APPENDIX T

Screening Level Oil Spill Modeling

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SCREENING LEVEL OIL SPILL MODELING

1.0 SPILL MODELING

1.1 PURPOSE

The approach used in this Supplemental EIS to identify impact to receptors is intended as a screening level approach and not intended to predict spill fate and transport for every condition along the pipeline route. The purpose of the screening is to identify reasonable distances release volumes would migrate over land or as dissolved-phase plumes in groundwater to facilitate identifying potential impact to receptors. Plumes were assessed for overland spreading and impact to groundwater and the resulting dispersion of the dissolved-phase constituent benzene. By identifying potential could-affect areas of the Project route, mitigation and response actions can be reassessed and addressed prior to pipeline operation.

1.2 METHODOLOGY

The approach attempts to be technically neutral but errs on the side of conservatism. As an example, overland spreading does not address volume losses due to evaporation and surface oiling of vegetation. Because of the technically neutral approach in this evaluation, it is assumed that management plans, emergency response plans (ERP), spill prevention, control, and countermeasure plans (SPCC), standard mitigation practice, and the Pipeline Hazardous Material Safety Administration (PHMSA) Special Conditions will be implemented consistent with industry best practice.

Spill volumes used in this screening approach were based on data listed in Section 4.13.2.5, PHMSA Historical Data: Spill Size Distribution, of this Supplemental EIS. Overland spreading was evaluated by calculating the area of potential impact for each of the identified spill volumes (Grimaz et al. 2007). Areas were then used to assess the distance of radial spreading (representing smooth, flat ground). To further validate the spreading analysis, two separate peer-reviewed methodologies were implemented to calculate an equilibrium spill thickness for heavy, sour crude oil. A standard boundary layer condition formula using an interfacial tension based on heavy oil was used to identify a relative oil permeability value of 0.5 for use in the Grimaz equation for oil spreading. To assess the applicability of the approach, oil thickness was calculated from the oil spreading distance (Grimaz et al. 2007) and it was found to be consistent with the thickness of heavy oil calculated from the boundary layer calculation. Both the Grimaz equation and standard boundary layer condition formulas resulted in similar spill thickness values in the range of 0.2 cm (0.079 in) to 0.7 cm (0.28 in) based on the surface tension and kinematic viscosity. The objective of the spreading analysis approach is to facilitate screening in potential could-affect areas for the entire pipeline rather than establishing discrete site-specific scenarios that could unintentionally be screened out for further evaluation areas.

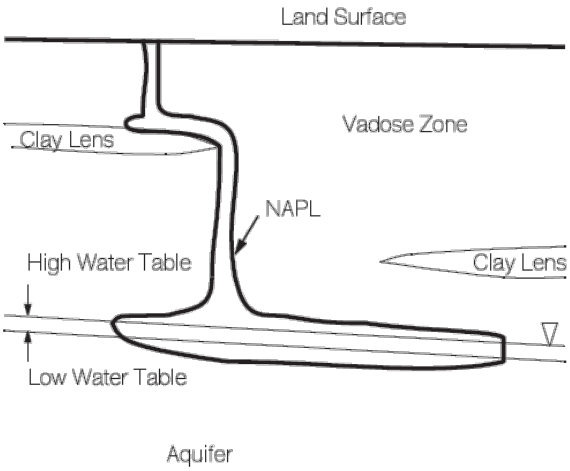
The model proposed by Grimaz et al. was developed as a simplified technique for predicting the maximum potential oil seepage depth into soil immediately after a release. As part of this model, Grimaz et al. proposed a simplified predictive formula derived from gravity current theory in

order to predict the extent of surface spreading after a release. The model as a whole is intended for use in estimating a window of opportunity for response action.

