recovery of Wildlife Following a Crude Oil Release

Determining recovery of wildlife populations following a crude oil release is contingent upon identifying specific effects and defining recovery from those effects. Determining a return to baseline conditions is difficult to assess because pre-release population data for wildlife species often do not exist, exhibit wide variability, or are of questionable accuracy. Long-term studies necessary to make such an assessment typically are not conducted.

In contrast to population-level recovery, the recovery of individual animals affected by a crude oil release is well documented. Animals captured quickly following oiling and properly treated can survive and, in many cases, be returned to the wild. The success of these wildlife rehabilitation efforts in freshwater environments was demonstrated following the John Heinz

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[23] Incidents must be reported to PHMSA if the incident results in one or more of the following consequences: 1) a release of 5 gallons or more, 2) death or serious injury necessitating hospitalization, 3) fire or explosion not intentionally set by the operator, or 4) property damage of $50,000 or more (49 CFR 195.50).

[24] The majority of PHMSA reportable pipeline incidents since January 2002 are small (3 barrels or less) and almost half of the PHMSA-reported pipeline incidents occur completely within operator-owned facilities (47%). Of those releases that were not contained completely within the operator's property, the median release volume was 20 bbl, again indicating that small releases are the most common and very large releases are uncommon (PHMSA 2016).

Wildlife Refuge, the Exxon Mobile Silvertip, and the Enbridge Line 6B crude oil releases (ARCADIS 2011; Enbridge 2012; Saba and Spotila 2003).

As noted above, population-level effects and recovery, particularly in the freshwater and terrestrial environments, are not well documented. Information taken mostly from better documented incidents in marine environments indicates that populations recover (Pearson and Fleece 2014; Kingston 2002). An individual's vulnerability to a crude oil release (presence of the individual within the affected area, behavioral avoidance, and sensitivity to contact with oil) may determine whether an individual organism may be affected by an oil release. The magnitude of the crude oil release, including the volume of oil released, type of oil released, and areal extent of the release, may influence how many individual organisms may be affected. A species biology (i.e., its life history strategies) will influence the resiliency of a population following a crude oil release. Species that are short lived, high fecundity, and early maturity ("r" strategists), may be able to recovery more quickly from the loss of individuals within a population than longer-lived organisms with low fecundity and longer maturation ("K" strategists). Scientific literature concludes that, despite the loss of multiple individuals, some populations may be substantially affected, while others will show minimal effects (Stantec et al. 2012a).

In general, species with long life spans and low annual reproduction take longer to recover, but other aspects of a species' biology may have a strong overriding influence (Stantec et al. 2012a). For example, turtles generally have long life spans, but appear not to be as affected by crude oil releases as birds and mammals, and can recover relatively quickly (for further explanation, see Saba and Spotila 2003, and the John Heinz Wildlife Refuge crude oil release case study below). Species resistance and resiliency to disturbance are determined by intrinsic factors (e.g., a species sensitivity to petroleum hydrocarbons) as well as extrinsic factors (e.g., the ability of the environment to recover and provide suitable habitat). Ecological measures, such as patchiness of the environment, the proximity and mobility of nearby populations available to recolonize, the mobility of a species, and population fecundity measures, all contribute to the ability of wildlife to recover from effects.

Interpretation of a wildlife population's recovery status can sometimes result in contradictions (Wiens et al. 2004). Since assessment of population recovery is highly dependent upon the selection of endpoints and the variability of the species prior to an event, different researchers may draw different conclusions regarding species recovery for the same release. Consequently, agreement on regulatory endpoints early in the clean-up phase is important.

In addition to a species' biology, the magnitude of the event on a population can affect how quickly it can recover. For example, two years after the *Exxon Valdez* oil release, sea otter populations in Prince William Sound had begun to increase, with the exception of the Knight Island population. The sea otter population at Knight Island experienced the highest exposure to the released oil and subsequent mortality. Two years following the release, sea otter populations at this location had not significantly increased (Bodkin et al. 2002).

Timely and effective spill clean-up can reduce potential effects on wildlife (Sellers and Miller 1999). Successful cleaning and rehabilitation can help the recovery of both affected individuals and affected populations. In addition to clean up, the use of temporary wildlife deterrents (e.g., bald eagle decoys, scarecrows, noise making devices) and exclusion fences at release sites also may reduce contamination of individuals and associated risks to populations (Enbridge 2013; Plains Midstream Canada 2012; SLR Consulting [Canada] Ltd. 2008).

The following case studies provide examples of the effects releases had on wildlife and the recovery process. Although broad generalizations cannot be drawn from a single event, case studies provide substantial data that, in combination with existing literature, can help regulators and operators gain a better understanding of the effects of oil releases and recovery of various environmental media. As discussed in Section 8.1, the number of releases that have occurred within natural environments and climates similar to Minnesota and that include recovery information is limited. Therefore, these case studies include releases from a broader temperate region of North America. However, even with inclusion of these additional case studies, the information on wildlife recovery in freshwater and terrestrial environments is limited.

> ***Ashland Oil Company, Storage Tank Release, Ashland, Pennsylvania**: On January 2, 1988, an Ashland Oil Company fuel storage tank at the Floreffe terminal site collapsed, releasing approximately 92,430 barrels of diesel fuel (CHMR et al. 1990). Of the estimated volume of released fuel, approximately 16,790 barrels entered a sewer line and eventually reached the Monongahela River. An estimated 70% of the fuel reached the Monongahela River within 2 hours of the release, and the remaining 30% of the fuel reached the river in the next seven hours before a plug was placed in the sewer. Waterfowl, principally mallards, were killed during the first few days following the release, with mortality estimated at 2,000 waterfowl by the Pennsylvania Game Commission. Most of the birds killed were characterized as semi-domesticated because they had remained in the area and had not migrated the preceding fall. In the spring following the fuel release, mallards breeding along approximately 25 miles of the Monongahela River below the release site had reduced nesting success with their first clutch of eggs compared to upstream reference locations. However, mallards in the stretch below the release site did successfully produce second clutches of eggs during the breeding season (CHMR et al. 1990). In the following year, breeding mallards showed no apparent residual effects from the oil release, indicating the species had recovered. Researchers indicated that because mallards have a high rate of reproduction, population-level effects from the diesel release likely were limited and short-term.*

> ***Sunoco, John Heinz Wildlife Refuge, Pennsylvania**: On February 5, 2000, approximately 4,770 barrels of crude oil leaked from a Sunoco pipeline adjacent to the John Heinz Refuge in Philadelphia, Pennsylvania (Saba and Spotila 2003). The crude oil flowed into an approximately 146-acre non-tidal freshwater*

impoundment within the refuge. The impoundment was ice covered at the time of the release, which helped to slow the initial flow of oil. As a result of warming temperatures and clean-up activities, the ice began to melt and turtles that had been hibernating within the impoundment began to surface and became contaminated with crude oil. A fence was erected to prevent additional oiling of turtles and other wildlife.

Oiled turtles were captured and taken to a rehabilitation facility to recover. Oiled turtles included 4 painted turtles (Chrysemys picta), 2 snapping turtles (Chelydra serpentina), 12 red-eared slider turtles (Trachemys scripta), and 1 red-bellied turtle (Pseudemys rubriventris) (Saba and Spotila 2003). The oiled turtles were cleaned and rehabilitated with 18 of the 19 turtles surviving. The researchers noted that these turtles may have had higher survival rates compared to other animal groups commonly affected by crude oil releases, such as seabirds and fur-bearing mammals, because oil does not adhere as readily to their shells and skin as it does to the fur and feathers of these other animals. In addition, other species ingest crude oil during the process of preening or grooming, a behavior limited in turtles due to their restricted flexibility. Crude oil ingestion by turtles is therefore limited to accidental ingestion of oil contaminated water and prey, which likely reduces effects from oil exposure (Saba and Spotila 2003).

In a monitoring study, radio-transmitters were placed on the oil-exposed turtles and two other groups of turtles to study the potential effects of crude oil exposure and subsequent rehabilitation. Because of the small sample size of oil-exposed and rehabilitated turtles, researchers captured 16 additional turtles near the release site that were classified as possibly exposed to crude oil. Thirty-two turtles from locations at least 0.6 mile from the release site were collected and treated as control specimens (not exposed to the crude oil release). Transmitters were placed on each of the 66 turtles to track their movements, record body temperatures, and assess potential survival and behavioral differences among the three groups. Researchers found that all of the rehabilitated turtles acted normally when released (Saba and Spotila 2003). This study found no differences in survival, home range, or temperature preference among the three study groups. This suggests that with rehabilitation, turtles can survive and recover from crude oil exposure.

***Canadian National Railway Company, Wabamun Lake Oil Release, Alberta**: On August 3, 2005, a Canadian National freight train derailed near the Village of Whitewood Sands, Alberta, releasing approximately 4,500 barrels of Bunker C Oil (Heavy Fuel Oil 7102; Hollebone et al. 2011) and 550 barrels of pole treating oil). An estimated 950 barrels of the Bunker C Oil entered Wabamun Lake where it formed a thick black slick approximately 0.5 inch thick (Wernick et al. 2009). While travelling overland, the oil mixed with soil and organic matter and, in the lake,* *OPAs formed quickly, including small tar balls, larger tar "logs", submerged sheets, and large lumps (Fingas et al. 2006; Hollebone et al. 2011). The heavy Bunker C Oil formed several types of aggregates including tar balls, larger tar "logs", submerged sheets, large lumps, tar balls that sometimes reformed into oil slicks, and a "slurry" composed of finely divided organic matter and small oil droplets (Fingas et al. 2006; Hollebone et al. 2011). The oil-sediment complexes exhibited a variety of behaviors including submergence, neutral buoyancy, and resurfacing as a result of contacting and taking up foreign matter (such as mineral particles and organic debris) on its path to the lake (Fingas et al. 2006).*

Not long after the initial release, the submerged and sunken tar balls were seen along the shoreline and in shallow water. Even after initial clean-up efforts, tar balls were still commonly observed along the vegetated shoreline (Hollebone et al. 2011). Tar balls in and around the vegetation continued to move laterally in the water column releasing oil during the course of their movement. Consequently, oil continued to be released and adhere to shoreline vegetation. Tar balls were still observed almost 2 ½ years later (February 2007) within shoreline vegetation, including roots (Hollebone et al. 2011).

The oil release occurred after the western grebe nesting period and efforts were made to prevent oil from entering their primary nesting area (AESRD and ACA 2013). Most of the birds affected by the release were adults. Approximately 368 western grebes (76% of this population) were affected. Of the 368 affected birds, 333 were found dead or were subsequently euthanized, and 35 were cleaned and released.

Prior to 2006, there had been a single breeding colony of western grebes at Wabamun Lake, but in 2006, a second breeding colony was established. The original western grebe colony had been present on Wabamun Lake for over 20 years with relatively stable reproduction since 2001 (AESRD and ACA 2013). However, the year following the oil release (i.e., 2006), the Wabamun Lake western grebe population nearly doubled, but in 2007 it dropped below the estimated pre-release population levels. The population level continued to fluctuate over the next several years, and in 2011 the population dropped to its lowest level in 10 years (AESRD and ACA 2013).

The literature is unclear as to what lasting effects, if any, the oil release might have had on this western grebe population and the observed fluctuation in population levels. Determining such lasting effects is complicated by other important influences on the lake habitat. Erickson (2010) noted that three of the largest populations of western grebes in Alberta, including Wabamun Lake, had shown consistent declines for 9 years and suggested that these declines potentially were the result of increased lakeshore development. In 2009, four *years after the release, water level increases in Wabamun Lake, reduced the extent and density of bulrushes (Schoenoplectus tabernaemontani) and caused some of the western grebes to shift nesting locations from bulrushes to cattails (Typha spp.) (Wollis and Stratmoen 2010).*

***Enbridge Line 6B, Marshall, Michigan**: On July 25, 2010, Enbridge's Line 6B pipeline experienced a release in a wetland near Marshall, Michigan. Approximately 20,000 barrels of heavy crude oil containing diluted bitumen were released over a period of approximately 17 hours. Approximately 8,200 barrels reached Talmadge Creek and the Kalamazoo River (Enbridge 2013). Wildlife monitoring programs reported 40 mammals were either found dead or they subsequently died during rehabilitation (USFWS et al. 2015a). In addition, 23 mammals were captured due to oiling, and were successfully rehabilitated and released. An unknown number of mammals are assumed to have been oiled but never found or captured. The primary species affected were muskrat (45%), raccoon (13%), and beaver (13%) (USFWS et al. 2015a).*

During clean up and monitoring, 52 birds were found dead or died during attempted rehabilitation (USFWS et al. 2015a). In addition, 144 oiled birds were captured, successfully rehabilitated and released. Approximately 140 birds that were observed to be oiled were never captured. The primary species were Canada goose (75%), mallard (9%), and great blue heron (5%) (USFWS et al. 2015a). Of the birds that were rehabilitated and released, 127 were equipped with leg bands including 109 Canada geese. Between 2010 and 2015, 39 of those bands were recovered from hunters (unpublished banding data), indicating that some birds survived post-release and subsequent migrations.

Additionally, 106 reptiles were found dead or subsequently died during rehabilitation, and approximately 3,900 turtles and 73 amphibians were captured, treated and released (USFWS et al. 2015a). The primary species affected were common map turtles (77%), snapping turtles (11%), painted turtles (6%), and eastern spiny softshell turtles (3%). Other species included common musk, Blanding's, and eastern box and spotted turtles.

***Enbridge Line 37, Fort McMurray, Alberta**: On June 22, 2013, approximately 1,300 barrels of synthetic crude oil were released from an underground pipeline located approximately 24.9 miles southeast of Fort McMurray, Alberta, Canada (Hemmings et al. 2015). The crude oil saturated nearby soil and flowed overland along the pipeline ROW to a fen where it eventually reached the shores of an unnamed lake. Just over a month after the release, the effects on wildlife were characterized as minimal. Nevertheless, the release site underwent remediation to reduce effects to other environmental receptors and remediation was completed four months after the release. Remediation efforts removed a majority*

> *of the crude oil (approximately 93%) and natural attenuation monitoring was employed to track the degradation of the remaining product. To reduce potential exposure of wildlife to the crude oil, wildlife deterrents were deployed and an exclusion fence erected (Enbridge 2013).*
>
> *A rigorous analysis of wildlife effects and subsequent recovery from this release is not provided in available literature, but information suggests that exposed wildlife is recovering. In 2014, wildlife, including boreal chorus frogs (Pseudacris maculata) and wood frogs (Lithobates sylvaticus), were using the previously oiled area. Researchers assessed that habitat suitability was moderate to high for wetland-dependent species based on the vegetation cover, shallow water, and availability of prey for species, such as the red-sided garter snake (Thamnophis sirtalis parietalis) and American mink (Neovison vison) (Hemmings et al. 2015). In a subsequent ecological risk assessment at the site, it was determined that the potential health risks to birds and mammals were negligible, with the exception of the mallard duck (Anas platyrhynchos). Although some risk was predicted for mallard ducks, the site did not have sufficient habitat to support a duck population and, therefore, effects related to growth, reproduction, and survival of ducks were not anticipated (Hemmings et al. 2015).*

Wildlife can be adversely affected by a release of hazardous material. However, the degree of severity is dependent on several factors.

In case studies involving heavy crude oil releases (e.g., Enbridge Line 6B, Marshall, Michigan), injuries were generally minor with most captured individuals being treated and released. Conversely, case studies consisting of light crude oil releases were where most reported injuries were fatalities.

Case studies illustrate that long term effects to wildlife can be reduced by swift spill response, remediation efforts, and effective rehabilitation techniques. Additionally, the type of wildlife affected is a major factor in the susceptibility of exposure to a release of crude oil. For example, turtles are less susceptible and respond better to rehabilitation than most mammals or birds, as crude oil cannot adhere to their skin and shell as well as it can to feathers and fur needed for buoyancy and thermoregulation.

8.3.4.2 Factors Affecting Recovery

The degree of exposure and a species' biology are the two principal factors affecting the degree and rate of recovery. A species reproductive strategy plays an integral role in how quickly populations will be able to recover from a crude oil release. Species that exhibit "r" reproductive strategies typically recover at much faster rates than do "K" strategists. Species that exhibit "r" strategies produce a large number of offspring, have short gestation periods, and have fast maturation rates. These characteristics are more adapted for fluctuating and unstable environments, including contaminated areas. Conversely, "K" strategists do not recover as well from contaminated environments as they typically have fewer offspring, longer gestation periods, and slower rates of maturation (Rafferty 2016a,b; Reser 2016).

Rapid and effective clean-up also can limit wildlife exposure to released crude oil, thus minimizing effects and accelerating recovery (AESRD and ACA 2013; Hemmings et al. 2015). Once individual wildlife are exposed to oil, rapid and effective rehabilitation efforts can accelerate the recovery of these animals (ARCADIS 2011; Enbridge 2012; Saba and Spotila 2003).

The body type, behavior, and other aspects of a species' biology can reduce crude oil effects and, as a result, accelerate recovery (Saba and Spotila 2003). For example, reptiles may be less susceptible to oil fouling than birds and mammals because they lack fur and feathers where crude oil can be trapped and affect buoyancy and thermoregulation. Species with high reproductive rates typically recover quickly following a crude oil release (CHMR et al. 1990).

Large release volumes potentially can adversely affect more habitat and more individuals slowing subsequent recovery processes (Sellers and Miller 1999). The time and specific location of a release can also be important. Releases that occur when animals are concentrated in an area (e.g., nesting periods) can result in more oiled individuals and, therefore, slower recovery of the population (CHMR et al. 1990; Sellers and Miller 1999). Instinctive behaviors, such as site fidelity, that deter animals from leaving oiled areas also can result in higher rates of oiling and delays to subsequent recovery (Esler 2000).

8.3.4.3 Summary of Wildlife Recovery

There is limited information available on the recovery of wildlife related to freshwater and terrestrial crude oil releases compared to that for marine releases. Much of the data about releases in freshwater and terrestrial environments relates to effects rather than remediation and recovery. Freshwater and terrestrial wildlife release effects typically are tracked by the number of individuals oiled, the number treated, and the number of mortalities. This type of information typically is collected during the initial weeks or months following a release. Long term comparisons with local, unaffected populations are typically unavailable. Even when these data are collected, population-level effects are difficult to clearly distinguish due to a number of factors such as the availability of pre-release population information, the timeframe of monitored events, and separating crude oil release effects on wildlife from other environmental influences. Natural fluctuations in population levels and natural or anthropogenic changes to habitat unrelated to a crude oil release can make it difficult to determine when a population has recovered from the effects of a release (Hemmings et al. 2015).

Evidence from the case studies presented and the more robust literature for marine wildlife indicate that wildlife populations can recover from release effects, although recovery may take several years. Recovery is generally faster in species that reproduce quickly with large litters (i.e., species that exhibit "r" reproductive strategies), as opposed to species that take longer to reach reproductive maturity, and have low fecundity rates (i.e., species that exhibit "K" strategies).

The most important element affecting the recovery of wildlife populations following a crude oil release is limiting the proportion of affected individuals within the population and their habitat. Limiting mortality, particularly in species with long life spans and low reproductive rates, is important in wildlife recovery. Timely and effective clean-up efforts that reduce the number of oiled individuals can benefit population recovery. In addition, rehabilitation of oiled individuals can successfully treat the affected individual as well as benefit the affected population.

8.3.5 Surface Waters

Surface waters in Minnesota include freshwater habitats that range from lakes and ponds to wetlands, rivers, and streams. Fens and peat bogs are discussed in Section 8.3.2. These habitats and the quality of water in them play a vital role in sustaining aquatic and terrestrial ecosystems, as well as health, economic, and social values vital to humans. Surface waters within rivers, lakes, and wetlands provide many beneficial functions to organisms and humans (Postel and Carpenter 1997), including:

- Habitat for wildlife and fisheries by providing areas for spawning, feeding, and foraging
- Nutrient cycling
- Purification of water by filtering, degrading or diluting pollutants
- Fresh water used as a source for potable use, irrigation, industry, and recreation
- Transportation routes for boats and ships
- Hydroelectric power generation

Crude oil releases can affect surface water quality and disrupt the services provided by surface water. Although the physical, chemical, and biological responses within the surface water and associated sediment are closely integrated, this section will focus on the quality of surface water, how it can be affected by a crude oil release, and the rate of recovery if such effects occur. For surface water, recovery is typically quantified by measuring hydrocarbon concentrations. Regulators generally consider recovery complete when water quality standards protective of human health and the environment are met. Other sections within this report address the response and recovery of the sediment (Section 8.3.6) and freshwater biota, including benthic macroinvertebrates (Section 8.3.7) and fish (Section 8.3.7).

National pipeline incident data[25] shows that approximately 6.2% of pipeline incidents affect surface water. Of those incidents, 40% require active remediation[26] (PHMSA 2016). Surface water that is used as a drinking water resource is infrequently affected, accounting for 0.16% of historical releases (PHMSA 2016).

8.3.5.1 Recovery of Surface Waters Following a Crude Oil Release

This section reviews factors that influence recovery, including release volume, weathering, clean-up efforts, weather conditions, and waterbody characteristics. Collectively, these factors influence how surface waters recover from a crude oil release.

For lotic waters (streams and rivers), the volume of the release coupled with the stream's discharge[27] are the most important factors influencing effects and subsequent recovery (Enbridge 2015). These factors, combined with stream velocity, seasonal hydrology, channel morphology, currents, and sediment load, can strongly influence crude oil behavior and its resultant effects (Stantec et al. 2012b; Lee et al. 2015). Higher stream volume helps to dilute the released crude oil, enhancing the rate of recovery of surface water. The stream discharge is influenced by the time of year, with lower volumes often occurring during the summer and early fall (Crunkilton and Duchrow 1990; Enbridge 2015).

Environmental conditions associated with certain times of the year also can influence how rapidly a release might spread. The flow and spread of crude oil across the surface of water can be slowed by cold temperatures and ice and can subsequently reduce the overall affected area (Saba and Spotila 2003). The undulating and uneven underside of ice can trap crude oil released into surface waters, which can reduce the downstream transportation of crude oil, localizing effects and facilitating clean up.

Effective and timely response and clean-up efforts reduce the extent of crude oil contamination and can accelerate recovery (Guiney et al. 1987). Following an Ozark Pipeline System 9,520-barrel crude oil release in Asher Creek, Missouri in 1979, areas protected with surface skimming siphon dams were less severely affected and recovered more rapidly than unprotected areas where the substrate became inundated with crude oil (Crunkilton and Duchrow 1990). Lee et al. (2015) characterized clean-up of oil products as very effective for light oils and effective for medium crude oils, provided efforts are initiated soon after the release. Heavy crude oils do not

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[25] Incidents must be reported to PHMSA if the incident results in one or more of the following consequences: 1) a release of 5 gallons or more, 2) death or serious injury necessitating hospitalization, 3) fire or explosion not intentionally set by the operator, or 4) property damage of $50,000 or more (49 CFR 195.50).

[26] The majority of PHMSA reportable pipeline incidents since January 2002 are small (3 barrels or less) and almost half of the PHMSA-reported pipeline incidents occur completely within operator-owned facilities (47%). Of those releases that were not contained completely within the operator's property, the median release volume was 20 bbl, again indicating that small releases are the most common and very large releases are uncommon (PHMSA 2016).

[27] Discharge is the volume of water moving down a stream or river per unit time, usually expressed in cubic feet per second (USGS 2015).

readily disperse in water, and have a lower proportion of low molecular weight hydrocarbons that quickly evaporate.

In the absence of effective spill response, heavy crude oils can form emulsions consisting of water, particulate matter in the water column and bottom sediments, especially during turbulent flow conditions. These emulsions eventually can approach or exceed the density of water. Depending on water temperatures and velocities, these emulsions can sink and rise in the water column and may become trapped in bottom substrates. Weathering reduces the amount of soluble hydrocarbons over time, and clean-up activities can help limit the extent of the affected area and the hydrocarbon concentrations within the surface water (Stantec et al. 2012a; Enbridge 2015).

Environmental factors that enhance weathering will accelerate recovery. For example, biodegradation[28] typically increases with increasing temperature. Higher ambient temperatures also can reduce the crude oil's surface tension allowing oil to spread out, thereby increasing the surface area available for evaporation and microbial activity (Lee et al. 2015).

Although high flow conditions typically result in a large affected area and the potential for increased dispersion of crude oil into the water column, greater flows also serve to dilute oil concentrations (Stantec et al. 2012b). Modeling conducted for the Enbridge Northern Gateway Project predicted that the water quality of larger rivers would recover more quickly than smaller watercourses because there is a larger volume of water to dilute the crude oil, limiting the dissolved hydrocarbon concentrations (Enbridge 2015; Stantec et al. 2012b). This concept is supported by crude oil releases on both the Plains Midstream pipeline (Red Deer River) and the ExxonMobil Silvertip pipeline (Yellowstone River) where high stream discharge volume appeared to have helped dilute the crude oil (ARCADIS 2011; ESRD 2012). High flow rates are not always beneficial and can cause negative effects, such as turbulent flows, which affect the fate and behavior of crude oil released to surface waters by increasing dispersion, introducing sediment and debris into the crude oil, and facilitating the formation of water-in-oil emulsions. Turbulent flows most often occur in watercourses with steep gradients, high-velocity flows, boulder or cobble substrates, or where man-made structures such as overflow dams exist (Enbridge 2015; Lee et al. 2015).

Because small ponds and wetlands experience less water exchange than continually flowing streams, recovery rates of water quality in these water bodies are often slower because there is less dilution and flushing (Enbridge 2015). Depending upon the surface area and hydrodynamics of relatively static water systems, flushing of crude oil from lakes also can be slow, particularly when compared to lotic systems (Stantec et al. 2012b). Dilution in lentic (e.g., lakes, ponds) settings helps accelerate recovery.

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[28] Biodegradation is a natural process of microbial transformation of chemicals, such as oil under aerobic or anaerobic conditions; oil biodegradation usually requires nutrients, such as nitrogen and phosphorus; transformation may be complete, producing water, carbon dioxide and/or methane, or incomplete, producing partially-oxidized chemicals (Lee et al. 2015).

As discussed above, crude oil effects on surface waters are influenced by the environmental setting, as well as the behavior of the oil on and within the surface waters. The following case studies present oil releases that affected surface waters and the subsequent recovery process. Because only a small body of information is available on surface water effects of oil releases and recovery in freshwater environments that are similar to those in Minnesota, additional case studies from temperate North America are included. Although broad generalizations cannot be drawn from a single event, case studies provide important information that, in combination with existing literature, can help regulators and operators gain a more comprehensive understanding of the effects of crude oil releases and recovery of various environmental media.

> ***Ozark Pipeline System, Asher Creek, Missouri****: Recovery of Asher Creek following an Ozark Pipeline System crude oil release of 9,520 barrels in August 1979 was impeded by low stream flow volume (Crunkilton and Duchrow 1990). This release occurred near the stream headwaters, and as a result, there was less contributing stream flow than locations further downstream. During the initial phase of this release, stream discharge volume was limited and water turnover[29] was slow. This increased the residence time of soluble oil compounds and resulted in loss of much of the macroinvertebrate community (Crunkilton and Duchrow 1990). When flow volumes were increased during spring flood events, they helped scour and dissipate residual oil in aquatic sediments and contributed to the recovery of the surface water and associated aquatic organisms.*
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> ***Laurel Pipe Line Company, Roaring Run Creek, Pennsylvania****: High flow volumes have been shown to enhance recovery rates, as demonstrated by a release of 1,310 barrels of aviation kerosene by the Laurel Pipe Line Company into Roaring Run Creek in Cambria County, Pennsylvania on October 16, 1982. The continuous supply of uncontaminated water from an upstream location contributed to recovery of water quality in less than two months (Guiney et al. 1987). Other factors contributing to the recovery of this system included a rapid clean-up response (Guiney et al. 1987).*
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> ***Advanced Fuel Filtration Systems, Inc., East Walker River, California****: On December 30, 2000, a tanker truck operated by Advanced Fuel Filtration Systems, Inc. overturned on State Route 182 north of Bridgeport, California, and released approximately 86 barrels of No. 6 Fuel Oil (Higgins 2002). Much of the released oil entered the East Walker River. Following the release, three surface water sampling events were conducted and samples were collected from seven locations (one control and six impact sites) and analyzed for PAHs. The PAH constituent analysis determined that the PAHs detected in the water samples were connected specifically to this event. Total PAHs were highest during the initial sampling effort*

[29] The turnover rate for water was calculated from the estimated volume of the wetted channel and stream discharge (Crunkilton and Ducrow 1989).

(January 2001) and in sampling locations located approximately 6.4 and 10 miles downstream of the release site that had the highest total PAH concentrations (Higgins 2002). Three months after the release (March 2001), the total PAH concentrations at the six impact sites had decreased, but two sites remained above the threshold effects levels for certain fish species. By the May 2001 sampling event (approximately 19 weeks post-release), total PAH levels at all of the affected sites had decreased to near background concentrations analyzed at the control site (Higgins 2002).

***Enbridge Line 6B Marshall, Michigan**: In July 2010, a pipeline rupture released approximately 20,000 barrels of diluted bitumen oil into Talmadge Creek and the Kalamazoo River in Marshall, Michigan. In July 2010, the Calhoun County Public Health and Kalamazoo County Health and Community Services Department banned recreational use of the Kalamazoo River. In August, these two organizations also banned the use of surface waters for irrigation and the watering of livestock (NTSB 2012). The MI DCH also issued swimming and fish consumption advisories for the Kalamazoo River (MI DCH 2014).*

Clean-up efforts began almost immediately, including installing oil sorbent and containment booms and using oil skimmers and vacuum trucks to recover the oil. By August 2010, clean-up efforts included excavation and removal of contaminated soil, sediment, vegetation, and debris. Recovery of submerged oil included more active methods such as sediment agitation, sediment traps, and sheen management (USFWS et al. 2015). As part of the NRDA process, a group of federal and state agencies, as well as local First Nation representatives (the Trustees), assessed the effects of this release, effectiveness of clean-up efforts, and potential options to compensate for effects (USFWS et al. 2015).

Between July 2010 and April 2012, surface water data were collected from the Kalamazoo River and Morrow Lake (MI DCH 2014). Chemical analyses were conducted for oil constituents such as PAHs and alkylated PAHs, at different depths within the water column (USFWS et al. 2015). Surface water analyses were conducted to evaluate potential human health effects, as well as potential exposure of fish embryos to the oil constituents. The July and August 2010 sample results showed that most chemical constituents were below human health water criteria for both the USEPA and the MI DEQ. Surface water sampling conducted from 2011 to 2012 detected only a few of the monitored chemicals (primarily PAHs) above health-protective screening levels (MI DCH 2014). Based upon sample results, it was determined that PAH concentrations were not high enough to adversely affect fish embryos (USFWS et al. 2015). In June 2012, most of the Kalamazoo River was reopened to recreation, and the MI DCH lifted its advisories and fish consumption guidelines, although people were advised to follow fish consumption guidelines in effect prior to the release.

***Plains Midstream Red Deer River, Alberta**: On June 7, 2012, between 1,000 and 3,000 barrels of light crude oil were released into the Red Deer River about 1.9 miles north of Sundre, Alberta (ESRD 2012). The release was caused by vertical stream scour that exposed a pipeline that failed under the excessive outside forces caused by high floodwaters. The river's discharge was about 10 times the seasonal flow prior to the release (AER 2014). Crude oil reached Gleniffer Lake (also known as Dickson Dam Reservoir) located approximately 24.9 miles downstream of the release site. Sampling between the release site and Gleniffer Lake indicated that the majority of the hydrocarbons had been transported to the lake. Booms placed on Gleniffer Lake effectively contained the free oil product, limiting further downstream migration. Contained oil was hauled offsite by Plains contractors (AER 2014).*

The lighter weight hydrocarbons that had dissolved in the water column continued downstream. Low levels of these dissolved hydrocarbon components were found approximately 30 miles downstream near the city of Red Deer (ESRD 2012). Five to nine days later (June 12 and 16, 2012), monitoring showed a "marked" decrease in hydrocarbon concentrations at all sample locations. Drinking water plant sampling concentrations dropped to below detection limits at all sampling locations by June 14, and all concentrations prior to this date were well below applicable Health Canada drinking water guidelines (0.005 ppm for benzene, 0.024 ppm for toluene, 0.0024 ppm for ethylbenzene and 0.3 ppm for xylenes) (ESRD 2012). The ESRD (2012) report stated that this decrease indicated that hydrocarbon concentrations had been diluted by input from the Red Deer River, and by the recovery of surface water.

Monitoring showed that BTEX decreased over time and by June 16 (less than 10 days after the release), BTEX concentrations were below detectable limits (ESRD 2012, Teichreb 2014). With the exception of toluene that exceeded protection of aquatic life guidelines for a few days but never Federal drinking water guidelines, examination of petroleum hydrocarbon concentration data from locations downstream of the city of Red Deer did not exceed Federal water quality guidelines [30] for petroleum hydrocarbons (ESRD 2012). One month after the release (early July 2012), BTEX levels continued to be below detection levels with two exceptions. One sample location in Gleniffer Lake near the Carefree Resort marina had a short-term period of detection between June 24 and 28, 2012, and was highly localized as evidenced by non-detectable concentrations of petroleum hydrocarbons at nearby sites. This area was undergoing

[30] Concentrations of dissolved petroleum hydrocarbons downstream of Gleniffer Lake were below the most sensitive applicable water quality guidelines for all parameters with the exception of toluene. Toluene frequently exceeded the protection of aquatic life guideline during the initial days of monitoring, but did not exceed applicable Health Canada drinking water guidelines downstream of Gleniffer Lake (ESRD 2012).

decommissioning at the time of the peak and thus was not open to recreational boating. Investigations into the cause of the peak were conducted, but no plausible explanation was found (ESRD 2012). A second small peak occurred on July 2, 2012, at the sample location near the Gleniffer Lake Resort, which may have been caused by recreational boat activity during the Canada Day holiday, but this could not be confirmed. This peak was also short-term and localized (ESRD 2012).

PAHs also were monitored post-release and, while they were initially detected in surface water from Gleniffer Lake downstream to the city of Red Deer. Concentrations decreased over time. The majority of samples after June 16 showed PAHs to be below detection limits (ESRD 2012). Although occasional detections of PAHs were found, they were very random in nature with no clear connection to the June 7, 2012 release.

***Enbridge Line 37, Fort McMurray, Alberta**: During this 2013 event, synthetic crude oil released from the pipeline rose to the surface in the saturated soils and flowed overland along the pipeline right-of-way to a fen and eventually reached the shores of an unnamed lake. Contaminants of concern in this event were certain petroleum hydrocarbon fractions, BTEX, and PAHs (Hemmings et al. 2015). Remediation efforts at the unnamed lake involved removing free product using barrel skimmers and sediment excavation in the northwest corner of the lake where the highest concentrations of certain petroleum hydrocarbons were documented. Approximately 118 cubic yards of sediment were excavated to a depth of 4 inches. Site remediation also involved installation of physical barriers (hard and soft booms), targeted soil excavation within the ROW, soil flushing within the affected fen, removal of oiled vegetation, and treatment of surface water and groundwater. Contaminated oily water, slurry, and sludge were collected in vacuum trucks and taken off-site for disposal or treated at an on-site water treatment facility. The effective containment and recovery of crude oil resulted in the collection of 93% of the released oil and contributed to the subsequent recovery of surface water.*

Surface water sampling occurred at the unnamed lake, at up-gradient and down-gradient waterbodies, and, when water was present, within the pipeline ROW. During initial response efforts, benzene, toluene, ethylbenzene, and certain petroleum hydrocarbon concentrations were above the applicable surface water guidelines within the affected area. However, approximately two months after the release, these contaminant concentrations were below applicable guidelines (Hemmings et al. 2015). Monitoring results from 2014 determined that contaminant levels continued to be below applicable guidelines.

Releases of oil have the potential to affect surface water adversely. Effects can vary in degree of severity depending on several factors, including the type and quantity of oil released, and timeliness of spill response. Heavier oils (e.g., Bunker C Oil, diluted bitumen) do not dissolve or naturally attenuate as quickly as a lighter crude oil due to their higher concentrations of high molecular weight compounds (e.g., asphaltenes). Lighter crude oils are composed of lighter hydrocarbons such as BTEX compounds and alkanes, which evaporate quickly and are relatively biodegradable. High levels of BTEX compounds can be toxic to humans and aquatic life if water quality thresholds are surpassed. Additionally, the quantity of crude oil released is a major factor in determining effects as it largely dictates how much area and aquatic wildlife may be affected. The case studies demonstrate that effects to surface waters can be mitigated by timely spill response efforts, including the placement of sorbent and containment booms and use of surface skimmers and vacuum trucks. Remediation can also occur naturally through processes such as natural attenuation, evaporation, and weathering.

8.3.5.2 Factors Affecting Recovery

Rapid and effective response to a release of crude oil can reduce the severity and extent of the effects to surface water, thereby accelerating its recovery (Guiney et al. 1987; Hemmings et al. 2015). Remediation practices that can accelerate the rate of surface water recovery include removal of oil, clean-up of oil-contaminated surfaces such as sediment and vegetation, and treatment of surface water (Guiney et al. 1987; Hemmings et al. 2015).

Environmental factors such as warm temperatures that enhance crude oil weathering also promote surface water recovery (Lee et al. 2015).

The type of oil released can influence the rate of recovery. Lighter oils typically weather more readily and more completely than heavier oils (Lee et al. 2015).

However, the fate, effects, and subsequent recovery from a crude oil release depend primarily on the effectiveness of emergency response and the environmental conditions in which the release takes place (Lee et al. 2015). Larger surface waterbodies typically recover more quickly than smaller waterbodies because the crude oil is more rapidly diluted in the larger volume of water (Anderson 2006; ESRD 2012). The volume and turbulence associated with high flows in rivers and streams can increase the dilution of crude oil and accelerate surface water recovery (ESRD 2012; Enbridge 2015).

Large release volumes typically result in greater area and severity of effects and, thus, slow the recovery of surface waterbodies (Crunkilton and Duchrow 1990). The time of year when a release occurs can impede recovery if the release occurs near or during a period of low flow (Crunkilton and Duchrow 1990).

8.3.5.3 Surface Water Summary

Freshwater resources include lakes, ponds, wetlands, rivers, and streams. These waterbodies are important for both the diverse assemblages of species they support and their associated human use. Released crude oil that enters a freshwater aquatic habitat can negatively affect water quality and the ecosystem that it supports. The fate and behavior of oil in surface waters is dependent on a number of factors that include the volume of the release, the type of oil, and the nature of the receiving environment. When crude oil enters surface water, it rapidly spreads out over the surface, but wind, waves, current, air temperature, and other conditions strongly influence the potential for dispersion, weathering, and sedimentation.

As demonstrated by the case studies described here, it is common for the recovery of surface water to be rapid and complete within weeks to months following the crude oil release. Recovery within larger lotic systems can occur very quickly, sometimes within a few days (e.g., Red Deer River and Silvertip Pipeline oil releases). The volume of crude oil released is often small compared to the receiving waterbody, and the higher flows can dilute the released oil. Smaller stream systems, such as Asher Creek, where the release volume was large compared to the size of the waterbody, and lentic systems such as the lake affected by the Fort McMurray release, may take longer to recover. Water quality recovery still can occur within a few months, particularly when clean-up and remediation efforts are employed. Emergency response and clean-up activities can help limit both the severity and extent of the effects of the release on surface water quality and promote the resulting recovery.

8.3.6 Aquatic Sediments

Aquatic sediments are the mineral substrate (e.g., sand, gravels, cobbles) and organic matter deposited into a waterbody by water, air, or ice. Sediments provide habitat for aquatic organisms, such as aquatic invertebrates, and are an integral part of aquatic ecosystems. The composition of aquatic sediments strongly influences the associated macroinvertebrate community (e.g., coarser substrates associated with higher flows have a very different macroinvertebrate community than fine-grained sediments in lower energy depositional substrates). Aquatic sediments also function as spawning habitat for many species of fish and the rearing habitat for larval or juvenile life stages for a variety of species. Additionally, many species of aquatic plants, such as water-lilies (*Nymphaea* spp.) and smartweeds (*Persicaria* spp.), use aquatic sediments as germination and rooting substrate. Like terrestrial soils, aquatic sediments function to accept, store, and process nutrients, making them available to plants and animals.

While aquatic sediment is often thought of as fine-grained material such as silt, clay, and sand, it may include coarse-grained mineral substrates such as gravel, cobble, boulders, and bedrock. The composition of aquatic sediment within a watershed or individual waterbody depends on factors such as channel slope, geologic history, and land use patterns. In some watersheds, fine-grained particles may dominate the sediment, while in other systems, these smaller particles may be essentially absent. Lakes and ponds generally contain sediment that has accumulated from external sources over extended periods of time and may be a legacy of glacial processes. Sediment in ponds and lakes also may be the result of more recent processes such as inputs from streams and rivers, wind and wave erosion, or nearshore transport (littoral drift) in larger waterbodies.

There are several generalizations regarding patterns of sediment deposition in aquatic ecosystems. In rivers, coarse-grained sediment (e.g., gravel, cobble, boulders) is typically present in high-velocity turbulent habitats, while sediments in low-velocity habitats are often fine-grained (e.g., silt, sand, clay) and may have high organic carbon concentrations. In the inner portion of meander bend, the water moves more slowly and fine-grained materials settle out of the water column creating deposits of sediment (areas of deposition). In contrast, in the outside of these bends, water moves more quickly, allowing water to transport more sediment, and can scour sediments from bedrock or substrates too large for transport. In some cases, especially in large riverine systems, substrates in the center of the channel may consist of coarse-grained substrates, while those on the margins are fine-grained as a result of secondary circulation patterns (Hey 1983).