The U.S. Environmental Protection Agency (USEPA) Hydrocarbon Spill Screening Model (HSSM) was used to assess the potential impact to groundwater and, if a dissolved phase plume develops, determine the axial length of the plume. HSSM is intended as a practical tool to assess the effects of a surface or shallow subsurface release of liquid hydrocarbons from a spill, leaking tank, or pipeline with the advantage of simplicity and ease of computation (Charbeneau 1995). Simplified conceptualizations of the flow and transport phenomena were used so that the resulting model would be a practical, though approximate, tool. The model is intended for use in evaluating light non-aqueous phase liquid (LNAPL) transport and is not suitable for denser-than-water NAPLs (DNAPLs) as the model assumes NAPL to "float" on the water table. HSSM is not suitable for application to heterogeneous geological formations and is intended to provide order-of-magnitude estimates of contamination levels only. Additionally, the model is not designed to address dynamic conditions such as fluctuating groundwater, changing gradient, or specific design conditions such as pipeline trench systems or pressurized leaks from a pipeline. Emergency response, initial phases of site investigation, facilities siting, and underground storage tank programs are potential areas for use of HSSM (Weaver et al. 1994).

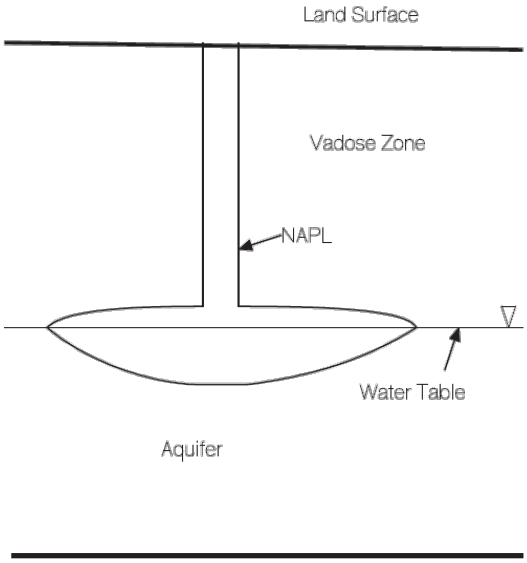
HSSM simulates the flow of LNAPL and the transport of a chemical constituent of the LNAPL from the surface to groundwater, radial spreading at the water table, and dispersion of a dissolved-phase constituent. A simplified conceptualization of the LNAPL release scenario is shown in Figure 1. The geometry assumed by HSSM is shown in Figure 2 and is based on the simplified conceptual LNAPL release scenario. At the water table, the LNAPL spreads radially, implying that the regional gradient has no effect on LNAPL flow. Dissolution of the chemical constituent obeys local equilibrium partitioning, but is driven by groundwater flow and recharge.

The model treats flow and transport as one-dimensional, which is a conservative approach as all the pollutant is assumed to move downward and contribute to aquifer contamination. Lateral contaminant spreading by capillary forces is neglected, except as these forces influence the infiltration of LNAPL into the soil. Also neglected is spreading due to heterogeneity since the subsurface is assumed to be of uniform composition. The presence of the water and air phases in the LNAPL is incorporated by use of a relative permeability model which uses measured soil properties (capillary pressure curve parameters) to approximate the relative permeability. The model does not include transport in fractures or macropores and assumes the LNAPL's transport properties (i.e., density, viscosity, capillary pressure, relative permeability) to be unchanging.



Source: Weaver et al. 1994.

Figure 1 Schematic view of NAPL release



Source: Weaver et al. 1994.

Figure 2 Schematic view of idealized NAPL release that is used in HSSM

For the HSSM simulations, groundwater was assumed to be 0.3 m (1 ft) below the base of the spill to evaluate potential impact to a shallow aquifer. Hydrologic parameters used in the model for permeable sands were based on Carsel and Parrish (1988). Sandy soils are associated with high permeability vadose zone and aquifer materials. The horizontal hydraulic conductivity was

assumed to be 15 m/d (50 ft/day). Porosity was assumed to be 0.15 (Stanton 2010) and vertical hydraulic conductivity was assumed to be one order of magnitude smaller than horizontal hydraulic conductivity or 1.5 m/d (5 ft/d).

A viscosity of 325 cP at a specific gravity of 0.93 was reported for diluted bitumen (Leis et al. 2012). A density for heavy sour crude oil, 0.93 g/cm^3, and a benzene concentration for light crude oil, 0.28% (exp Energy Services Inc. 2012), were used as conservative assumptions to evaluate the resulting dispersion of the dissolved-phase constituent. Other model parameters were within typical value ranges suggested for use in HSSM by Weaver et al. (1994). Table 1 summarizes the key input values used in the model simulation.