For lakes, factors that influence sediment deposition patterns and grain size composition include basin size, lake depth, lake surface area, and lake age (Horne and Goldman 1994). The length of open water where wind may blow (i.e., fetch) is an important determinant in the kinetic energy profile for nearshore environments on lakes and other standing waterbodies. Substrates along windswept shorelines in large lakes typically are coarse-grained, while substrates in sheltered embayments typically are fine-grained. Sediments often exist in aquatic ecosystems as a patchwork mosaic of substrate types. These patterns contribute to resource partitioning that controls the distribution and abundance of aquatic organisms. For example, some benthic spawning fish use coarse-grained substrates, while others use sand (Welcomme et al. 2006).

8.3.6.1 Recovery of Aquatic Sediments Following a Crude Oil Release

For aquatic sediments, recovery is measured by hydrocarbon concentrations and contaminant levels in sediments decreasing to a point where they meet sediment quality standards or meet risk-based objectives in assessments, such as the sediment quality triad.[31] Other sections in this report address the response and recovery of sediment-associated species, including benthic macroinvertebrates (Section 8.3.7) and fish (Section 8.3.7).

Many factors influence the recovery of aquatic sediments from crude oil, including oil properties, weathering, emergency response, site-specific conditions, and environmental conditions. Most crude oils, including heavy crude oils such as diluted bitumen, are less dense than water and will float. Initial effects to sediment occur along shorelines due to oil stranding. If not removed from

[31] Sediment quality triad (SQT)—chemistry to measure contamination, bioassay to measure toxicity, in situ biological assessment to measure effects [i.e., benthic community alteration]) (Chapman 1990).

the environment, crude oil on the water's surface will undergo weathering processes such as evaporation, dispersion, emulsification, or contact with suspended sediment in the water.

These processes may increase the specific gravity of the released crude oil to a point that it becomes neutrally or negatively buoyant and submerges. Specifically, as the volatile lightweight hydrocarbons within crude oil evaporate, the remaining oil will consist of an increasingly larger proportion of non-volatile heavy molecular weight hydrocarbons that have a strong affinity to suspended sediments, particularly those with a high organic content. As the density of the remaining product increases, the residual material may submerge or sink (Fingas 2015).

Crude oil's tendency to bind tightly with suspended or benthic sediments helps reduce the residual oil's toxicity by decreasing its availability to organisms even when ingested (bioavailability). Heavy molecular weight PAHs that weather more slowly are resistant to biodegradation, but they also are not generally as toxic as lower molecular weight hydrocarbons (Prince et al. 2003). In combination, these factors contribute to the magnitude of sediment contamination and effects which, in turn, influences the duration of recovery of aquatic sediments.

The site-specific characteristics of the receiving environment also may influence the recovery of aquatic sediments. For example, the 2010 Enbridge Kalamazoo River pipeline release occurred during a spring flooding event. The Cold Lake diluted bitumen (i.e., heavy oil) that was released had an average API gravity of 21.0 and floated on the water initially (Crude Monitor 2016). However, extreme turbulence due to the flooding, extremely high sediment loads, suspended debris, as well as the presence of a roller dam, created oil-water-sediment emulsions ladened with debris. These emulsions became negatively buoyant, resurfacing, and re-sinking, and eventually settling out in depositional areas. During the clean-up of this release, river sediments were physically removed to allow recovery of the affected river segment.

Weathered oil-particulate aggregates may settle to the bottom sediments, where clean-up is more difficult than collection of crude oil from the water's surface. The amount of unrecovered oil and the proportion of complex PAHs in the submerged sediment influence the biodegradation rates that lead to recovery.

The recovery of aquatic sediments affected by crude oil will progress at different rates depending on the types of aquatic habitat and environmental conditions. In general, high energy habitats, such as riffles in rivers and wave-swept shorelines in lakes, tend to recover rapidly in comparison to low energy habitats such as backwaters in rivers, large surface water impoundments, or wetland sloughs (Poulton et al. 1997). This is attributed to several physical, chemical, and biological processes. These habitat types differ substantially in terms of sediment retention times. Riffles have a near continuous supply of turbulent flow from upstream, resulting in the transport, dispersal, and dilution of released product. Low energy environments have lower rates of flushing, and sediments in these locations may be both high in organic content and anoxic. Anaerobic biodegradation of crude oil generally is acknowledged to be a less efficient process than aerobic biodegradation (Prince et al. 2003).

The case studies and other supporting literature discussed below describe several remediation approaches and environmental factors that can accelerate or impede recovery of aquatic sediments following a crude oil release. These case studies are primarily from lotic (streams and rivers) habitats because there is little available sediment recovery literature from oil releases in lentic (ponds and lakes) habitats. Case studies are ordered chronologically as practices have evolved from previous experience within the oil and gas industry. As illustrated in Attachment A, the number of petroleum hydrocarbon releases with recovery information within the geographic region similar to Minnesota was very limited. The case studies below include incidents from a broader temperate region of North America. Stantec et al. (2012a) and Enbridge (2015) provide additional descriptions of some of these sediment case studies, including incident details and recovery information. Although broad generalizations cannot be drawn from a single event, case studies provide significant data that, in combination with existing literature, can help regulators and operators gain a more comprehensive understanding of the effects of releases of petroleum hydrocarbons and the subsequent recovery of various environmental media.

Laurel Pipe Line Company, Roaring Run Creek, Howell's Run, and North Branch of Little Conemaugh River, Pennsylvania*: On October 16, 1982, approximately 1,310 barrels of aviation kerosene was released from a Laurel Pipe Line Company pipeline. The release affected multiple streams, including Roaring Run Creek, Howell's Run, and the North Branch of Little Conemaugh River. Clean-up operations for this incident included booming and vacuuming of the kerosene, and resulted in recovery of approximately 760 barrels of the released material.*

The aviation kerosene saturated sediments downstream of the release site, resulting in contaminated sediments with high concentrations of petroleum hydrocarbons. Recovery information on the affected area indicated that water chemistry recovered in less than two months. While sediment hydrocarbon concentrations remained elevated for 14 months after the release, hydrocarbons were no longer detected in sediments after 21 months (Guiney et al. 1987). Factors contributing to the recovery of this system included the rapid clean-up response, and a continuous supply of uncontaminated water from upstream of the release site (Guiney et al. 1987).

Shell Pipe Line Company, Gasconade River, Missouri*: On December 24, 1988, a Shell Pipe Line Company pipeline ruptured releasing approximately 20,760 barrels of crude oil into Shoal Creek, a tributary of the Gasconade River which eventually reached the Missouri River. Clean-up operations for this incident were conducted for a month following the release and recovered approximately 50% (10,380 barrels) of the released crude oil. Sediment quality was studied for 18 months after the release (Poulton et al. 1997). Sampling conducted by the Missouri*

Department of Natural Resources during the first months after the incident showed rapid recovery of aquatic sediments in fast flowing stream reaches, and were comparable to unaffected sites within six months following the incident. In contrast to fast flowing stream reaches, crude oil had accumulated in backwater areas and took longer to recover to background conditions. While some backwater sites reached background concentrations in 15 to 18 months, other sites had not reached background levels (defined as a range of total petroleum hydrocarbons between 30 ppm [detection limit] and 80 ppm) when the study was concluded 18 months after the release. Spring floods that flushed and scoured the sediments within the stream bed were thought to increase the rate of recovery of aquatic sediment quality.

***St. Lawrence River, Quebec**: This 1999 experimental oil treatment was conducted in a freshwater wetland along the shoreline of the St. Lawrence River in St. Croix de Lotbinière, Quebec. The experiment involved the intentional release of 0.8 barrels of crude oil into each of the four blocks of vegetation wetland plots (Hodson et al. 2002). A weathered medium crude oil was applied to vegetated wetland plots to examine the effects of nutrient enrichment (bioremediation) and plant growth (phytoremediation) on sediment recovery. The experiment examined a biomarker of exposure (a liver enzyme known as cytochrome p450) in trout as an indicator of remediation success (Hodson et al. 2002). After 15 months, sediments showed an approximate 80% reduction in petroleum hydrocarbons, which corresponded with similar reductions in biomarker activity in the trout. Reductions in hydrocarbons were attributed to weathering of volatile components and flushing due to tidal and wave action. It also is possible that clean sediment deposited through littoral drift and erosion contributed to hydrocarbon reductions.*

***Enbridge Line 3 Glenavon, Saskatchewan**: On April 15, 2007, Enbridge's Line 3 pipeline released an estimated 6,230 barrels of heavy crude oil into a slough (wetland) located on agricultural land near Glenavon, Saskatchewan (SLR Consulting 2008b). Approximately 5,740 barrels were recovered from the release (TSBC 2008). Emergency response efforts included repair of the pipeline, recovery of surface oil from the slough, removal of affected vegetation from the perimeter of the slough, and removal of affected surface water. Remediation included excavation of affected sediments from the slough that had PAH concentrations that exceeded freshwater sediment criteria set by the CCME. Subsequent sampling of sediments conducted in May through September 2007 indicated hydrocarbon concentrations were below the remedial criteria established for the site. In September and October, reclamation of both the slough and riparian zones commenced after the remedial criteria were met. The reclamation program consisted of contouring the site to match surrounding topography;*

relieving shallow soil compaction from equipment; and topsoil replacement, cultivation, and bank seeding of the slough (SLR Consulting 2008b).

Enbridge Line 6B Marshall, Michigan*: In July 2010, Enbridge's Line 6B pipeline released approximately 20,000 barrels of crude oil near Marshall, Michigan over a period of approximately 17 hours. At the time of the release, the pipeline contained two different batches of crude oil estimated to consist of approximately 77% CLWB diluted bitumen and 23% Western Canadian Select crude oil (NTSB 2012). Of this, approximately 8,200 barrels reached Talmadge Creek and the Kalamazoo River (Enbridge 2013).*

As described previously, the combination of extreme turbulence due to the flooding, water flow over a dam, and mixing of the released crude oil with suspended particulates in the water column formed oil-water-sediment aggregates ladened with debris. As a result, in the weeks following the incident, OPAs became submerged in some locations, especially low energy depositional areas. Surface oil was removed during the clean-up operations, and submerged oil was removed through targeted dredging of contaminated sediments. To monitor the effects and recovery of the residual oil in sediments, Enbridge completed a weight-of-evidence SQT analysis in 2013 that incorporated sediment contaminant chemistry, sediment toxicity, and macroinvertebrate community analysis. These three lines-of-evidence were reviewed together to determine whether significant ecological effects remained, and whether there was evidence of sediment recovery. The macroinvertebrate results from this analysis, as well as other studies[32], are further reviewed in Section 8.3.7.

The SQT analysis focused on sediments in depositional areas of the Kalamazoo River where residual submerged oil was present. Talmadge Creek sediments lacked sufficient accumulations of oil to be included in the study. Taking into account the sediment chemistry results, sediment toxicity, and the macroinvertebrate community results, the SQT analysis concluded the recovery to pre-release conditions was well advanced, and residual oil was not having a significant adverse effect on the aquatic ecosystem.

Enbridge Line 37 Fort McMurray, Alberta*: On June 22, 2013, approximately 1,300 barrels of synthetic crude oil was released from the Enbridge Line 37 pipeline. The released crude oil rose to the surface in the saturated soils and flowed overland along the pipeline ROW to a fen, eventually reaching the shores of an unnamed lake.*

[32] Other studies include MI DEQ Procedure 51, which consists of separate qualitative evaluations of the macroinvertebrate community, fish community, and habitat quality. These protocols can be used to assess the existing condition of Michigan's wadeable streams and rivers as well as detect spatial and temporal trends (MI DEQ 2016).

> *Remediation of the affected area was carefully planned to minimize effects to the sensitive fen and lake environment. Initial remediation efforts focused on removal of crude oil from the surface of the lake and wetland, removal of affected soil, and targeted removal of sediment from the lake during a period of low water. The initial remediation removed 93% of the released crude oil.*
>
> *A human health and ecological risk assessment was conducted on the remaining oil to develop site-specific remediation targets and inform subsequent monitored natural attenuation. For lake sediments, a net environmental benefit approach was used to determine if the remaining sediment posed a negligible environmental risk. Leaving the remaining oil in place was determined to be less detrimental to the overall ecosystem than additional disturbance of the lake. As of the date of this report, monitored natural attenuation is ongoing to confirm that remediation objectives are being met (Hemmings et al. 2015).*

The above case studies focused on the recovery of aquatic sediments following very large petroleum hydrocarbon incidents. Despite the volumes released, aquatic sediments in the affected watercourses and waterbodies recovered fully in most cases. The only exceptions to full recovery were in studies where monitoring was terminated after short periods (e.g., 18 months), such as the study on the Gasconade River. The case studies demonstrated that sediment recovery may differ based on: 1) incident circumstances (e.g., quantity of crude oil, type of oil, flooding); 2) remediation activities and regulatory thresholds; and 3) the type of affected environment (e.g., stream velocity, sediment characteristics).

8.3.6.2 Factors Affecting Recovery

Human intervention to protect sensitive habitats and reduce the amount of affected sediments can speed the rate of recovery (Hemmings et al. 2015). Freshwater sediments in high energy habitats tend to recover more rapidly than low energy habitats due to the increased flushing and weathering of crude oil (Guiney et al. 1987; Poulton et al. 1997; Higgins 2002). Episodic flood events in rivers and wind-generated wave energy in lakes can mobilize sediments and disperse contamination (Poulton et al. 1997; Hodson et al. 2002). In some circumstances, this physical agitation can increase weathering of crude oil by restoring aerobic metabolic processes.

Some constituents of crude oil (e.g., asphaltenes) are particularly resistant to weathering and, if not removed from the environment, may persist in sediment for decades, slowing recovery (Prince et al. 2003). Weathering of oil in poorly oxygenated (anoxic) sediments relies on anaerobic processes that are less efficient than aerobic processes and can prolong recovery (Prince et al. 2003). Dredging has been used to accelerate sediment recovery. Regulators and industry have effectively worked together to evaluate site-specific conditions at the release site to determine effective remediation strategies that address the net environmental benefit. In some cases, the use of heavy equipment many cause greater environmental harm than allowing natural attenuation to occur.

8.3.6.3 Summary of Aquatic Sediment Recovery

Aquatic sediments are an important habitat component of freshwater systems, providing substrate that is utilized by both macroinvertebrates and fish for habitat, reproduction, and feeding. Crude oil releases that reach freshwater environments may affect aquatic sediments, especially riverbanks and lake shorelines. Timely and effective emergency response can reduce effects and recovery time. If crude oil is not removed from the environment, weathering will increase the oil's density. Under certain circumstances, oil-water-particulate aggregates may form with suspended sediment and debris, which can then sink to the substrate surface.

Following a crude oil release, monitoring the recovery of aquatic sediments is important to restore ecological function. Recovery can be assessed using a variety of techniques including comparison of petroleum hydrocarbon concentrations in sediment compared to sediment quality guidelines; recovery of the benthic macroinvertebrate communities; or risked-based weight-of-evidence approach.

Recovery of aquatic sediments is a fairly rapid process in high energy habitats where flushing and an accelerated weathering process can occur. In low energy habitats, recovery may take longer, especially when crude oil is incorporated with finer grain sediments that may be anoxic. Fast, effective response to oil releases in the freshwater environment can minimize effects to sediment. In some circumstances, human intervention measures can be used to facilitate sediment recovery; however, it is important to consider the net environmental benefits before major interventions are initiated.

8.3.7 Aquatic Biota

Aquatic biota are often used to monitor the ecological health of aquatic ecosystems, including effects and recovery from crude oil releases. In streams and rivers, time to recovery varies with waterbody size and habitat type, but recolonization usually begins soon after the release with full or substantial recovery within one year. The type of oil and volume released also affect recovery of aquatic biota. Depending on the species, recolonization can occur through a combination of downstream drift, upstream and downstream migration, migration from within the substrate, and aerial sources.

The primary factors accelerating recovery include utilization of clean-up techniques that minimize crude oil penetration into substrates, dilution and degradation of oil by higher flows, and the presence of individuals in nearby unaffected reaches. Recovery may be impeded by residual crude oil contamination, habitat alterations, and supplemental environmental stressors such as low flow and drought conditions during the recovery process.

8.3.7.1 Aquatic Vegetation

Aquatic plants are defined as those that live in freshwater, brackish, or saltwater environments. Many species of aquatic plants such as water-lilies (*Nymphaea* spp.), broad-leaf cattail (*Typha* *latifolia*), and smartweeds (*Persicaria* spp.) use aquatic sediments as germination and rooting substrate. Other aquatic plants grow in the water column such as green algae (*Selenastrum* capricornumtum) or along the surface of slow moving water such as duckweed (Lemna minor). Aquatic communities provide diverse ecological functions that support both natural and human environments, including providing wildlife and fisheries habitat, shoreline stabilization, flood and storm surge reduction, and water quality protection through the uptake of excess nutrients and toxins.

8.3.7.1.1 Recovery of Aquatic Vegetation Following a Crude Oil Release

Many factors influence the recovery of aquatic vegetation from a crude oil release, including the resiliency of the species affected, the type of oil and its properties, weathering, and emergency response. Release volume, time of year, and environmental conditions at the time of the release also can influence the rate of recovery (Hoff et al. 1993; Lin and Mendelssohn 1996). For example, high energy habitats such as riffles in rivers and wave-swept shorelines in lakes tend to recover rapidly in comparison to low energy habitats such as backwaters in rivers, large surface water impoundments, or wetland sloughs (Poulton et al. 1997). High energy habitats can scour crude oil from sediments, help break up and disperse crude oil, and create aerobic conditions that help to facilitate the biodegradation of crude oil.

Most crude oils, including heavy crude oils such as diluted bitumen, are less dense than water and therefore will initially float on the water's surface. Crude oils may physically coat the surface of aquatic vegetation on or near the water surface. Over time and if clean-up is not complete, crude oil present on surface water eventually may submerge through a combination of weathering processes such as evaporation, dispersion, emulsification, or contact with particles in the water column or sediment. These weathering processes reduce the concentrations of volatile and water soluble compounds, including some that are toxic to aquatic plants. As crude oil weathers, the composition of the remaining material becomes dominated by heavy molecular weight hydrocarbons (e.g., asphaltenes). These residual compounds tend to be more resistant to biodegradation, have a higher affinity to sediment, and are not generally as toxic to aquatic vegetation as lower molecular weight hydrocarbons (Prince et al. 2003).

The resiliency of aquatic vegetation to a crude oil release depends on the sensitivity of the plant species, the time of year when the release occurs, the recovery rate of surface water and sediments used by the aquatic plants, and the proximity of nearby plant communities that can help recolonize the affected area. For example, both green algae and duckweed are relatively sensitive to many water soluble contaminants, but their ability to reproduce quickly with many offspring allows algae and duckweed populations to recover quickly once water quality improves.

Physiology and reproductive strategies can affect how readily plants recover from a crude oil release or other environmental disturbance. For example, some plants have rhizomes, which are shallow horizontal roots that allow plants to reproduce asexually as an alternative means of reproduction. Softstem bulrush (*Schoenoplectus tabernaemontani*) and cattails are common aquatic plants with rhizomes. In the event of a crude oil release, rhizomes may allow plants to survive and more readily recover following a crude oil release (Lin and Mendelssohn 1996). While annual species tend to be susceptible to the initial effects of a crude oil release, these species are frequently among the first to reestablish themselves if there is an available seed source near the release site (Michel and Rutherford 2013).

The time of year when a release occurs can substantially influence the type and extent of effects to vegetation, as well as the time it can take for aquatic plant communities to recover. A crude oil release that occurs during or just prior to senescence (i.e., seasonal quiescence of vegetation) will have fewer initial effects on vegetation and a more rapid recovery than releases during the active growing season (Michel and Rutherford 2013; Pezeshki et al. 2000). Senescence, including leaf drop in many aquatic plants, occurs prior to the onset of dormancy when biological processes within a plant cease until the next growing season. There is less surface area exposed to oiling if leaf drop has already occurred, and the plant does not experience the same metabolic or reproductive effects under dormant conditions as during the growing season.

Other environmental processes such as the flow and movement of water, whether from natural or anthropogenic activities, can advance or potentially hinder recovery. Natural stream flow, tidal action, and wakes created by boat traffic were attributed to helping flush oil from a contaminated marsh along the Delaware River from the Panamanian tank vessel *Grand Eagle* in 1984 (Michel and Rutherford 2013). Flood events can occur simultaneously with crude oil releases, such as in oil releases from oil well pad sites (e.g., Missouri and Yellowstone rivers in 2014 near Trenton, North Dakota; Platte and Big Thompson rivers in Colorado, 2013); pipeline releases (e.g., Bridger's Poplar Pipeline in Yellowstone River, Montana, 2015; ExxonMobile's Silvertip pipeline in Yellowstone River, Montana, 2011; Enbridge's Line 6B near Marshall, Michigan, 2010); and home heating oil releases (e.g., homes in Grand Forks during 1997 Red River flood, North Dakota) can result in oil becoming stranded over large areas. These flood events resulted in the oiling of aquatic, terrestrial, and riparian vegetation. While flooding can help to flush oil from affected areas, it can also strand oil above normal water levels where it can remain for longer periods if it is not cleaned up. The stranding of oil can slow vegetation recovery and reestablishment (Michel and Rutherford 2013).

Emergency response methods can either facilitate or impede recovery of aquatic vegetation recovery depending on how the methods are employed and the type of vegetation affected (Section 8.4). Rates of aquatic vegetation recovery are improved when techniques selected for crude oil removal account for the sensitivity and reproductive strategies of the affected vegetation (e.g., reduce disturbance to rhizomes), reduce soil/sediment disturbance to the extent practical, and ensure clean-up is timely and effective. When regulators determine that clean-up techniques may cause net environmental harm, recovery results can be variable. In the absence of clean up, recovery is influenced by the type and severity of effects on aquatic plants, magnitude of the area affected, the type of aquatic plant community, and other environmental factors (e.g., water flow, water quality, time of year.).

***Enbridge Line 4 Cohasset, Minnesota**: In 2002, an underground pipeline located west of Cohasset, Minnesota, ruptured and released approximately 6,000 barrels of crude oil in a large wetland complex (NTSB 2004). Because of concerns that the oil contamination would spread with forecasted rain, the decision was made to burn the oil in place (NTSB 2004). After the vegetation in and adjacent to the release site was burned, temporary mat roads were constructed to allow access for heavy equipment.*

Approximately 11 acres of wetlands were affected by the initial crude oil release and remediation activities. Following remediation, wetland restoration efforts included reestablishing site topography and vegetation. As of 2005, the affected site was a mix of emergent vegetation and open water habitat. Although the site was dominated by cattails, other species such as broad-leaved arrowhead (Sagittaria latifolia), water plantain (Alisma subcordatus), duckweed (Lemna minor), sedges, and rushes also were becoming established.

***Canadian National Railway Company, Wabamun Lake Oil Release, Alberta**: On August 3, 2005, approximately 4,400 barrels of heated Bunker C Oil and 554 barrels of pole treating oil were released as a result of a Canadian National Railway Company train derailment near Wabumun Lake, Alberta, Canada. Wabumun Lake is approximately 32 square miles in size and supports extensive beds of bulrush and cattails along its shoreline and in shallow areas.*

The railway company did not respond promptly to the release, did not have an emergency response plan, and their clean-up efforts were not highly effective. They eventually pleaded guilty to failing to take reasonable measures to confine, clean up, and remedy the release.

As the Bunker C and pole treating oils flowed overland toward the lake, the oils adsorbed to sediment and vegetative debris, and combined with water. The resulting oil-sediment-matter mixture was more dense than the initial oil that sank in water (Hollebone et al. 2011). The authors also noted the oil-sediment-vegetable matter conglomeration was 500 to 50,000 times more viscous than Bunker C Oil, which greatly reduced the possibility of the oil breaking into smaller particles (Hoolebone et al. 2011). Strong winds and wave action transported the oil-sediment-vegetative debris mixture across the lake, forming neutrally and negatively buoyant tar balls[33].

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[33] Bunker C Oil is extremely heavy and viscous. Therefore, formation of neutrally and negatively buoyant tar balls and emulsions is more likely than with other crude oils.

> *Not long after the initial release, submerged tar balls were seen along the shoreline and in shallow water, as well as dispersed among the emergent shoreline vegetation (Hollebone et al. 2011). Some of the submerged oil-sediment-vegetative matter mixtures formed relatively large mats and logs. Tar balls on and around the vegetation continued to move laterally in the water column and release oil during the course of their movements. Those tar balls in contact with and adhering to shoreline vegetation continued to release oil. In February 2007, tar balls were still observed within shoreline vegetation and adhering to roots of shoreline vegetation (Hollebone et al. 2011).*
>
> *The shoreline of Wabamun Lake is dominated by softstem bulrush (Schoenoplectus tabernaemontani) and broad-leaf cattail (Typha latifolia) (Wernick et al. 2009). Much of the oil became trapped in the softstem bulrush beds along the lakeshore. During clean-up efforts, the oiled softstem bulrush was cut manually or with mechanical weed cutters. The sediments were then flushed and/or vacuumed (Thormann and Bayley 2008; Wernick et al. 2009). In general, areas that were accessible from shore were cut manually. Those areas inaccessible from shore and considered to be particularly sensitive to disturbance were cut primarily using reed cutters (Thormann and Bayley 2008).*
>
> *In post-release studies that followed the softstem bulrush beds, it was determined that the oil itself did not negatively affect the species, but clean-up efforts did have a substantial negative effect on rhizome density and biomass. Based on study results, it appeared that the oil had no measurable negative long-term effects on the biomass, cover, height, or seedhead production of the softstem bulrush (Thormann and Bayley 2008).*
>
> *In general, monitoring sites with shallower water depth, regardless of the degree of oiling or intensity of treatment, had a greater biomass of softstem bulrush. The difference in biomass in shallower water likely could be attributed to increased rates of seed germination, seedling growth, and rhizome survival and re-growth (Thormann and Bayley 2008). The researchers also concluded that the richness and cover of submerged aquatic vegetation was not affected by the release or subsequent clean-up treatments (Thormann and Bayley 2008).*

8.3.7.1.2 Factors Affecting Recovery of Aquatic Vegetation

Aquatic vegetation can recover from crude oil releases. Species that reproduce quickly with numerous offspring can recover quickly once clean-up has occurred. Aquatic plants that use rhizomes to reproduce also can recover quickly, provided that the root zone is not overly disturbed and the clean-up occurs prior to substantial toxicological effects to the roots. Crude oil releases occurring during a season when vegetation is dormant, when there is less biological activity and less leaf surface area, may recover more quickly than a release during the active growth period (Michel and Rutherford 2013; Pezeshki et al. 2000).

Remediation of heavily oiled vegetation that focuses on vegetation removal with minimal root disturbance (e.g., cutting and removal of vegetative matter above the water surface without disturbing the root zone) can accelerate recovery (Hemmings et al. 2015; Hoff et al. 1993; Thormann and Bayley 2008). The removal of existing natural seed banks and disturbance of root masses delay the re-establishment of vegetation or potentially expose a natural community to invasive species (Rood and Hillman 2013).

Properly employed use of low-pressure flushing and vacuuming of residual crude oil can be effective remediation techniques. Natural flushing by stream flows, waves, or tides can benefit the recovery of vegetation (ESRD 2012; Michel and Rutherford 2013).

Under certain circumstances, natural attenuation may be an available remediation strategy, particularly in areas sensitive to disturbance. Natural attenuation of crude oil includes the physical weathering of oil by evaporation, photodegradation, and dispersion, as well as biodegradation of oil by bacteria. Natural attenuation can be an effective approach in areas with light to moderate oiling, where clean-up activities have removed the bulk of the released product, or where clean-up activities are likely to result in greater environmental harm than allowing natural attenuation to occur (ESRD 2012; Hemmings et al. 2015).

Previous releases have shown that recovery may be slower than expected under certain circumstances. High release volumes that cause substantial dieback of large areas of vegetation can delay recovery due to reduced asexual reproduction and distance to unaffected seed sources (Michel and Rutherford 2013). Clean-up activities, including use of heavy equipment, that inadvertently damage root masses and remove aquatic sediments, can also delay recovery (Thormann and Bayley 2008; Wernick et al. 2009; USFWS et al. 2005; Hoff et al. 1993). Incomplete clean up in heavily oiled areas, especially when the vegetation has been heavily coated and root masses are affected, also can delay recovery (Michel and Rutherford 2013; Corn and Copeland 2010).

8.3.7.1.3 Summary of Aquatic Vegetation Recovery

Effects to aquatic vegetation communities from a crude oil release can subsequently affect the functions they support, including wildlife and fisheries habitat, shoreline stabilization, and water quality. Depending on the resistance and resiliency of the aquatic plants, some species may show little or no response to crude oil while others die back, at least temporarily, or show other signs of stress or impairment. The effects to and recovery of aquatic vegetation following an oil release vary, depending on the type and amount of product released, type and intensity of response activities, time of year relative to plant dormancy, weather conditions, aquatic sediment characteristics, and vegetation type.

There is a limited amount of information about the effects and recovery of freshwater aquatic vegetation from crude oil releases compared to marine releases. The information that is available shows that the type and intensity of remediation efforts does have a strong influence on the subsequent recovery of affected vegetation communities. While vegetation communities can recover through natural attenuation following some releases, remedial action is often needed to prevent further spread of the released crude oil, and reduce additional contamination of the environment.

Recovery of vegetation from a crude oil release is contingent upon many factors, some of which cannot necessarily be anticipated at the time of the release or during the subsequent remedial efforts. The information from the case studies and general restoration literature suggest that the greater the intensity and extent of disturbance resulting from a crude oil release, response, and remediation activities, the longer it will take aquatic vegetation to recover. This includes recovery of the aquatic vegetation and the functional capacity of the community. Overall, the case studies and other literature demonstrate aquatic vegetation can recover, provided remediation techniques appropriate to the circumstances are used.

8.3.7.2 Benthic Macroinvertebrates

Aquatic invertebrates are an assemblage of taxa that live at least part of their life cycle in an aquatic habitat. Benthic macroinvertebrates are further defined as those individuals living in or on bottom substrate and that are large enough to be seen without magnification. In freshwater environments, the main taxonomic groups of benthic macroinvertebrates include insects, annelid worms, mollusks, flatworms, and crustaceans. These macroinvertebrates can be found on a variety of benthic substrates from soft sediments to large rocky substrate, submerged woody debris, aquatic vegetation, and root masses (Klemm et al. 1990).

Macroinvertebrates have a number of important roles in aquatic food webs, including the digestion of organic material and recycling of nutrients. They serve as a conduit of energy flow from organic matter to vertebrate populations (Madsen and Nightengale 2009). This energy transfer is critical for smaller forested stream ecosystems that may derive the majority of their energy budgets from terrestrial sources such as leaf and needle litter (Allan and Castillo 1995; Vannote et al. 1980). Although benthic macroinvertebrates themselves have little commercial value, they are an important food source for recreational and commercial fish species.

Benthic macroinvertebrates are widely used for monitoring the ecological health of aquatic ecosystems, including effects and recovery from crude oil releases. The merits of these organisms as test subjects include ease of sampling and identification, high site fidelity, sessile life stages, complex life cycles, variable positions in the food web, relatively high abundance in most aquatic habitats, variable susceptibility to environmental stressors, and importance as a food source for commercial and recreational fish species (Barbour et al. 1999). Macroinvertebrate data are regularly collected by federal and state agencies as a measure of waterbody health and these data can provide a robust record of waterbody status over time.

8.3.7.2.1 Recovery of Benthic Macroinvertebrates Following a Crude Oil Release

Recovery of macroinvertebrate communities can be influenced by many factors, including the type of habitat(s) affected by a release, species life history (reproductive strategy, life stage, habitat preferences), sensitivity of the species, and timing of the incident in relation to these factors.

Benthic macroinvertebrates recolonize affected stream or riverine environments by four main routes: downstream drift, upstream migration, migration from within the substrate, and aerial sources including oviposition (egg laying). Williams and Hynes (1976) studied these recolonization mechanisms in an Ontario stream and found that 4.1% of recolonization was from drift, 28.2% was from aerial sources, 19.1% was from migration from substrate, and 18.2% was from upstream migration. This study illustrates the importance of all methods of recolonization for macroinvertebrates and the potential influence of season, flow, and life history on recolonization. Other studies also report drift as the most important mechanism of recolonization, although the other mechanisms are usually not studied (Wallace 1990). Wallace (1990) also reports that drift may be less important than aerial sources for small streams where there is less of an upstream source of colonists and that headwater taxa generally have lower drift rates than those in larger streams.

Wallace (1990) defines macroinvertebrate recovery as "the reestablishment of community structure to within the range expected over the annual cycle within a particular habitat prior to the initial disturbance." Studies on recovery of macroinvertebrates need to take into account that aquatic environments are dynamic systems and there is little long-term evidence to suggest that benthic macroinvertebrate communities approach equilibrium conditions (Wallace 1990).

The case studies described below followed recovery of benthic macroinvertebrates from oil releases. These case studies are primarily from lotic (streams and rivers) habitats because there is little available macroinvertebrate recovery literature from oil releases in lentic (ponds and lakes) habitats. Impoundments, pools, and backwaters in lotic systems can have similar habitat features and communities to lentic systems and some of the same factors influencing recovery may apply.

The number of incidents with freshwater aquatic invertebrate recovery information from petroleum releases within the geographic region most similar to Minnesota was limited. Therefore, these case studies include incidents from a broader temperate region of North America. Stantec et al. (2012a) and Enbridge (2015) provide additional descriptions of some of these macroinvertebrate case studies, including incident details and recovery information specific to the scope and objectives of their analysis.

A common theme in the evaluation of recovery of macroinvertebrate populations and communities is the importance of one or more reference sites. Macroinvertebrate communities are typically diverse, complex, and subject to a high degree of variability. Therefore, the selection of an appropriate reference site with similar flow and habitats to the affected sites is an important aspect for making a recovery determination. When reference sites do not meet these criteria, the confirmation of recovery can be confounded.

For similar reasons, studies should rely on multiple metrics to determine if recovery of the macroinvertebrate community is occurring. Due to high natural variability, reliance on a single metric is much less reliable than a weight-of-evidence approach.

> ***Ozark Pipeline System, Asher Creek, Missouri****: This incident occurred in August 1979 when a 22 inch diameter pipeline constructed in 1949 ruptured along its longitudinal seam, releasing approximately 9,520 barrels of crude oil into Asher Creek in southwest Missouri. Asher Creek is a small stream with low flows that limited the dispersal and dispersion of the large volume release of crude oil. The benthic macroinvertebrate community was sampled for 18 months after the event (Crunkilton and Duchrow 1990). This study followed macroinvertebrate density, diversity, and the number of taxa of mayfly (Ephemeroptera) and stonefly (Plecoptera) over time.*
>
> *Initial sampling found that the site directly downstream of the release site was most affected. The study monitored species density, diversity, and mayfly/stonefly taxa over time and compared these community metrics with reference site metrics. Recovery occurred within nine months, and the re-colonization of affected stream reaches included organisms normally associated with unpolluted waters. A drought in August and September (about one year after the incident) caused macroinvertebrate metrics to decline, but diversity and mayfly/stonefly taxa rebounded approximately six months later following increased flows. Similar trends were seen in reference sites indicating recovery at the affected stream sites. It should be noted that additional environmental stressors were likely affecting aquatic macroinvertebrates within the region. For 11 months after the release, species diversity indices and the number of mayfly/stonefly taxa in reference sites were less than the minimum values established for unpolluted Missouri streams (Crunkilton and Duchrow 1990).*
>
> *Factors impeding recovery time included: 1) the additional stress of warm summer temperatures and low flows, 2) the large volume of the crude oil compared to the volume of the creek at the time of the incident, and 3) the origination of the creek from a spring only 0.4 miles upstream of the release site, which limited the abundance and diversity of upstream macroinvertebrates available for re-colonization.*
>
> *The primary contributing factor accelerating recovery was the scouring spring floods, which the authors believe flushed residual crude oil from the area and promoted additional species recruitment. Consistent spring flows and numerous riffles in the creek also promoted recovery by increasing turbulence and maintaining dissolved oxygen concentrations near saturation levels, both of which helped weather and degrade the released oil.*

This study also found that siphon dams and absorbent materials used in the emergency response phase retained floating, insoluble oil fractions and were valuable in protecting stream substrate in downstream areas. Areas protected from oil inundation below these dams recovered faster than unprotected areas.

Tennessee Experimental Pond Trials: *Experimental trials in Tennessee ponds were undertaken to quantify effects of oil releases on macroinvertebrates. The trials were conducted for four months starting with the addition of synthetic crude oil in July 1981 (Cushman and Goyert 1984). Different levels (i.e., 0.375, 0.075, 0.015 ppm) of synthetic crude oil were applied to the ponds to examine effects on and recovery of the macroinvertebrate community. Recovery in the species diversity, number of taxa, and total abundance were apparent three months following the application. An increase in the numbers of some chemical-tolerant species was also observed at some treatment levels. Macrophytes (aquatic vegetation, excluding photosynthetic algae and plankton) were found to mediate some effects on macroinvertebrates at lower treatment levels (e.g., 0.015 ppm).*

Laurel Pipe Line Company, Roaring Run and Howell's Run, Pennsylvania*: On October 16, 1982, a pipeline released approximately 1,310 barrels of -kerosene by Laurel Pipe Line Company into Roaring Run and Howell's Run near Ebensburg, Pennsylvania (Guiney et al. 1987). Clean-up operations recovered approximately 66% of the kerosene within the first 2 weeks. Acute effects included large reductions of macroinvertebrates in the reaches of both creeks.*

The study was initiated within one month of the incident and followed the macroinvertebrate recovery for over a year. Sampling indicated recovery of the macroinvertebrate community had begun by the following spring and, after a year, recovery was nearly complete with a high species diversity index.

Major factors that accelerated the recolonization process in the streams in this case study included the immediate and effective clean-up activities, uncontaminated flow from upstream of the release site that aided in dilution, and the drift of benthic organisms from upstream areas for recolonization. Recovery was delayed in some of the upstream sites directly below the release due to drought conditions. Sediment hydrocarbons were elevated for up to 14 months after the incident and authors reported these elevated concentrations could have slowed recolonization. However, after 21 months, no additional kerosene hydrocarbons were detected. The authors concluded that "Biological recovery appeared complete after only 12 months."

Yellowstone Pipeline Company, Wolf Lodge Creek, Idaho: *This incident occurred on June 4, 1983, when a Yellowstone Pipeline Company pipeline released approximately 595 barrels of unleaded gasoline into Wolf Lodge Creek, Idaho (Pontasch and Brusven 1988). Macroinvertebrate sampling sites were set up in riffle stream sections following the incident, with riffles sampled 17 days post-release and then at weekly and monthly intervals for 16 months.*

Although there were immediate effects from the release on the creek's macroinvertebrate community, community metrics documented a progression of recovery with time. Macroinvertebrate densities at the impact sites were not significantly different than reference sites 7 months after the release, and species richness was not significantly different after 16 months. The study also found that macroinvertebrates with higher drift densities, like mayflies and chironomids, rapidly recolonized the impact sites while stoneflies and caddisflies with low drift densities colonized more gradually. A bulldozer was used to agitate stream bed sediments to release hydrocarbons one month after the incident, but it is unclear from this study what additional effects this clean-up technique had on the macroinvertebrate community.

Shell Oil Company, Gasconade River, Missouri*: A Shell Oil Company pipeline released approximately 20,760 barrels of crude oil into Shoal Creek, a tributary of the Gasconade River near Vienna, Missouri on December 24, 1988. Clean-up operations occurred between December 1988 and January 1989 consisting of absorbent booms, surface oil removal, and pumping from backwater areas. Macroinvertebrate sampling occurred in July and October 1989, and in January, March, and June of 1990. Macroinvertebrate sampling occurred in both riffle and backwater areas of the Gasconade River during the two summers after the incident (Poulton et al. 1997).*

In riffle habitats, the study found that the total number of organisms; taxa richness; number of mayfly (<u>Ephemeroptera</u> spp.), stonefly (Plecoptera spp.), and caddisfly (<u>Trichoptera</u> spp.) (EPT) taxa; and EPT/Chironomidae ratio had recovered to reference levels after seven months. Authors noted that spring floods reduced the abundance and diversity of macroinvertebrates at both reference and impact areas, and the high flows and scouring may have contributed to subsequent recovery in riffle habitats. The flows in the riffle habitats contributed to weathering and flushing of oil residue, allowing more rapid colonization and faster recovery in these habitats.

In *contrast, benthic diversity and the scrapers and shredders functional feeding groups in the backwater areas remained diminished until the end of the study at 18 months post-release. These backwater areas would have experienced far less scouring from high stream flows. Authors attribute the slower recovery of benthic* *invertebrates in backwater areas to residual hydrocarbon contamination, despite an overall decline in hydrocarbon levels during the study period.*

Amoco, Chariton River, Missouri*: On November 5, 1990, a pipeline owned by Amoco released approximately 2,620 barrels of crude oil into a small tributary and then into the Chariton River near Ethel, Missouri. One month after the release, the abundance and taxa richness of collector and shredder functional groups and taxa richness of EPT from control and impact sites differed significantly indicating crude oil had affected the macroinvertebrate community.*

After one year, differences between impact and reference sites were no longer statistically significant with the exception of slightly lower taxa richness and overall abundance in the impact areas. The recovery of certain macroinvertebrates (i.e., filtering collectors) downstream of the oil release and the changes in a downstream community metric between sampling periods also suggested partial recovery after one year. The authors state that the effects to benthic biota observed after the release appeared to be associated with oil sorption and substrate coating, creating conditions unsuitable for successful colonization.