Table 1 Summary of Key Input Values Used in HSSM Simulation

Parameter	Input Value[e]	Source
Hydrologic Properties		
Depth to groundwater (m)	0.3	
Horizontal hydraulic conductivity (m/d)	15	Gutentag et al. 1984, Stanton 2010
Vertical hydraulic conductivity (m/d)[a]	1.5	
Porosity (vol%)	15	Stanton 2010
Hydrocarbon Phase Properties[b]		
Viscosity- dilbit (cP)[c]	325	Leis et al. 2012
Density - heavy crude oil (g/cm^3)	0.93	exp 2012, Attanasi et al. 2007, Enbridge 2011
Benzene concentration – light crude oil (vol%)[d]	0.28	exp 2012, Section 3.13

[a] Assumed 1/10th of horizontal hydraulic conductivity.
[b] These hydrocarbon phase properties represent the range of possible products being transported through the pipeline.
[c] Viscosity of dilbit was used to provide a larger plume size.
[d] Light crude oil was used since it has a higher benzene content than heavy crude oil or dilbit.
[e] % = percent; dilbit = diluted bitumen, cP = centipoise; ft/d = feet per day; g/cm^3 = grams per cubic centimeter; m = meter or meters; m/d = meter per day

Additional simulations of HSSM for the 50 bbl and 20,000 bbl spills were run to delineate a lower and upper bound of the dissolved-phase plume length. Key input values modified included aquifer hydraulic conductivity and porosity, benzene concentration, and crude oil viscosity. For the lower bound simulation, aquifer vertical hydraulic conductivity was reduced to 0.7 m/day and porosity remained at 0.15. The benzene concentration reported for heavy crude oils, 0.16% (exp Energy Services Inc. 2012), and a crude oil viscosity of 157 cP (Enbridge 2011) were used to generate a smaller dissolve-phase plume size for the lower bound simulation. For the upper bound simulation, aquifer hydraulic conductivity was increased to 3.0 m/day and porosity was increased to 0.26 (Stanton 2010). Benzene concentration for light crude oil (0.28%) and a viscosity reported for dilbit (325 cP) were used in the upper bound simulation to generate a larger dissolved-phase plume size. All other model parameters not discussed above remained the same values as listed in Table 1 during these simulations.

1.3 RESULTS

The results of the HSSM simulations were used to identify reasonable benzene concentrations at the source from infiltrating LNAPL and distances the dissolved-phase plume could migrate until the benzene concentration attenuated to less than 0.005 mg/L, which is the maximum contaminant limit for Montana, South Dakota, and Nebraska. Using benzene to assess the

groundwater dispersion, model results show a spill would reach groundwater and migrate downgradient in each of the spill volume scenarios. Table 2 summarizes the axial length of surface and dissolved-phase plumes developed for each of the spill volumes assessed. A high level sensitivity analysis was also conducted using the same parameters above and identified that the three spill volumes could affect groundwater at a depth of 15 m (50 ft) or less. Additionally, the input parameters for the model were modified (e.g. aquifer hydraulic conductivity and porosity, benzene concentration, and crude oil viscosity) to simulate the largest dissolved plume length. The range of dissolved-phase spill plume lengths under these conditions was between 55 m (180 ft) and 490 m (1,608 ft).

Table 2 Axial Length of Plumes Based on Radial Spreading of Dissolved Constituent

	50 bbl	**1,000 bbl**	**20,000 bbl**
Surface plume axial length in meters (ft) [a]	34 (112)	112 (367)	370 (1,214)
Dissolved-phase plume axial length in meters (ft) [b]	195 (640)	250 (820)	320 (1,050)
Initial constituent concentration 1 meter from source (mg/L) [b]	8.3	8.8	9.0

[a] Calculated from the formula proposed by Grimaz et al. (2007)

[b] Output values from HSSM

2.0 DEFINITIONS

% = percent

bbl = barrel

cm = centimeter

cP = centipoise

ft = feet

ft/d = feet per day

g/cm^3 = grams per cubic centimeter

in = inch or inches

m = meter or meters

m/d = meter per day

mg/L = milligrams per liter

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