Yellowstone Pipeline Company and Conoco, Flathead Reservation, Montana*: The Yellowstone Pipeline released approximately 100 barrels of refined fuel into Camas Creek on the Flathead Reservation in Sanders County, Montana in the winter of 1993.*

Macroinvertebrates were severely affected as a result of direct and indirect toxicity and the diversion of the stream channel during clean-up activities, which resulted in reduced flows at sampling stations downstream of the release. The affected area was characterized by low EPT taxa abundance and richness.

The benthic community underwent progressive spatial recovery. Fifteen months after the incident, the taxa richness and EPT Index at the site closest to the release site approached levels observed at the upstream reference site. Sites farther downstream exhibited only partial recovery after 15 months, but authors noted that based on the observed recovery rate, the benthic community in the affected reach would likely recover (Van Derveer et al. 1995).

Consolidated Railways, Train Derailment, Cayuga Inlet, New York*: This release occurred on November 3, 1997, when a Consolidated Railways train derailed and released 167 barrels of diesel fuel into the Cayuga Inlet stream near West Danby, New York. Aquatic macroinvertebrate sampling occurred for 15 months after the derailment (Lytle and Peckarsky 2001).*

Researchers measured various macroinvertebrate community metrics and documented recovery during the 15-month study period. The authors concluded that the initial effects on benthic macroinvertebrates during the first 3 months were severe and that these effects extended up to 3.1 miles downstream. Despite the initial severity of the effects, macroinvertebrate density and taxonomic richness recovered within a year (Lytle and Peckarsky 2001).

The 15-month study period was not considered long enough to document full recovery for all community metrics because some sample sites immediately below the release site were dominated by a single taxa. The researchers speculated that the recovery time was potentially prolonged by lingering contamination during the initial colonization period and by the winter conditions that followed. Colonization from downstream macroinvertebrate drift and aerial recolonization of adults was mostly limited to the growing season following the incident (Lytle and Peckarsky 2001).

***Olympic Pipeline Company, Whatcom Creek, Washington**: On June 10, 1999, the Olympic Pipeline released approximately 5,640 barrels of unleaded gasoline into Hannah Creek that subsequently flowed into Whatcom Creek in Bellingham, Washington (Madsen and Nightengale 2009). The gasoline was ignited, causing a fire that burned over 26 acres of riparian trees and vegetation. Aquatic life in a 3-mile stretch of Whatcom Creek was affected. The fuel release and subsequent fire had direct and indirect effects on the water quality of Whatcom Creek, including: 1) the direct effects from the fuel release (introduction of PAHs); and 2) the indirect effects from the burn that resulted in reduced shade (resulting in increased temperatures and decreased dissolved oxygen) and reduced ground cover adjacent to Whatcom Creek (resulting in increased sediment loading, fecal coliform, and other pollutants).*

Following clean-up, a number of restoration projects were implemented to restore stream habitat that was affected by the fuel release and subsequent runoff from burned areas. Macroinvertebrates were monitored for five years after the incident and again in 2007 (eight years after the incident) to assess recolonization and recovery. Sampling seven days after the release and associated fire showed almost complete loss of the macroinvertebrate community, but after four months, macroinvertebrates had rapidly populated sampling sites. Initial colonizers were mayfly species that tend to be more tolerant of poor water quality conditions than other aquatic invertebrates. Fourteen months after the incident, community metrics for benthic invertebrates (e.g., taxa richness, B-IBI scores, presence of stonefly taxa, EPT taxa richness) in Whatcom Creek had returned to pre-event levels at most sites.

***Enbridge Line 6B Marshall, Michigan**: In July 2010, a pipeline released approximately 20,000 barrels of diluted bitumen oil into Talmadge Creek that subsequently flowed into the Kalamazoo River near Marshall, Michigan. Clean-up efforts began almost immediately, including installing oil sorbent and containment booms and using oil skimmers and vacuum trucks to recover the oil. By August 2010, clean-up efforts included excavation and removal of contaminated soil, sediment, vegetation, and debris. Recovery of submerged oil included more active methods such as sediment agitation, sediment traps, and sheen management (USFWS et al. 2015a).*

Following the release, the MI DEQ conducted standard macroinvertebrate surveys in September 2010 with subsequent surveys in 2011, 2012, 2013, and 2014 to examine effects and recovery. A final synthesis of data will be prepared by MI DEQ following surveys in 2015 and 2016.

The survey methods followed MI DEQ Procedure 51 (MI DEQ 2008), which is a rapid, qualitative biological and habitat survey for assessing resource status in wadeable streams and rivers. Procedure 51 preferentially samples gravel, cobble, and boulder substrates in riffle/run habitats, but other lower flow habitats may also be sampled. Metrics used in this procedure include total number of taxa, total number of mayfly taxa, total number of caddisfly taxa, total number of stonefly taxa, percent mayfly composition, percent caddisfly composition, percent contribution of the dominant taxa, percent composition of isopods, snails, and leeches, and percent surface dependent macroinvertebrates (MI DEQ 2008). These individual metrics are used to calculate a total community score for a site, which falls into one of three community ratings defined in Procedure 51 guidance: "Excellent," "Acceptable," and "Poor."

Following the 2010 survey, MI DEQ found that both abundance and diversity of macroinvertebrates were affected by the release and by the associated clean-up activities (Walterhouse 2011). Data from 2011 and 2012 surveys showed that most of the Procedure 51 community scores were increasing for the Kalamazoo River sites. The one exception was the control site where the score decreased slightly due to a lack of stoneflies in 2012. Results for Talmadge Creek also showed improvement post-2010. The total number of taxa at the affected sites in the Kalamazoo River and Talmadge Creek increased over time, with most sites returning to near baseline conditions by 2012 (Matousek 2013; Walterhouse 2012). Matousek (2013) noted a shift in species composition at Talmadge Creek compared to upstream control site due to the presence of more open habitat following response activities that was attributed to the removed trees and shrubs and thereby allowed more sunlight to reach the stream by opening the vegetative canopy. Based on initial survey data in the Final DARP, the NRDA Trustees conclude: "After showing initial impacts, the data generally indicate

> *trends toward recovery with trends interrupted during periods when additional oil recovery efforts occurred" (USFWS et al. 2015).*
>
> *Enbridge also evaluated potential chronic effects of residual oil in the Kalamazoo River using a weight-of-evidence SQT approach (Enbridge 2014). The sediment quality triad approach included assessment of benthic macroinvertebrate field samples, sediment chemistry, and bioassays to assess sediment contamination from areas where effects were expected based on poling and depositional setting.*
>
> *The study found that taxa richness and diversity in affected areas of the Kalamazoo River were not different from upstream reference locations. Density was lower in the affected areas, but this result may have been confounded by sandier substrate conditions at reference sites compared to affected sites. Incorporation of the sediment chemistry and toxicity data from the SQT approach also showed no discernible pattern between the observed and predicted sediment toxicity and the benthic community indices, suggesting recovery to pre-event conditions is well advanced. Benthic invertebrate density was not correlated with predicted PAH toxicity. Biodiversity was not affected by the release.*
>
> *Enbridge (2014) also evaluated the Procedure 51 data collected through 2012 by MI DEQ. Based on their review, it was concluded that it was not possible to detect effects of the release conclusively in the Procedure 51 evaluations and, by 2011, the community ratings were consistent with pre-release conditions. These conclusions were supported by: 1) highest quality macroinvertebrate community being present at the impact site closest to the release site; 2) lowest score of all sampled stations in 2012 being located at the reference site; and 3) the lower scores being located at the site furthest from the release site in an area of poor habitat where there were potential additional effects from the Battle Creek wastewater treatment plant and other system stressors.*

8.3.7.2.2 Factors Affecting Recovery

The rate of recovery of aquatic macroinvertebrate populations and communities is governed by multiple factors including the resistance and resiliency of the species, including the presence of nearby macroinvertebrate populations that can help recolonize the affected area; time of year that the release occurs; the volume released and the type of petroleum product released; water movement through the physical habitat (e.g., lentic versus lotic system, riffles versus backwaters, flushing flows); other environmental stressors; and the speed and efficacy of clean up.

After a crude oil release, macroinvertebrate communities closest to the release recovered faster than less affected areas downstream because they are closest to unaffected upstream reaches of the stream or river that are a source of recolonization by drift (Enbridge 2014; Van Derveer et al. 1995). Headwaters streams with minimal upstream macroinvertebrate habitat to contribute to recolonization by drift may be slower to recover (Crunkilton and Duchrow 1990). Macroinvertebrates that have higher drift densities, like mayflies and chironomids, rapidly recolonize affected sites (Guiney et al. 1987; Pontasch and Brusven 1988).

Timing of the release in relation to typical macroinvertebrate colonization periods may affect recovery. If a release occurs during or after the species' dispersal period, macroinvertebrates may not recolonize the affected area until the following season, thereby delaying recovery (Lytle and Peckarsky 2001; Poulton et al. 1997).

In general, aquatic macroinvertebrates recover more quickly from small scale events that are not persistent in the environment and that do not substantially disrupt the physical habitat. Consequently, the speed and efficacy of containment and use of appropriate clean-up activities can limit the spatial extent of a release and its effects, and facilitate recovery of the aquatic macroinvertebrate communities. The use of absorbent booms and dams enhances recovery and reduces the amount of crude oil that is available to weathering, thereby limiting the potential for submerged crude oil and associated effects to sediments and accelerating recovery (Crunkilton and Duchrow 1990). A large volume of crude oil in relation to stream volume can increase recovery time (Crunkilton and Duchrow 1990).

The physical action and dilution caused by swift flowing waters help disperse crude oil from aquatic habitats and can accelerate weathering of released oil. Flows from upstream areas also provide a source of benthic colonizers via downstream drift that enhances macroinvertebrate recruitment (Crunkilton and Duchrow 1990; Guiney et al. 1987; Poulton et al. 1997). Riffle areas of streams and rivers recover faster than slower flowing or backwater areas because greater flows in riffles provide oxygen to degrade crude oil and contribute to flushing, allowing for faster recolonization time (Crunkilton and Duchrow 1990; Poulton et al. 1997).

It is important to have one or more reference sites when evaluating recovery since confounding environmental factors which are independent of the release event, can facilitate or slow recovery. Environmental stressors such as low flows and high summer temperatures can delay recovery (Crunkilton and Duchrow 1990; Guiney et al. 1987). Anthropogenic environmental stressors (e.g., altered flow regime, habitat alterations) unrelated to the release may further impede recovery (Enbridge 2015). Changes in stream habitat due to removal of riparian vegetation during the response to a release or subsequent clean-up activities may influence macroinvertebrate abundance, species composition, and subsequent recovery (Matousek 2013).

Recovery of macroinvertebrates may also be impaired by persistence of crude oil or anthropogenic actors. For example, substrate oiling or residual hydrocarbon contamination in sediment may slow recovery (Guiney et al. 1987; Poulton et al. 1998). This includes slow flowing or backwater areas that contain finer sediment with residual contamination that does not weather as quickly as riffle areas (Crunkilton and Duchrow 1990; Poulton et al. 1997).

8.3.7.2.3 Benthic Macroinvertebrate Summary

Aquatic macroinvertebrates represent an extremely diverse range of organisms that fulfill many critical ecological functions within the aquatic environment. Benthic macroinvertebrates are important components of aquatic food webs and are prey items for recreationally and commercially important fish species. Macroinvertebrates are often used to monitor the ecological health of aquatic ecosystems, including effects and recovery from crude oil releases.

Effects to macroinvertebrate communities following a release can be substantial and include physical oiling and smothering of organisms, acute or chronic toxicity to organisms, and altering essential habitat by both the release and subsequent clean-up activities. Recovery of benthic macroinvertebrates from these effects is well documented in freshwater lotic environments across a wide geographic area. While macroinvertebrate recovery from lentic systems (e.g., lakes, ponds) is not as well documented, the case study from the Tennessee pond trials demonstrates that macroinvertebrates do recover from crude oil releases.

In streams and rivers, time to recovery varies with watercourse size and habitat type. Recolonization usually begins soon after the release with full or substantial recovery often within one year. Recolonization occurs through a combination of downstream drift, upstream migration, migration from within the substrate, and aerial sources. The initial extent of effects to macroinvertebrate and subsequent recovery is strongly related to the magnitude of the release volume compared with the volume of the receiving waterbody. Smaller streams that receive high volume releases experience both a greater effect and longer recovery time.

The primary factors accelerating recovery include utilization of clean-up techniques that minimize crude oil penetration into substrates, dilution and degradation of oil by higher flows, and the recruitment of individuals from adjacent unaffected reaches. Recovery may be impeded by the presence of residual crude oil, habitat alterations, and environmental stressors such as low flow and drought conditions that may occur during the recovery process. The selection of an appropriate reference site with similar flow and habitats to the affected sites is an important aspect for making a recovery determination. Given the inherent variability of macroinvertebrates and sensitivity to other environmental stressors that can confound results, multiple reference sites may assist with the confirmation of recovery.

8.3.7.3 Fish and Fish Habitat

Freshwater fish spend the majority of their life cycle in freshwater streams, rivers, ponds, and lakes. These fish occupy many trophic levels within a food web and are often the top predators in freshwater systems. They are an important food source for semi-aquatic mammals such as river otter (*Lontra canadensis*) and American mink (*Neovison vison*); wading birds and waterfowl such as great blue heron (*Ardea herodias*) and common merganser (*Mergus merganser*); and raptors such as osprey (*Pandion haliaetus*) and American bald eagle. Recreational freshwater fishing is a multi-billion dollar industry in North America and traditional fisheries have been (and remain) an important food source for native people.

Freshwater fish are often used as indicators of the health of a waterbody (Karr 1981). Fish surveys are often used to assess both effects and recovery from disturbance (Klemm 1993; Simon 1999). The advantages of using fish for biomonitoring include:

- Longer life span of fish compared to macroinvertebrates allows for improved monitoring for potential long-term effects
- Fish occupy multiple positions in the aquatic food web, and a fish assemblage usually incorporates omnivores, herbivores, insectivores, planktivores, and piscivores, allowing for monitoring across multiple trophic levels
- Fish are relatively easy to collect and identify and can be released unharmed
- Life history traits and environmental requirements of most fish species are relatively well known
- Many fish are important recreational and commercial species (Barbour et al. 1999)
- Fish can be one of the more sensitive indicators of water quality (Klemm 1993)

Fish community data are regularly collected by federal and state agencies as a measure of waterbody health and these data can provide a robust record of waterbody status over time. Standard protocols for fish collection exist in many states and are often based on the USEPA Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers (Barbour et al. 1999). Collected fish are typically identified and counted, and analyses of data are used to determine population and community metrics such as abundance, diversity, species composition and dominance, indicator species, and similarity indices.

National PHMSA pipeline incident data[34] show that approximately 1.2% of releases affect fish[35] (PHMSA 2016).

8.3.7.3.1 Recovery of Fish and Fish Habitat Following a Crude Oil Release

Similar to the recovery of benthic macroinvertebrates, recovery of fish communities can be influenced by many factors including the sensitivity to petroleum hydrocarbons; species life history (reproductive strategy, life stage, habitat preferences); presence of nearby unaffected populations from which recruitment can occur; types of habitats affected by a release; timing of a release in relation to these other factors; and the speed and efficacy of clean-up activities.

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[34] Incidents must be reported to PHMSA if the incident results in one or more of the following consequences: 1) a release of 5 gallons or more, 2) death or serious injury necessitating hospitalization, 3) fire or explosion not intentionally set by the operator, or 4) property damage of $50,000 or more (49 CFR 195.50).

[35] The majority of PHMSA reportable pipeline incidents since January 2002 are small (3 barrels or less) and almost half of the PHMSA-reported pipeline incidents occur completely within operator-owned facilities (47%). Of those releases that were not contained completely within the operator's property, the median release volume was 20 bbl, again indicating that small releases are the most common and very large releases are uncommon (PHMSA 2016).

Fish differ in their sensitivities to petroleum hydrocarbons. Salmonids, including trout, salmon, and whitefish, are among the most sensitive aquatic species. Because of this known sensitivity, trout larvae, the most sensitive life stage, are often used to evaluate water quality. Life history traits can also affect both exposure and recovery. Kubach et al. (2011) speculated that the slower observed recovery time for species such as flat bullhead (*Ameiurus platycephalus*) and northern hogsucker (*Hypentelium nigricans*) following a release was due to relatively slow growth and longer time to reproductive maturity for these species.

The presence of nearby unaffected fish populations either upstream or downstream of an affected area can facilitate recovery. Where fish populations have been reduced by a petroleum release or associated clean-up activities, these areas can be recolonized quickly through the downstream and upstream migration of fish from unaffected areas. Unaffected tributaries adjacent to release sites also can be an important refuge for fish and a pathway for recolonization (Kubach et al. 2011). Habitat fragmentation disrupts the ability of fish to easily move between areas of suitable habitat and this loss of habitat connectivity can impede recruitment into affected areas. Kuback et al. (2011) found that less fragmented streams recovered faster than fragmented streams and rivers. Another process to facilitate recovery is through fish stocking (Guiney et al. 1987).

Recovery determinations are complicated by the availability of suitable reference habitats for comparison to the impact sites (USFWS et al. 2015a). Without suitable reference sites to account for natural variability and confounding environmental factors, it can be difficult to clearly ascertain whether full recovery has occurred.

The following case studies have been selected as examples of fish and fish habitat recovery from crude oil releases and describe time to recovery and influences of oil release characteristics and environmental conditions on effects and subsequent recovery. As noted earlier, the number of releases with recovery information within the geographic region most similar to Minnesota was limited. Therefore, these case studies include releases from other similar temperate regions of North America. Additional descriptions of some of these releases as case studies for fish and fish habitat can be found in Stantec et al. (2012a) and Enbridge (2015).

With the exception of Lake Wabamun, these case studies are from lotic (flowing water) habitats because there is little available literature from lentic (stationary water) habitats. Nevertheless, impoundments, pools, and backwaters in lotic systems can have similar habitat features and communities to lentic systems and share some of the same factors influencing recovery.

> ***Laurel Pipe Line Company, Roaring Run and Howell's Run, Pennsylvania**: On October 16, 1982, a pipeline released approximately 1,310 barrels of kerosene by Laurel Pipe Line Company into Roaring Run and Howell's Run near Ebensburg, Pennsylvania (Guiney et al. 1987). Following the release, a fish survey by the Pennsylvania Fish Commission indicated fish populations at least four miles downstream of the release had been killed. Electrofishing surveys were initiated*

seven months after the release and again one year after the incident. Results of these surveys indicated the fish population had recovered with the reappearance of diverse assemblages and drastic increases in abundance. An abundance of young-of-the-year sunfish and minnows also indicated successful breeding was occurring.

This study found that the major factors accelerating recolonization included the immediate and effective clean-up activities; uncontaminated flow from upstream of the release site that aided in dilution; and natural recruitment of fish from unpolluted portions of the watershed. The authors concluded that "biological recovery appeared complete after only 12 months."

***Colonial Pipeline Company (Colonial), Reedy River, South Carolina**: On June 26, 1996, a Colonial pipeline released approximately 22,800 barrels of No. 2 Fuel Oil (diesel) into the Reedy River near Fork Shoals, South Carolina (Kubach et al. 2011). Approximately 94% of the released oil was recovered within 12 days of the rupture.*

Initial surveys of fish showed near complete mortality up to 23 miles downstream of the release site (Rankin et al. 1996, Glover 1996 as cited in Kubach et al. 2011). Electrofishing techniques were used from August 1996 (2 months post-release) through October 2005 (52 months post-release) to evaluate recovery of the fish community. Authors used "non-metric multidimensional scaling ordination to evaluate change in fish assemblage structure among sites, and determine the degree of recovery in assemblage structure." The results showed that by 52 months post-release, the assemblage groups in the impact and reference sites reached their greatest similarity, indicating recovery. The authors found that recovery occurred fastest at the sites closest to the release site (16 months). This was attributed to these sites being closest to undisturbed reaches upstream of the release site where fish were available for recolonization. The three sites farthest downstream from the release site were slower to recover. The slower recovery was attributed to habitat fragmentation caused by anthropogenic barriers (dams/ponds), as well as depletion of the macroinvertebrate community as a food source for fish, resulting from the diesel release.

Olympic Pipeline Company, Whatcom Creek, Washington: The Olympic pipeline incident occurred on June 10, 1999, releasing approximately 5,640 barrels of unleaded gasoline into Hannah Creek, which then flowed into Whatcom Creek in Bellingham, Washington (Madsen and Nightengale 2009). The release ignited, killing three children, and burning approximately 25 acres of riparian vegetation along the Whatcom Creek corridor (Madsen and Nightengale 2009).

After the release and resulting fire, over 100,000 dead salmon, trout, lamprey, and crayfish were documented. The stream was recovering in 2000 and 2001 with Chinook salmon (Oncorhynchus tshawytscha) spawning in the burn zone. While the number of anadromous Chinook salmon, coho salmon (Oncorhynchus kisutch), and steelhead trout returning to the creek was lower post-incident compared to pre-incident, Madsen and Nightengale (2009) presented fish stocking and return data that correlated the reductions in stocking with post-incident declines in these same fish populations. The authors concluded that the decrease in these species was attributed to reduced stocking for these species rather than the potential effects of the release and fire.

Restoration projects were conducted after the release, including restoring fish habitat. These projects included construction of backwater areas and reconfiguration of the stream channel to include large woody debris, meanders, pools, backwaters, and more complex habitats in the former channelized stream. Since the incident, more consistent flows from an upstream dam have been maintained during the spawning season, and the physical habitat and water quality have been maintained or improved by the emergency response and restoration projects. The authors concluded that, "while the fire may have temporarily reduced spawning success, it seems unlikely that it is responsible for the observed decline in adult returns."

***Advanced Fuel Filtration Systems, East Walker River, California**: This release occurred on December 30, 2000, when a tanker truck operated by Advanced Fuel Filtration Systems overturned north of Bridgeport, California and released approximately 86 barrels of No. 6 Fuel Oil into the East Walker River. Fish mortality from oil exposure was observed, with 21 dead fish were recovered during clean up. Fish surveys were conducted in the fall of 2001, approximately nine months after the event. Fish survey results were compared to results of regional annual fish surveys conducted in California and Nevada in 1999, considered to reference sites for the affected area. The survey data showed that rainbow trout, brown trout (Salmo trutta), and mountain whitefish were present in affected reaches, but fish density was below the average for reference sites and most fish captured were adults.*

The authors theorized that residual No. 6 Fuel Oil had caused toxicity to early life stages of these salmonid species, resulting in low numbers of juvenile fish (Hampton et al. 2002). Water quality data support this hypothesis. Concentrations of certain PAHs in water samples from the affected area did exceed threshold levels for trout embryo mortality for one month after the release and sub-lethal effect concentrations for at least three months after the release. After five months, PAH levels no longer exceeded effect thresholds and were not considered to pose a threat to fish.

Data from affected area were collected in 2001 and were compared to 1999 regional data. Differences in fish density and age-class structure based on spatial and temporal variation were not addressed. As this report does not include data on subsequent surveys after 2001, no additional information on the recovery of the fish population from the oil release was available.

***Canadian National Railway Company, Wabamun Lake, Alberta**: On August 3, 2005, a Canadian National railroad incident involving the release of 4,400 barrels of heated Bunker C Oil (a very high density oil) and 554 barrels of pole treating oil flowed across lawns adjacent to the railway and into Wabamun Lake. Direct mortality of fish was reported immediately following the oil release. Transportation Safety Board of Canada (TSBC 2007) reported that dead fish were observed after the release, but attributed the low fish abundance to natural causes. Birtwell (2008) argued that approximately 100 fish collected after the release died as a result of the release, although there were no toxicological tests to support this assertion.*

Fish population dynamics were not studied following the incident. However, because of concerns that a large spawning shoal used by lake whitefish (Coregonus clupeaformis) had been oiled by the release, several in situ studies were conducted that evaluated the exposure of eggs and larval fish. Studies were conducted to examine the pattern, frequency, and severity of deformities in lake whitefish and northern pike (Esox lucius) larvae incubated in situ at impact sites versus reference sites. Although the studies showed very high variability, Hodson (2008) concluded in his review of the studies that the data were sufficient to determine that the quality of the spawning habitat of whitefish and pike in Lake Wabamun was negatively affected for up to 20 months by the oil released in August 2005 (Debruyn et al. 2007; Hodson 2008; DeBruyn et al. 2009).

***Enbridge Line 6B, Marshall, Michigan**: In July 2010, a pipeline released approximately 20,000 barrels of diluted bitumen oil into Talmadge Creek and the Kalamazoo River in Marshall, Michigan. Following the release, no fish kills were observed by state biologists (Winter et al. 2012) and only 42 fish were found dead during the response effort in 2010 (USFWS et al. 2015). The Trustees concluded in the DARP that this was a negligible number of fish for this time period (USFWS et al. 2015a).*

Preliminary results from the MI DNR show that after initial reductions in fish abundance and diversity in Talmadge Creek in 2010, these metrics were recovering during subsequent surveys. Some changes in species composition were noted and may be related to changes in habitat following clean up (i.e., a wider and shallower stream with less cover). Preliminary results for the Kalamazoo River were less definitive with some reductions in smallmouth bass (Micropterus

> *dolomieu) in 2010, but overall results were variable across all sites and years (USFWS et al. 2015). The DARP does not offer further analysis of effects to fish or recovery for the Kalamazoo River.*

8.3.7.3.2 Factors Affecting Recovery

Oiling of spawning habitat may affect fish reproduction and delay recovery (Debruyn et al. 2007; Hodson 2008). Some species (e.g., trout) may be more vulnerable to initial effects of a release, while others may be more susceptible to long-term effects because of their association with the sediment (e.g., suckers) (Goldberg 2011; Higgins 2002). Long-lived fish species with slower growth and later reproduction may take longer to recover than other species (Kubach et al. 2011).

The presence and proximity of fish for recolonization in unaffected reaches and tributaries adjacent to the release site can accelerate recovery, as can successful reproduction in the affected waterbody (Goldberg 2011; Guiney et al. 1987; Kubach et al. 2011; Madsen and Nightengale 2009). The immediate and effective clean-up of the release can reduce effects of exposure to crude oil and increases the rate of recovery (Guiney et al. 1987). Additionally, clean flows from upstream that dilute and degrade hydrocarbons can improve water quality and enhance recovery (Guiney et al. 1987).

Post-release restoration efforts and maintained flows during spawning periods can improve fish habitat in previously degraded streams and accelerate recovery (Madsen and Nightengale 2009). Stocking of fish in the affected waterbody can also promote recovery (Madsen and Nightengale 2009; Guiney et al. 1987).

The removal of woody debris and log jams during clean-up operations can negatively affect fish habitat and stream structure (Bustard and Miles 2011). Effects to stream geomorphology and riparian vegetation can influence fish assemblage structure and subsequent recovery (USFWS et al. 2015a). Natural and anthropogenic barriers to fish movement can impede fish recolonization and recovery (Kubach et al. 2011).

8.3.7.3.3 Fish and Fish Habitat Summary

Freshwater fish are important components of aquatic food webs and occupy many trophic levels, which can vary by species or life stage. Recreational freshwater fishing is a multi-billion dollar industry in North America, and traditional fisheries remain an important food source for native people. Freshwater fish are often used to monitor the ecological health of aquatic ecosystems, including effects and recovery from crude oil releases.

Effects to fish following a petroleum hydrocarbon release can be substantial and may include acute or chronic toxicity, alteration of habitat by physical oiling and habitat disturbance resulting from clean-up activities. Recovery of freshwater fish populations after a crude oil release is well documented in freshwater lotic environments. While there are fewer studies on the recovery of freshwater fish recovery in lentic systems, the case study information from Wabamun

Lake does support recovery. Lentic habitats and communities have some similarities to lotic impoundments, pools, and backwaters, and some of the same factors influencing recovery may apply.

In streams and rivers, recolonization usually begins soon after the petroleum hydrocarbon incident with substantial recovery within one year. Complete recovery of fish assemblages may take several years. Some community metrics, such as species richness, relative abundance, and ecological function, may recover more quickly while others, such as overall abundance and community similarity, may take longer.

The primary factors accelerating recovery of fish populations include immediate and effective clean up, restoration of stream habitats, natural flushing of the system, and recolonization of fish from adjacent unaffected areas. Impediments to recovery include habitat alteration resulting from the removal of riparian vegetation, woody debris and log jams, the presence of physical barriers that limit fish movement and recolonization, species life history, and oiling of spawning habitat. The selection of suitable reference areas is critical for making sound determinations of recovery as part of any recovery study.

8.3.7.4 Summary for Aquatic Biota

The recovery of an aquatic community from the effects of a crude oil release depend on the physical and chemical characteristics of the oil, the extent that the oil penetrates the substrate, size and flow characteristics of the stream, the speed and efficacy of clean up, time of year, and tolerance of stream organisms (Crunkiton and Duchrow 1990). Several studies attribute stream discharge and flushing as the major factors accelerating recolonization and recovery (Crunkilton and Duchrow 1990; Guiney et al. 1987; Lytle and Peckarsky 2001). This factor has implications for stream size with smaller streams recovering more slowly and releases occurring during low flow conditions potentially having greater effects. In addition, the timing of a release in comparison to the life history stage of affected organisms can be an important influence on initial recovery as some macroinvertebrate life stages are unable to recolonize an effected area (Lytle and Peckarsky 2001; Wallace 1990). Recovery determinations were also influenced by the suitability of reference habitats for comparison (Enbridge 2015; Matousek 2013).

8.3.8 Socio-Economics

Crude oil releases can affect people from a financial and emotional perspective. For large releases that affect a large area, local and regional economies may be affected, sometimes for an extended period. Individuals, groups, and entire communities can be affected in different ways.

While effects to emotional well-being, cultural values, sense of community, and other important human emotional values can occur, determining if recovery from these release effects occurred is subjective and difficult to quantify objectively. As a result, literature on recovery of human emotional values is limited. Consequently, this report acknowledges this importance, but focuses on recovery of socio-economic conditions that can be more easily quantified and for which sufficient literature and case studies exist.

The majority of crude oil releases occur during maintenance activities, inside transport or storage facilities, or in locations removed from businesses and homes. These small and isolated releases are generally cleaned up without substantial socio-economic damage or inconvenience and are often reported and documented in agency databases with little public attention.

> ***Marathon, Albion, Illinois***: *A Marathon pipeline release occurred on August 10, 2008, near Golden Gate in Wayne County, Illinois. The pipeline released approximately 5,000 barrels of crude oil (more than 3,260 barrels of the crude oil were recovered), affecting agricultural and forested land and some wetlands. Containment and clean-up activities commenced immediately after the release and restoration was completed within about one month (Arcadis 2011). The entire process occurred quickly and received little press coverage. The quick response and lack of concern was later attributed to the release occurring in a sparsely populated area, the lack of evacuations or fire, and the preparedness of emergency responders who had simulated a hypothetical oil release from this pipeline only a year earlier (Wells 2008b).*

Socio-economic effects that affect more than a few individuals generally occur in populated areas where people's lives and livelihoods may be affected. Releases in populated areas can cause people to evacuate their homes, disrupt social services, require a large influx of clean-up workers, and affect employment and business activity. Based on recent national incidents reported to PHMSA[36] [37], approximately 24% of reported incidents have occurred within populated areas (PHMSA 2016). Evacuations occurred in 2.3% of releases with an average evacuation of 101 evacuees per incident (PHMSA 2016). Such releases can result in heightened media attention, a substantial public record, and increased research. Data gathered from these large events adds to the scientific knowledge base, can provide insight into the effects that a large-scale crude oil release can have on individuals and communities, and how efforts to address and mitigate those effects during spill response have evolved.

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[36] Incidents must be reported to PHMSA if the incident results in one or more of the following consequences: 1) a release of 5 gallons or more, 2) death or serious injury necessitating hospitalization, 3) fire or explosion not intentionally set by the operator, or 4) property damage of $50,000 or more (49 CFR 195.50).

[37] The majority of PHMSA reportable pipeline incidents since January 2002 are small (3 barrels or less) and almost half of the PHMSA-reported pipeline incidents occur completely within operator-owned facilities (47%). Of those releases that were not contained completely within the operator's property, the median release volume was 20 bbl, again indicating that small releases are the most common and very large releases are uncommon (PHMSA 2016).

Review of media reports, published literature, and case studies suggests that the socio-economic damages resulting from crude oil releases can be discussed within three general categories: 1) disruptions of daily life and associated economic burdens; 2) loss of use of natural resources; and 3) loss of income and commercial activity. These three categories of socio-economic effects and their recovery are examined in more detail in the following sections.

8.3.8.1 Development of Socio-Economic Spill Response Elements

In 1969, the Union Oil release in Santa Barbara showed that the U.S. lacked adequate resources to respond to releases and that federal law provided insufficient mechanisms for providing individual and public compensation for oil releases (Easton 1972; Miller 1999; Clarke and Hemphill 2002; Mai-Duc 2015). Other notable oil releases since that time include the Texaco Oklahoma off Cape Hatteras, North Carolina (1971); the Corinthos in the Delaware River near Marcus Hook, Pennsylvania (1975); the Argo Merchant off Nantucket, Massachusetts (1976); and the Hawaiian Patriot near Honolulu, Hawaii (1977). In response to these releases, as well as concerns from the general public, environmental groups and other public organizations, Congress passed a number of laws, including:

- National Oil and Hazardous Substances Pollution Contingency Plan (1968)
- Clean Water Act (1972)
- Trans-Alaska Pipeline Authorization Act (1973)
- Deep Port Act (1974)
- Outer Continent Shelf Lands Act Amendments (1978)
- Hazardous Liquid Pipeline Act (1979)

States also passed laws and oil transporters developed programs for safety and spill response preparedness, communication, and compensation.

> ***Ashland Oil, West Elizabeth, Pennsylvania****: In January 1988, Ashland Oil's storage tank near West Elizabeth, Pennsylvania collapsed during filling, releasing approximately 92,860 barrels of diesel fuel into a containment area and the Monongahela River. Ashland Chairman John Hall immediately went to the site, took responsibility for the release, and instituted an aggressive clean-up effort including open communications and outreach to affected persons and businesses. According to after-action reports, Ashland's cooperative relationship with federal officials overseeing the effort and stakeholders greatly contributed to the effectiveness of the overall response (Miklaucic and Saseen 1989; Randle and Reinhardt 2014). As a result, 77% of the people interviewed following clean up thought that Ashland had done a good to excellent job with the clean-up (Trauth et al. 1988).*
>
> *In terms of the community's socio-economic well-being, Ashland's response included providing advance payments to communities in anticipation of incurred costs and proactively attempting to contact individuals and businesses that*

> *might have claims. Ashland representatives noted that many individuals and businesses that could have filed a claim chose not to do so; some did not because the losses were intangible and others did not because they had simultaneously benefitted and suffered losses (Trauth et al. 1989).*
>
> ***Exxon Valdez Crude Oil Release, Prince William Sound, Alaska**: Although the 1989 Exxon Valdez crude oil release in Prince William Sound, Alaska was a marine oil release, the incident marked a sentinel moment that defined public perceptions of both the effects and recovery of human and natural environments to crude oil releases. The Exxon Valdez event made it clear that the country still did not have adequate resources, planning, or compensatory mechanisms in place to address a major marine oil release. From a socio-economic perspective, Exxon's response to the release was vastly different to Ashland Oil's efforts a year earlier.*
>
> *Exxon was slow to address the release's socio-economic effects on local communities and its dealings with residents often appeared uneven and unfair. Increases in population due to the influx of emergency responders, limitations on spill response resources, inadequate communication, and discrepancies in how residents were involved in the spill response led to negative community perceptions (Impact Assessment Inc. 1990, 2001).*
>
> *The negative community perceptions that developed following the Exxon Valdez release have been referred to as a "corrosive community"—a community characterized by uncertainty, ambiguity, psychological isolation, division, and a general sense of anger, frustration, and betrayal of those responsible to properly carry out their responsibilities (Fall et al. 2001; Gill 2007; Picou 2009). These feelings were reinforced and prolonged by the reliance on litigation as the primary avenue for compensation. Litigation stress became a secondary trauma to the socio-economic stress, further damaging the affected communities and greatly delaying the start of recovery such that it became disconnected from the environmental recovery (Picou et al. 2004; Picou and Martin 2007).*

Because both the magnitude of effects from the Exxon Valdez release and subsequent recovery of the human and natural environments were controversial and highly publicized, the event helped provide the impetus to reexamine the state of oil spill prevention, response, and clean up (NOAA 2016). In response to the release, Congress passed the Oil Pollution Act in 1990. The Act is now the primary domestic legislation and associated regulations for addressing oil releases.

Other federal laws, such as the Clean Water Act and the Outer Continental Shelf Lands Act, contain provisions that pertain to oil releases, as do a variety of local, state, and federal tort laws. However, with respect to socio-economics, Oil Pollution Act 90 established a specific legal framework that sets out both damage and loss liabilities and a claims process for providing compensation for such injuries. This regulatory framework guides relationships between a responsible party and resource agencies and provides affected individuals and groups a clearer legal basis for obtaining compensation when direct negotiation is unavailable or found lacking (Nichols 2010; Ryan 2011).

Following the Exxon Valdez crude oil release, oil producers and transporters took additional steps to develop comprehensive frameworks for response planning and compensation , and obtain a better understanding that crude oil releases are both technical and social disasters (Clarke and Hemphill 2002; Webler and Lord 2010; Webler et al. 2010). Spill response plans now include mechanisms that are designed to rapidly address the socio-economic disruptions that can occur following a crude oil release. These mechanisms help reduce disruptions, and facilitate recovery of communities. As a result, responsible parties have been doing an increasingly better job understanding, supporting, and compensating individuals and communities affected by oil releases.

> ***Enbridge Line 6B, Marshall, Michigan****: In July, 2010, approximately 20,000 barrels of diluted bitumen oil were released out of Enbridge's Line 6B pipeline near Marshall, Michigan. The company followed Ashland's proactive approach. Pat Daniel, Enbridge President, traveled to the site immediately, took responsibility, and began setting mechanisms in place to address both the environmental and social elements of the disaster (Iltan and McCarthy 2010).*
>
> *Enbridge brought in public affairs staff and community agents, and set up centers where members of the community could obtain information, assistance with practical matters, and financial support (Enbridge 2010a). Releases of information were coordinated and consistent, and Enbridge maintained contact with local agencies. Enbridge contracted land agents to work with property owners and businesses to address access, nuisance, and other operational issues. An Enbridge spokesman noted: "The intent from the onset always has been if anyone has a legitimate concern they could file a claim and the intent was to avoid litigation" (Christenson 2015).*
>
> *For its part, the USEPA implemented a community involvement plan to promote communication between Incident Command operations and members of the public and to involve members of the public in activities and decisions relating to the clean-up (Weston 2011). Enbridge participated in many of the public and stakeholder meetings as a part of the Incident Command structure. The overall effort operated cooperatively—local media played a large role in disseminating messages with information on the evacuation, clean-up efforts, and emergency resources. Federal, state, and local agencies held town hall meetings to respond to residents' concerns and Enbridge worked directly with those affected to address damages and compensation (Lisabeth 2012). For example, to address concerns about property values, Enbridge instituted a home purchase program*

for households located within 200 feet of the shoreline in affected areas (Enbridge 2010b).

General natural resource damages relating to the Line 6B oil release were addressed through a NRDA process led by the USFWS. Enbridge started addressing lost use of the Kalamazoo River by constructing five river access locations for the public while the damage assessment was ongoing. This was part of an agreement between Enbridge and the State of Michigan to address resource damages. The company subsequently also agreed to remove a dam, and restore several miles of impounded river in addition to providing 300 acres of wetlands. Enbridge also funded restoration of three creek areas, improvements to several inland lakes, a savannah restoration program, a turtle nest protection program, and two tribal cultural projects (USFWS et al. 2015). The compensatory agreement was achieved without litigation and followed cessation of remediation activities relatively closely.

Viewed as a whole, Enbridge's efforts to address socio-economic elements of the oil release, in conjunction with the USEPA community involvement plan, were generally successful. Pat Daniel's initial efforts were later used as a case study by the Harvard Business Review on effective leadership (Seijts and Watson 2012). There were some protests about pipelines and fossil fuels, political viewpoints sometimes were expressed in the media, litigation was not completely avoided, and some individuals were not completely satisfied with their compensation. However, it appears that the lack of communication and development of a "corrosive community", described following the Exxon Valdez release, did not develop and compensation was worked out in a timely manner. Enbridge managed to address most socio-economic issues directly and disagreements that were litigated did not appear to cause substantial strain on the community or impede a return to residents' pre-spill ways of life (Christenson 2015; Davis 2015).

8.3.8.2 Recovery of Various Socio-Economic Effects Following a Crude Oil Release

8.3.8.2.1 Disruptions of Daily Life

Crude oil releases have the potential to disrupt people's daily lives and cost them money while the release is being cleaned up and the environment restored. For small releases and releases in isolated areas, the disruption and costs may be negligible. Examples might include a closed road, increased traffic and noise, or an increased demand on limited municipal services. For larger releases, such as the ones making national news, the disruption and costs may be substantial. In these cases, adequate access to affected areas and resources can be challenging. People in the vicinity of a release may need to leave their homes, board their animals, or be required to have clean-up crews and equipment crossing or staged on their property. In some cases, these nuisances may persist for a considerable period of time, costing the affected families money, as well as the quiet use and enjoyment of their property.

To address the costs and nuisances that people in affected communities may experience as a consequence of a crude oil release, responsible parties have established units within their spill response teams to deal specifically with community issues. In most cases following a sizeable release, the responsible party will set up an office or community center where affected people can come for support in finding housing, paying bills, and obtaining other daily life resources. Agents within these offices also address matters of nuisance and land use through payments for access easements, property damages, and lost use. The intent of these actions is to reduce the inconvenience to affected households by avoiding straining household finances, paying landowners for the use of their property, and compensating for damages. Some states have established laws addressing oil releases that include provisions for the state to relocate people affected by a release, if necessary, and charge the responsible party for the costs plus fees (Knauf and Reichhart 2010). In most cases, however, responsible parties prefer to address matters of compensation directly, outside a formal claims process.

With private land and resource owners and users, compensation arrangements are negotiated and implemented cooperatively and can occur relatively quickly. The claim system may be administered either directly by the company or indirectly through a third-party administrator. The terms of such settlements are typically not made public. When managed this way, the compensation process can be efficient. However, when those affected cannot reach a financial agreement with the company responsible for the release, final resolution of compensation may move into the court system, and this process can be adversarial and lengthy. Several case studies serve to illustrate how the claims process can work.

> ***Chevron, Red Butte, Utah**: In 2010, Chevron's Red Butte incident released approximately 800 barrels of crude oil near Salt Lake City, Utah. As of September 9, 2010 (three months later), Chevron had reported that they recovered 778 barrels of the released crude oil. Chevron took responsibility, committed to pay for damages and expenses, set up a claims process, and notified residents of their ability to seek compensation (Foy 2010). Chevron paid most claims directly; however, a class action lawsuit was filed by 66 landowners, who argued that they did not receive adequate compensation. The lawsuit was not settled until 2015 (Fox 13 News 2015).*

> ***Exxon Silvertip Pipeline, Laurel, Montana**: In July 2011, Exxon's Silvertip pipeline under the Yellowstone River near Laurel, Montana burst and released 1,000 barrels of crude oil. As a result, 140 people were evacuated from their homes and numerous farm animals were temporarily relocated. Exxon established a claims process to compensate those evacuated for lodging, food, boarding, property and environmental damage, and other expenses incurred from the release*

(Reuters 2011). Most people seemed satisfied with the process, although three lawsuits seeking damages were filed against Exxon and remain unsettled.

***Exxon Pegasus Pipeline, Mayflower, Arkansas**: In March 2013, Exxon's Pegasus pipeline in Mayflower, Arkansas failed, releasing around 5,000 barrels of diluted bitumen crude oil. Residents of 22 homes were evacuated and temporarily housed in hotels with expenses paid by Exxon (Hasemyer 2015). A class action lawsuit filed by some residents seeking damages also remains unsettled.*

For larger releases, compensatory efforts can be complex. As described above, Enbridge's community response to their 2010 Line 6B release included not only payment of claims for relocation costs, but also purchase of homes from owners in proximity to the release who wished to relocate permanently. A limited number of lawsuits were filed against Enbridge, with only one currently remaining unsettled.

8.3.8.2.2 Loss of Income and Commercial Activity

Crude oil releases and the associated clean-up activities may lead to individual losses of income, as well as changes in local commercial activity. For example, releases on agricultural land can result in damages to crops and future lost productivity (Inoni et al. 2006). Releases in areas of resource harvesting can lead to a loss of income from blocked access and reduced catches (Pulsipher et al. 1999; Impact Assessment Inc. 2013). Releases in commercial areas may lead to forced business closures and/or lessened demand for goods and services due to decreased travel and tourism or a tendency for local residents to stay away (Tourism Economics 2011). Compensation for losses of income and commercial activity typically are paid directly through a claims process.

Some economic activity generated by clean-up related expenditures may partially offset some losses of commercial activity, particularly in increased demand for lodging and other services, as well as increased business for supply companies (Killian 2010; Aldy 2014; Tankersly 2014; Masunaga and Panzar 2015; Davis 2015). However, a vast majority of reports regarding the overall consequences of crude oil releases on wages, income, and business activity are negative (McDowell Group 1990; Pulsipher et al. 1999; Garza-Gil et al. 2006; Impact Assessment 2013).

Oil Pollution Act 90 requires the party or parties responsible for causing an oil release to pay damages to all injured parties and remediate the release. Under OPA 90, damages are defined as:

1. Natural Resources—Damages for injury to, destruction of, loss of, or loss of use of natural resources, including the reasonable costs of assessing the damage, which shall be recoverable by a United States trustee, a State trustee, an Indian tribe trustee, or a foreign trustee.

2. Real or Personal Property—Damages for injury to, or economic losses resulting from destruction of real or personal property, which shall be recoverable by a claimant who owns or leases that property.
3. Subsistence Use—Damages for loss of subsistence use of natural resources, which shall be recoverable by any claimant who so uses natural resources which have been injured, destroyed, or lost, without regard to the ownership or management of the resources.
4. Revenues—Damages equal to the net loss of taxes, royalties, rents, fees, or net profit shares due to the injury, destruction, or loss of real property, personal property, or natural resources, which shall be recoverable by the Government of the United States, a State, or a political subdivision thereof.
5. Profits and Earning Capacity—Damages equal to the loss of profits or impairment of earning capacity due to the injury, destruction, or loss of real property, personal property, or natural resources, which shall be recoverable by any claimant.
6. Public Services—Damages for net costs of providing increased or additional public services during or after removal activities, including protection from fire, safety, or health hazards, caused by a discharge of oil, which shall be recoverable by a State, or a political subdivision of a State.

Under *Oil Pollution Act* 90, a party responsible for causing an oil release is under an affirmative duty to set up a claims procedure and process claims for damages. Damages may be payable to individuals, businesses, or government entities. Two examples serve to illustrate how the required claims process can operate.

> ***BP, Deepwater Horizon, Gulf of Mexico****: Shortly after its 2010 Deepwater Horizon crude oil release in the Gulf of Mexico, BP established 31 field offices with 500 field adjusters to handle claims for damages including loss of income and commercial activity (Gulf Oil Spill Litigators 2010). The company also established a 20 billion dollar trust fund and appointed an administrator to handle additional claims relating to natural resource damages, state and local response costs and individual compensation (McDonell 2012). In March 2012, BP settled a class action lawsuit covering other individuals and businesses affected by the release. BP's total expenditures for compensation were estimated at approximately 20 billion dollars, which the company had set aside in the Trust Fund (Fahey and Kahn 2012).*

> ***Chevron, Willard Bay, Utah****: On March 18, 2013, a pipeline owned by Chevron Pipeline Company leaked approximately 500 barrels of diesel fuel into wetlands adjacent to Willard Bay, a reservoir connected to the Great Salt Lake (USEPA 2014). The release caused temporary closure of the Willard Bay State Park. The North Marina and campground at Willard Bay remained closed through May and June, 2013 (UDEQ 2011). The campground reopened on July 22, 2013, once a fence had been constructed to keep the public out of the contaminated area (O'Donoghue and Cabrero 2013). A year later, as part of its settlement agreement, Chevron agreed to pay $500,000 for lost-use damages at the park and campground (UDEQ 2011).*

8.3.8.2.3 Lost Use of Natural Resources

Crude oil releases may damage or restrict access to natural resources that community residents, Indian tribes and visitors use for various purposes. Examples of such lost uses include closure of recreation areas or access points, restrictions on hunting, fishing, and gathering, reductions in harvestable fish, wildlife and plant populations, and changes in the visual landscape. Responsible parties compensate individuals and communities who experience lost use of natural resources in two different ways.

When lost resource use is suffered by a single entity such as a landowner, parties responsible for the release now typically try to provide compensation directly to those affected using a claims process or through agents assigned to communicate with property owners and other individuals to address their unique situations.

When lost resource use is a general public matter, compensation is generally provided through the NRDA process for larger releases, and through similar state proceedings for smaller releases (Ryan 2011). As described by NOAA in its guidance documents (Huguenin et al. 1996):

> "A major goal of the *Oil Pollution Act* of 1990 is to make the environment and public whole for injury to or loss of natural resources and services as a result of a discharge or substantial threat of a discharge of oil (referred to as an "incident"). This goal is achieved through returning injured natural resources and services to the condition they would have been in if the incident had not occurred (otherwise referred to as "baseline" conditions), and compensating for interim losses from the date of the incident until recovery of such natural resources and services through the restoration, rehabilitation, replacement, or acquisition of equivalent natural resources and/or services."

In accordance with the *Oil Pollution Act* 90, when an oil release occurs, designated representatives of federal agencies, state agencies, Indian tribes, and, in limited instances, foreign governments having affected resources under their jurisdiction form a "Trustee Council." The Council members begin by completing a pre-assessment to determine if trustees have the jurisdiction to pursue restoration under *Oil Pollution Act* 90, and, if so, whether it is appropriate to do so. If damages to resources under their jurisdiction are expected to continue and feasible restoration alternatives exist to address such damages, trustees may proceed with the NRDA process. The process then proceeds through injury assessment, calculation of damages, evaluation of potential restoration actions, and restoration planning and implementation. In most cases, these steps are taken cooperatively with the party responsible for the release. At the end of the NRDA, one or more compensatory projects are implemented to address losses incurred by the public between the time of the oil release and the time when affected resources have recovered back to approximately their pre-spill condition (baseline). The following case studies illustrate how the natural resource damage compensation can work.

***Enbridge Line 4, Cohasset, Minnesota**: After Enbridge's Line 4 ruptured near Cohasset, Minnesota, on July 4, 2002, releasing approximately 6,000 barrels of crude oil, the NRDA Trustees, which included the United States of America, the State of Minnesota and the Leech Lake Band of Ojibwe, invited Enbridge to participate in a cooperative NRDA process and Enbridge agreed. In June 2003, the Trustees provided Enbridge with a recommended process for completing the NRDA requirements and associated restoration. A memorandum of understanding between the Trustees and Enbridge related to the NRDA and restoration process was signed in May 2004. A draft restoration plan and environmental assessment was submitted in August 2005 (USFWS et al. 2005). In 2008, the Draft Restoration Plan and Environmental Assessment became the basis for a Consent Decree negotiated between the Trustees and Enbridge Energy Limited Partnership (United States District Court District of Minnesota 2009). Under the decree, Enbridge committed to finance and perform the substantial scope of work identified in the Restoration Project Implementation and Monitoring Work Plan. In addition to funding the restoration projects identified in the Implementation and Monitoring Work Plan, Enbridge was also directed to make payments in the amount of $16,300 for outstanding unreimbursable assessment costs and costs to be incurred for monitoring the performance of the restoration work. Of this, $12,200 was to be paid to the U.S. Government, $1,400 to the State of Minnesota, and $2,700 to the Leech Lake Band of Ojibwe. The court approved the Consent Decree in January 2009. No administrative penalty was issued to Enbridge.*

***Chevron, Red Butte, Utah**: In 2010, Chevron's Red Butte incident released approximately 800 barrels of crude oil near Salt Lake City, Utah. As of September 9, 2010 (three months later), Chevron had reported that they recovered 778 barrels of the released crude oil. Following the incident, Chevron entered into negotiations with the city and the Utah Department of Environmental Quality regarding damages. In September 2011, the parties reached a settlement on released crude oil. The settlement included a payment of $1.0 million to Salt Lake City for lost use, which included environmental and social effects (Utah Water Quality Board 2011). The State of Utah received a $3.5 million settlement, which included a $0.5 million civil penalty and $3.0 million for a waterfowl project and mitigation projects to enhance and protect waterways that may have been affected by the released crude oil (Salt Lake City 2012). The settlement agreement also specified amounts that Chevron would pay to Salt Lake City and the State of Utah for expenses associated with clean up, remediation, and restoration. Chevron paid $1.3 million to the University of Utah for additional remediation and restoration, and $900,000 as compensation to third parties affected by the release.*

> ***Enbridge Line 6B, Marshall, Michigan****: When Enbridge's Line 6B released approximately 20,000 barrels of diluted bitumen oil near Marshall, Michigan in July 2010, a NRDA Council was formed by the State of Michigan, the United States Department of the Interior (though the USFWS and Bureau of Indian Affairs), the U.S. Department of Commerce (through NOAA), the Nottawaseppi Huron Band of Pottawatomi Indians (the Huron Tribe), and the Match-E-Be-Nash-She-Wish Band of Pottawatomi Indians (the Gun Lake Tribe) (USFWS 2015b). The pre-assessment phase of the NRDA process began in November 2010. Enbridge initially cooperated in the NRDA Council's efforts and then, starting in 2013, focused on damage compensation negotiations through the State of Michigan. At that point, the state negotiations and NRDA process ran parallel paths. On May 13, 2015, Enbridge agreed to a partial settlement for resource damages with the State of Michigan that included development of five river access locations, removal of the dam in Ceresco, Michigan, restoration of several miles of impounded river, and provision of 300 acres of wetland compensation (MI 37th Circuit Ct 2015). In June 2015, Enbridge reached agreement with the NRDA Trustees regarding the remaining resource damages at issue (Enbridge 2015). Details of the agreement were presented in the Trustees' October 2015 Final DARP (USFWS et al. 2015b). The additional compensation included funding for restoration of three creek areas, improvements to several inland lakes, a savannah restoration program, a turtle nest protection program, and two tribal cultural projects. The total estimated cost of the two compensation packages was estimated at 66.9 million dollars (Williams and Brush 2015; USFWS et al. 2015b).*

When looking at these recent case studies, it is apparent that the current NRDA process contrasts markedly with the process used to come to final resolution and recovery of the socio-economic environment from past events such as the Exxon Valdez crude oil release. The information summarized in Stantec et al. (2012a) suggested that for the Exxon Valdez crude oil release, full "recovery" of the socio-economic environment was still underway, even though the biophysical environment had largely recovered. Because it took 19 years to resolve outstanding legal claims with the Exxon Valdez crude oil release, this extended litigation process delayed the perceived recovery of the socio-economic environment. This process also perpetuated the misconception that the socio-economic environment is extremely slow to recover from a crude oil release. In addition, the presence of lawyers in small Alutiiq villages following the Exxon Valdez crude oil release likely served to intensify the actual social effects and masked more subtle and culturally unique responses to the crude oil release (Picou 2009; Wooley 1995). By comparison, settlements for recent releases such as Line 4, Red Butte Creek, Line 6B, and even Deepwater Horizon, while to some degree adversarial, were much more direct and efficient, with most damage claims being closed within several years of the clean-up.

8.3.8.3 Factors Affecting Recovery

While recovery time is partly a consequence of release size and complexity, decisions made by parties involved in a crude oil spill response can greatly affect the means and timeframe that an affected community needs to recover. The influence of various decisions plays out by affecting each of the three resource categories: daily life and associated economic burdens, lost use of natural resources, and loss of income and commercial activity, as discussed in the previous section. In general, more rapid recovery is encouraged by actions that are proactive about addressing the possibility of a release, fully recognize the people who are affected, address effects quickly and evenly, are respectful, and are sensitive to the fact that response actions can also cause damage. On the other hand, actions that delay responses, increase damages, neglect the social environment, and/or create adversarial relationships tend to increase recovery time. These actions can be considered in terms of two general categories: operational and response.

Operational actions are those that can be carried out before a release occurs to increase the likelihood that a release is detected and recognized rapidly, and to better prepare the responsible party, oversight agencies, and local communities once a release is identified. Acting in this manner means assuming that a release has occurred when monitoring data suggests one is possible, rather than assuming that one has not.

Response actions involve oil transporters developing detailed response and resourcing plans for sensitive areas along their routes, practicing the plans, and ensuring plan coordination with agency and community emergency units. The process of developing emergency response plans serves as a “heads-up” about the potential for releases and other risks associated with a pipeline. They are also a very useful method of educating parties about the design measures being taken to reduce release probabilities and risks, the monitoring system that is in place, and the procedures that would be implemented should an event occur. Having the public involved in the development of the response plans helps incorporate the unique and special circumstances of every community in the plans (Perkins and Bullock 2014).

Detailed, area-specific emergency response plans are even more effective when shared and practiced with community officials, public emergency response officials, and contracted emergency responders. Such coordination can typically be achieved by periodically conducting spill simulation exercises (Aurand and Coelho 2004; Enbridge 2015; Rayburn et al. 2004). Public involvement in these exercises also provides a means of demonstrating corporate understanding of the unique characteristics and concerns of the communities along a pipeline route, as well as the proponent’s commitment to response plans that are functional, viable and up-to-date.

By limiting the release of crude oil, planning well, and promoting efficient, coordinated responses, responsible parties can reduce damages, involve the affected community, and promote socio-economic recovery. With respect to operational matters, one can consider the differences between Marathon's pipeline release near Albion, Illinois and Enbridge's Line 6B release near Marshall, Michigan.

> ***Marathon, Albion, Illinois**: As described above, in spite of releasing nearly 6,000 barrels of crude oil, Marathon's Albion pipeline rupture received little notice (Wells 2008a, 2008b). The lack of attention was attributed in part to occurrence in a relatively isolated location. The other reason appeared to be good preparation and an efficient response. When Marathon operators noted a sudden pressure drop, they assumed a leak had occurred, shut down the pipeline, and sent a field crew to investigate (Arcadis 2011). When the field crew identified a leak, they notified the company emergency response unit which immediately responded with equipment and 250 personnel. Marathon responded according to a prepared plan that was rehearsed with emergency responders only a year earlier (Wells 2008b). Marathon's caution, preparedness, and rapid response appear to have reduced environmental damages and social disruption and facilitated rapid recovery.*
>
> ***Enbridge 6B, Marshall, Michigan**: In the case of the 2010 Enbridge Line 6B approximately 20,000 barrel diluted bitumen oil release, damages from the release could have been reduced if monitors in Enbridge's control center had responded to a pressure drop in the pipe as a release. Instead, they assumed it was a column separation and ignored operating guidelines stating that "[i]f an operator experiences pressure or flow abnormalities or unexplainable changes in line conditions for which a reason cannot be established within a 10-minute period, the line shall be shut down, isolated, and evaluated until the situation is verified and/or corrected" (NTSB 2012). The pipeline was restarted twice and the rupture remained undetected for 17 hours.*
>
> *Enbridge, the state of Michigan and the local community were also not prepared to respond to a release. The NTSB accident report noted several contributing factors including "Enbridge's failure to identify and ensure the availability of well-trained emergency responders with sufficient response resources" and "insufficient public awareness and education" (NTSB 2012). The state of Michigan was similarly unprepared. One first responder noted: "when we got a call that there was an oil release we expected to see an overturned truck or something like that. Half the river was black. My staff had never been trained for this type of event" (Brooks 2014). While Enbridge's community response was extensive (as noted above) and well received, the release damages and community disruption could have been reduced through a little caution, better preparation and coordination, and better resource planning. Fewer damages would have resulted in less disruption and a shorter period for socio-economic recovery.*

Once a release occurs, response actions taken by the responsible party, oversight agencies, and affected communities can also influence the extent of damage and disruption and, by association, the length of time to recovery. Rapid, efficient responses that consider tradeoffs with different clean-up techniques are able to address the social elements of the disaster in a timely manner and attempt to avoid adversarial situations in settling claims. Responses that take contrary actions tend to increase environmental damages and community disruption with associated longer recovery times. Response effectiveness for socio-economic elements can be measured in minimization of damages, communication effectiveness, and the fairness and timeliness of compensatory and damage payments.

Minimization of damages involves both damages relating to the natural environment in which the community is based, as well as damages to the daily life and economy of the community. The more damages are avoided, the less recovery is required by the community and the faster recovery can occur. Natural resource damages can be reduced by being prepared but it is also important to implement the plans rapidly and efficiently. This means effective and respectful communications, appropriate deployment of resources, and a sensitivity to the tradeoffs between different sorts of clean-up techniques and the damages that those techniques themselves can cause. To address this latter element, researchers and spill responders have developed and implemented a Net Environmental Benefits approach where various parties involved in a spill response can evaluate tradeoffs and provide guidance regarding suggested response techniques that consider the specific resources affected (Efroymson et al. 2003). Various government agencies and companies have been involved in developing the process and workshops have been held in many different areas around the country (Rayburn et al. 2004; Aurand and Coelho 2004). The concept is that better understanding of resources in specific locations that may be affected will result in more focused and resource-sensitive approaches, thereby helping to reduce damages and enhancing the rate of recovery.

From a community standpoint, minimization of adverse effects on the socio-economic environment includes taking immediate actions that can lead to safe and effective means of removing people, their pets and other important possessions from immediate harm. It also includes providing for individuals' needs for as long as it is required, before they can safely return to their homes and businesses and getting them home or back to work as soon as possible. Such actions can include such things as establishing temporary shelters, providing food and water, providing health care, setting up claims centers, making temporary financial resources available, and proactively following up with those individuals who have been dislocated. To the degree that responsible parties and other spill responders can rely upon local sources of materials, supplies, and labor, associated expenditures can also help reduce the economic disruption and establish a foundation for more rapid recovery. People affected by a crude oil release want and deserve to have responsible parties care about and address their well-being. When that occurs, damages can be reduced and recovery is promoted. When it does not, as in the Exxon Valdez case, animosity can linger for decades.

Effective communication with affected communities is also an important element of spill response that can either impede or enhance recovery. It is important that the Incident Command and local officials establish a communications center that will issue routine updates on the status of the release, answer questions about the release, and inform people about when they will be able to resume normal activities. Ineffective communications can damage the relationship between the responsible party, government agencies and the public, creating suspicion and ill will, and impeding community recovery. For example, communication issues were identified as a hindrance to recovery related to health effects resulting from the Enbridge Line 6B Marshall, Michigan release (Eykelbosh 2014). Eykelbosh noted that the lack of health specialists with social media skills who could effectively communicate technical issues in a proactive manner meant that activists were able to influence public opinion unduly with false or misleading information. Her analysis suggested that the recovery process, especially in the early stages following a release, can be hampered by ineffective, overly technical communication. In contrast, she noted that Kinder Morgan's Trans Mountain Pipeline 1,520-barrel crude oil release in Burnaby, British Columbia in 2007 was an example of effective communication of risk to the media and concerned citizens (Eykelbosh 2014). It involved using town hall meetings and identification of monitoring and remediation endpoints that were simple for the public to understand. In addition, communication following the Burnaby 2007 oil release included early and ongoing reporting of air quality and other potential health related effects using data that could be understood by the public.

Implementation of effective and timely procedures for compensating private parties for damages is also a key to the recovery process. Timely payments, through direct compensation and programs/mechanisms that promote social support and community resilience, can help address the mental health and household loss/inconvenience effects of a release, reduce damages and support recovery (Eykelbosh 2014). The differences between the Deepwater Horizon release and the Exxon Valdez crude oil release are a good example of this. Deepwater Horizon was over four times as large as the Exxon Valdez crude oil release and affected portions of four states. Yet, nearly all damage claims had been settled in five years. In contrast, following the Exxon Valdez crude oil release, the drawn out legal battles and delays in reaching a final settlement in the form of punitive damages meant that final resolution was not achieved 20 years after the release. Some authors addressing the Exxon Valdez crude oil release observed that "The inability of the legal system to produce a timely resolution to damages experienced by survivors of the Exxon Valdez oil release has actually resulted in a secondary disaster which may be more significant than the Exxon Valdez oil spill" (Picou and Martin 2007). Enbridge's Line 6B release, though substantially smaller than either Exxon Valdez or Deepwater Horizon, was still one of the largest inland releases in U.S. history. Its damages were also settled in approximately five years.

As summarized above, the published record of oil releases that have occurred during the past 50 years provides some clear lessons. Cautious transport operations and prevention are of utmost importance. When releases occur, communities do recover, and how releases are responded to when they happen can greatly influence the extent of damages and the time it takes a community to recover. Failure to be prepared, failure to implement effective response and recovery actions in a timely manner, and delays in settling damages or NRDA claims can extend recovery of the socio-economic environment beyond recovery of the biophysical environment. This delayed recovery results from a lack of compensation to make affected parties whole, lingering ill will toward the responsible party and/or poor perceptions regarding environmental conditions. On the other hand, when oil transporters, government, and communities are prepared and work together effectively, disruptions, damages, and resentment can be reduced and managed so socio-economic recovery can be achieved as rapidly as possible.

8.3.8.4 Summary of Socio-Economic Effects and Community Recovery

Review of literature, media reports, and case studies regarding oil releases over the past 50 years clearly illustrates that clean up and oil recovery technologies have improved over the past decades. Human communities can and do recover from the socio-economic effects caused by oil releases. The speed and efficacy of spill response can limit the severity and the area affected by a release, which facilitates recovery rates.

People responding to releases now are better trained, better organized, and have better technology at their disposal than what existed at the time of the Union Oil and Ashland releases. There is a much better understanding on the part of oil transporters and government agencies that oil releases are human and ecological disasters, and that an effective response must immediately and directly address the people affected. The Exxon Valdez crude oil release, while studied in depth and often cited, is not a good example of the present status of crude oil release response efforts, potential socio-economic effects, or how compensation processes are carried out. The Exxon Valdez crude oil release occurred prior to most governing legislation being enacted. Modern day spill responses by oil transporters, regulators, and researchers have over 25 years of technological improvements, field studies, and training to utilize.

Crude oil releases affect people in a community in a variety of ways and not all individuals or businesses may be completely satisfied with how the effects are addressed. However, the experiences demonstrated by the recent case studies indicate that socio-economic environments can and do recover after a crude oil release, and that the current regulatory framework usually results in recovery within two to five years. Within this framework, full community socio-economic recovery for a given release seems to occur when each of the following effect categories applicable in a particular location has been addressed.

Restoration of daily life activities and reimbursement of spill-related household costs is a critical part of recovery. This part of recovery is partially dependent on applicable regulations and involves completion of efforts to restore the natural biophysical environment and ecosystem to conditions required by regulations and clean-up endpoints. Once infrastructure (e.g., buildings, roads, water intakes) and the residential environment (e.g., recreational areas, agricultural land) have been returned to a safe and functional state, day-to-day socio-economic activities can return to near normal. This means that affected residents may return to their homes, and municipalities and companies can return to withdrawing water for public and private consumption or can access an alternate source of water. Tourists and recreationists can resume visiting the area. This stage of recovery can be achieved relatively quickly, usually within one to two years. The duration of recovery will depend partly on the effectiveness of the response process which can be greatly enhanced by having a robust spill contingency planning and preparedness regime that includes an effective and community-based response.

The second measure of the recovery of the socio-economic environment relates to the return of ecological functionality for affected land and resources. This means that individuals and communities are able to return to land and resource use, including harvesting activities, as they existed prior to the release, without having to worry about the effects of residual oil. For example, a release on agricultural land could be cleaned up the first year, but the return to planting and harvesting may be delayed for another year or two while the land recovers from the release and the effects of remediation on yields diminish. Also, the return to commercial and traditional fishing may be delayed for several years until fish populations recover and issues related to fish contamination and other food safety concerns have been addressed. This stage of recovery is especially important for communities that are dependent on aquatic resources for food and employment.

The third measure of recovery of the socio-economic environment involves restoring the well-being of individuals and communities adversely affected by the release through financial compensation for damages. Full recovery of the socio-economic environment is only possible once the affected parties perceive that recovery has occurred and that adequate compensation has been paid. However, the timing of this event will depend on the processes by which compensation is negotiated and provided, and whether or not extended litigation occurs. While final payment of compensation marks the formal completion of the recovery process for the socio-economic environment, there may still be some unresolved issues for both communities and individuals. These issues may relate to ongoing (pre-spill) social issues, longer term problems from having release responders living in small communities, and community angst from delays in implementing the emergency response plans or in communicating the risks and issues. In addition, within communities, there can be perceptions that there are winners and losers. These issues and perceptions may lead to longer term resentment. Widespread negative publicity through sensationalized press coverage can also extend the recovery timeframe in ways that are difficult to predict even though full compensation may have been paid (Wooley 1995; Wooley 2002). These residual effects for individuals can extend beyond completion of the formal socio-economic recovery process for the community as a whole.

8.4 RESPONSE AND REMEDIATION

Emergency response, clean up, and post-release activities can mitigate the extent of environmental effects and influence the course of recovery from a crude oil release. This section assesses the relationships between emergency response and remediation to petroleum releases and how they can influence ecosystem recovery.

In general, published articles and case studies illustrate that post-response recovery is enhanced when responsible parties are well prepared in advance, the initial response is organized, communication during the emergency response is timely and effective, the response adapts well to changing conditions, and attention is paid to tradeoffs between oil removal and environmental damage. Consistent with this pattern, response efforts have improved substantially over the past decades, reflecting the increase in attention paid by oil producers, transporters, and other parties to improve preparedness. Preparedness can include proactive information gathering, analysis and database development, mock response exercises, communication and coordination with local emergency response officials, and alignment with regional planning efforts. Calls for continued efforts along these lines are common and are likely to be implemented given the interest by responsible parties, regulators, and local citizens to minimize the likelihood of a crude oil release and its potential consequences (Fingas 2014 2014; Fingas 2015; Lee et al. 2015).

For the purposes of discussion within this section, terms are used as follows:

- Response: Emergency activities to achieve two goals, containment and clean up
- Containment: Activities designed to contain released crude oil and prevent it from moving farther (especially into sensitive areas) and to facilitate crude oil collection and removal
- Clean up: Active collection and removal of crude oil and oiled materials from the environment
- Recovery: Return of an ecosystem or environmental receptor to some desired state that provides similar ecosystem benefits following disturbance (See Section 8.2)
- Remediation: Physical, chemical, or biological processes applied post-clean up to reduce any residual crude oil
- Rehabilitation: Collection of oiled wildlife to clean the crude oil from the individual, return it to health and, ideally, release it back into the environment
- Restoration: Activities carried out to promote the return of natural resources affected by a crude oil incident to the condition that would have existed if the event had not occurred (baseline condition)

Natural attenuation and compensatory restoration are also terms that are widely used. Natural attenuation refers to various physical, chemical, and biological processes that occur without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in the environment (USEPA 1999). Compensatory restoration refers to action taken to reimburse for interim losses of natural resources and services that occur from the date of the incident until recovery is deemed complete (French et al. 1996).

8.4.1 Response

Numerous authors have discussed how the early historical practice of using heavy earthmoving equipment, even in sensitive areas such as marshes, can substantially delay recovery (e.g., review in Stantec et al. 2012). The lessons learned from these historical incidents have led modern response strategies to target preventing crude oil from reaching sensitive environments, and make informed decisions concerning heavy equipment use. There has been a growing interest within the industry regarding how timely and appropriate response approaches can enable and accelerate recovery. Current practice focuses on the following variables that can either impair or enhance recovery (Dollhopf and Durno 2014; Jones and Plourde 2011; Lindstedt-Siva 1999; Purnell and Zhang 2014; Stevens and Aurand 2008):

- Preparedness—Are the responsible party and regulatory agency staff trained in the Incident Command Structure, a formalized, uniform response framework used throughout the U.S.? Is response staff knowledgeable, trained, and capable of deploying a variety of response techniques? Have they participated in previous responses or drills? Is there sufficient staff with the appropriate skill sets available? Is the proper equipment available and in sufficient amounts? Can personnel and response equipment be immediately deployed to release sites? Has advance planning been carried out? Do responders have knowledge of the type of oil released and environmental resources in proximity to the affected area?
- Cooperation and communication—Has the responsible party initiated its emergency response plan, including the notification of federal, state, and local authorities, as appropriate? Has the responsible party involved in the response coordinated with local responders to create trust and respect? Can the parties work together and is there a willingness to communicate so that prompt, efficient, and appropriate actions can be taken?
- The role of the public and press—Do the responsible party and regulatory agencies communicate clearly and routinely with the public? Is there sufficient trust with interested stakeholders that meaningful discourse can occur? Have personal or political agendas or the threat of legal action led to decisions that might contribute to longer recovery?
- Flexibility and willingness to learn—Does the Incident Command (i.e., response managers) apply knowledge from other responses and adjust tactics during a response to address changing conditions and different resource types?
- Understanding of trade-offs and the net environmental benefits of different approaches—Does the Incident Command consider whether response activities in certain areas may cause more environmental damage and lead to longer recovery than allowing natural recovery?

The importance of these response variables is apparent when contrasting incidents prior to the advent of the *Oil Pollution Act* of 1990 (OPA 1990) with more recent releases. As summarized in the 1999 International Oil Spill Conference report:

> Prior to the Exxon Valdez spill, RPs [responsible parties], federal agencies, and individual states tended to plan independently for responses. When a spill occurred, each found that the others' plans were inadequate or incompatible with its own. The result was confusion and recrimination, creating an impression in the public's eyes that chaos reigned (Lindstedt-Siva 1999, p.15).

The *Oil Pollution Act* 1990 required industry and government to produce contingency plans to help guide activities in the event of future incidents. Since the passage of *Oil Pollution Act* 1990, efforts at emergency preparedness planning and collaborative efforts, such as joint planning sessions and response exercises, have been widely implemented within the industry (Aurand and Coelho 2004; Enbridge 2015a; Rayburn et al. 2004). As a result, responses to crude oil releases have become more efficient and adaptive, with much better prospects for reduced environmental damages and more rapid recovery (Aurand and Coelho 2004; Enbridge 2015a; Rayburn et al. 2004).

Reports from the 2010 Enbridge Marshall Incident Commander, for example, show that the incident response was organized, adapted to changing conditions, and attempted to "balance between cleaning a riverine environment and minimizing adverse effects to the ecosystems and/or changing river dynamics" (Dollhopf and Durn 2011). The U.S. Coast Guard reports regarding the 2010 Deepwater Horizon release also illustrate how responders to that event were well prepared and modified the Incident Command System structure to provide for better communication, better understanding of local field conditions, and better congruence between response actions and ecosystem sensitivity (Jones and Plourde 2011, USCG 2011).

8.4.2 Remediation

Remediation involves active human intervention to remove contaminants from environmental media following initial response efforts. For crude oil releases, the environmental media requiring remediation are often soil and groundwater (PHMSA 2016). The contaminants are remediated through engineered means or through enhancement of biological processes, usually applying some combination of microorganisms, nutrient additions, oxygenation, and phytoremediation (i.e., use of plants to promote biodegradation).

8.4.2.1 Engineered Remediation

Engineered remediation uses chemical and physical processes to address crude oil trapped in the unsaturated zone, oil at the water table, or a dissolved plume of contaminants. Techniques include hydraulic removal (e.g., pumping, skimming), volatilization (e.g., soil vapor extraction or air sparging), or a combination of approaches (e.g., multi-phase extraction).

For example, at the Enbridge 1979 Bemidji release site, a pump-and-skim system was installed and operated from 1999 to 2003 and removed approximately 724 barrels of the estimated 1,760 to 1,990 barrels of crude oil that remained following the initial clean-up responses (Delin and Herkelrath 2014). The remedial effort was expected to decrease the time to recovery by substantially reducing the amount of residual crude oil remaining for degradation through natural attenuation (Cozzarelli et al. 2001; USGS 1998).

At the Enbridge Cass Lake site, approximately 1,143 barrels of crude oil were released (discovered in 2001). To mitigate groundwater effects, a bioventing system was installed in 2014. After just three months of operation, monitoring data suggest the rate of biodegradation was enhanced with increased oxygen, decreased carbon dioxide, and increased temperature in the vadose zone (AECOM 2015).

8.4.2.2 Bioremediation

Bioremediation has been studied by microbiologists since the 1940s, but it did not become broadly considered as a viable technology for crude oil clean up until the Exxon Valdez incident in 1989. In the years since Exxon Valdez, bioremediation has become a better developed and more broadly understood technology that can be considered and applied in many different circumstances. As Wilson and Jones (1993) noted, the bioremediation approach "has advantages over thermal and some physio-chemical techniques in terms of cost and because the soil as a living system suitable for plant growth is not destroyed."

Bioremediation should be considered within the context of biodegradation, a naturally occurring process whereby bacteria or other microorganisms alter and break down organic molecules into other substances, eventually producing fatty acids, carbon dioxide, and water. There are hundreds to thousands of species of bacteria, archaea, and fungi that can degrade petroleum and these oil-degrading microorganisms are ubiquitous throughout the world. While the microorganisms capable of petroleum hydrocarbon degradation may only represent a small proportion of the entire microbial community in the area affected by crude oil, bioremediation accelerates biodegradation through supplementing microbial populations, stimulating existing microbial populations, or manipulating the contaminated media using techniques such as aeration, nutrient augmentation, or temperature control to enhance growth of microbial populations (Lee and Merlin 1999).

Phytoremediation is a type of bioremediation using plants, their associated root/soil microorganisms, and agricultural practices (e.g., nutrient amendments, tilling) to accelerate the removal or degradation of environmental contaminants (Frick et al. 1999; White Jr. et al. 2006). Phytoremediation manipulates natural synergistic relationships among plants, microorganisms, and the environment without intensive engineering techniques or excavation. Intervention by phytoremediation is carried out to establish or augment an appropriate plant-microbe community at the site or to implement agronomic techniques (e.g., tillage, fertilizer application) to enhance natural degradation or containment processes (Frick et al. 1999). Phytoremediation acts primarily by promoting the growth of microbes, including petroleum hydrocarbon degraders, within the root zone. Soil in proximity to the plant roots supports as much as one to two orders of magnitude more microbes than unvegetated soil (Kamath et al. 2004; Robson et al. 2004; Siciliano and Germida 1998). Plants infiltrate soil with their roots, releasing nutrients and supporting growth of indigenous microbes throughout the soil profile, which is more effective than the addition of nutrients without plant growth.

Perhaps the largest bioremediation effort ever undertaken was in response to the 1989 Exxon Valdez event. After the event, a substantial portion of the crude oil floated ashore and was stranded in areas where physical washing and collection of crude oil from the environment were difficult. A portion of the deposited oil also moved into the subsurface, often due to wave and tidal actions. Based on prior research and response-related testing, fertilizer additions were used on shoreline areas starting in 1990. Results showed that the fertilizer treatments resulted in total losses of petroleum hydrocarbon as high as 1.2% per day (Atlas and Hazen 2011). By 1992, only 1.3% of the initially oiled shoreline had detectable amounts of crude oil (Atlas and Hazen 2011; Pritchard et al. 1992).

Since the Exxon Valdez, additional smaller-scale bioremediation efforts also have taken place in various locations, and techniques have been tested using laboratory and field experiments to validate observations at other crude oil releases, and test new methods (Venosa et al. 1996). For example, research at a contaminated land farm site indicated that as much as 70% of the oil contamination can be degraded over the course of three years with enhanced phytoremediation using Plant Growth Promoting Rhizobacteria (PGPR) (Gurska et al. 2009). This includes degradation of high molecular weight hydrocarbons in the lube oil and crude oil range. Other studies have shown that it is possible to adapt these phytoremediation systems to other sites by utilizing site-specific PGPR-enhanced phytoremediation. A series of experimental studies were carried out in a wetland along the south shore of the St. Lawrence River to evaluate the influence of nutrient enrichment and plant growth on crude oil degradation rates. These studies documented results similar to the land farm site (Greer et al. 2003; Venosa et al. 2002; Venosa and Zhu 2003).

Research carried out from 1994 through 1999 "[d]emonstrated that the application of fertilizers stimulated the activities of indigenous hydrocarbon-degrading and denitrifying bacteria, and the presence of crude oil either enhanced or had no detrimental effect on these activities. As a remediation strategy, the application of fertilizers to a wetland shoreline following a crude oil release would promote the growth of indigenous plants and their associated microbial flora, resulting in increased metabolic activity and the potential for increased oil degradation activity" (Venosa and Zhu 2003).

8.4.3 Rehabilitation

Rehabilitation includes activities that can be undertaken to protect wildlife from harm that have come into contact or may come into contact with the released product. There are numerous proactive measures that can be implemented (e.g., deterrents, ex-closures, relocation) to keep wildlife from contacting crude oil that has been released into the environment. Despite efforts, individuals still may become oiled, most often in the immediate aftermath of a release. Rehabilitation involves the capture, cleaning, medical treatment (if necessary), and release into unaffected areas. For the most severe cases, rehabilitation takes place in a special facility, though lightly oiled and uninjured animals may be cleaned in the field and released. Planning, training, experience, and networks of wildlife rehabilitators have improved and expanded considerably over the past several decades such that, depending on site conditions, a vast majority of captured individuals survive the experience and are released as discussed below.

Perhaps the largest wildlife rescue and rehabilitation effort in freshwater environments that has been conducted to date took place in response to Enbridge's Line 6B release near Marshall, Michigan in July 2010. Approximately 20,000 barrels of crude oil was released and 8,200 barrels entered Talmadge Creek and the Kalamazoo River (Enbridge 2013). Active wildlife response activities were initiated on July 28, 2010, and concluded on October 2, 2011. This effort included the care and overwintering of 463 animals.

Additional wildlife captures and in-river relocations were made in 2013 to inspect, clean (when necessary), and remove individuals from areas where active oil dredging was occurring.

Between the initiation of wildlife response activities in 2010 and the conclusion of dredge activities (December 31, 2013), a total of 14,053 individual animals had been collected and 13,543 (96.4%) survived (Enbridge 2014). An additional 157 turtles that were hatched during captivity were released. Survival rates were highest for amphibians, crustaceans, and turtles, and lowest for mammals (Table 8-1).