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Risk-Based Screening Levels for the Protection of Livestock Exposed to Petroleum Hydrocarbons

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Table of Contents

Tables

Figure

1. Executive Summary

Livestock may be exposed to accidental releases of petroleum hydrocarbons at or near exploration and production sites and, in these cases, there may be a need to estimate potential risks to these receptors. A framework was developed to 1) determine when livestock should be included in a risk evaluation and 2) estimate risks of petroleum hydrocarbon exposure to livestock. A conceptual site model (CSM) was developed to assess whether complete and significant exposure pathways for livestock exist at a site.

To estimate potential risks in this screening-level risk assessment, toxicity reference values (TRVs) and drinking water and soil risk-based screening levels (RBSLs) for petroleum hydrocarbons, including: crude oil; benzene, toluene, ethylbenzene, and xylene (BTEX); and polycyclic aromatic hydrocarbons (PAHs) were developed for livestock. TRVs and RBSLs were developed for the protection of a variety of livestock including dairy cattle, beef cattle, calves, sheep, goats, camels, and horses.

TRVs for petroleum hydrocarbons were based on available toxicity values from studies conducted on livestock, if available, or on small mammals extrapolated to be protective of livestock evaluated in this report. RBSLs were calculated for the two complete and significant exposure pathways identified in the CSM, drinking water ingestion and incidental soil ingestion. Drinking water and soil RBSLs were calculated based on the TRVs and the selected exposure assumptions for the livestock.

The TRVs and RBSLs developed for this framework were comparable to human health RBSLs as shown in the following table:

	Toxicity Reference Values (TRVs; mg/kg-bw/day)						
Livestock	Crude Oil	Benzene	Toluene	Ethylbenzene	Xylene	LMW PAH	HMW PAH
Dairy Cattle	211	5.70	35.6	4.65	28.5	0.798	0.160
Beef Cattle	211	5.95	37.1	4.86	29.8	0.833	0.167
Calves	211	10.3	64.5	8.43	51.7	1.45	0.289
Sheep	211	10.0	62.5	8.17	50.1	1.40	0.280
Goats	211	11.8	73.6	9.62	58.9	1.65	0.330
Camels	211	5.55	34.6	4.53	27.8	0.777	0.155
Horses	211	5.67	35.4	4.63	28.4	0.794	0.159

	Drinking Water Risk-Based Screening Levels (RBSLs; mg/L)						
Livestock	Crude Oil	Benzene	Toluene	Ethylbenzene	Xylene	LMW PAH	HMW PAH
Dairy Cattle	1,199	32.4	202	26.4	162	4.53	0.907
Beef Cattle	1,114	31.4	196	25.6	157	4.40	0.880
Calves	293	14.3	89.5	11.7	71.7	2.01	0.402
Sheep	855	40.5	253	33.1	203	5.68	1.14
Goats	622	34.8	217	28.4	174	4.87	0.974
Camels	7,673	202	1,259	165	1,009	28.3	5.65
Horses	2,763	74.3	464	60.6	371	10.4	2.08

Livestock	Soil Risk-Based Screening Levels (RBSLs; mg/kg)						
	Crude Oil	Benzene	Toluene	Ethylbenzene	Xylene	LMW PAH	HMW PAH
Dairy Cattle	47,151	1,273	7,946	1,039	6,367	178	35.7
Beef Cattle	44,894	1,266	7,901	1,033	6,331	177	35.5
Calves	44,894	2,198	13,715	1,794	10,990	308	61.5
Sheep	20,095	953	5,949	778	4,767	133	26.7
Goats	17,583	982	6,129	802	4,911	138	27.5
Camels	69,522	1,829	11,412	1,492	9,144	256	51.2
Horses	28,133	756	4,719	617	3,782	106	21.2

mg/kg-bw/day = milligrams per kilogram body weight per day.
mg/L = milligrams per liter.
mg/kg = milligrams per kilogram.
LMW PAH = low molecular weight polycyclic aromatic hydrocarbon.
HMW PAH = high molecular weight polycyclic aromatic hydrocarbon.

2. Introduction

Consumption of petroleum hydrocarbons by livestock has been found to lead to a range of health problems, including neurotoxicity (Coppock *et al.* 1995; Khan *et al.* 1995), fetal toxicity (Coppock *et al.* 1995), damage to the gastrointestinal tract (Coppock *et al.* 1996), respiratory system, kidney, and liver (Meadows and Waltner-Toews 1979; Edwards 1985*a*; Coppock *et al.* 1995; Coppock *et al.* 1996; Stober 1962). Petroleum ingestion has also been linked to anorexia (Edwards and Zinn 1979), lethargy (Meadows and Waltner-Toews 1979; Edwards 1985*b*), and fatal poisoning in cattle (Edwards and Zinn 1979; Meadows and Waltner-Toews 1979; Edwards and Gregory 1991).

The purpose of this study was to develop toxicity values and screening guidelines for evaluating risks to livestock from exposure to petroleum hydrocarbons. This report addresses how to: (1) determine whether livestock should be included in a risk evaluation, and (2) estimate risks of petroleum hydrocarbon exposures to livestock.

In this report, the approach used to develop toxicity values and screening guidelines for livestock from petroleum hydrocarbon exposures was divided into two steps:

- The first step included evaluation of the potential for exposure through the development of a conceptual site model (CSM).
- The second step included development of Toxicity Reference Values (TRVs) and Risk-Based Screening Levels (RBSLs) for the protection of livestock.

This report focused on whole crude oil and its toxicologically important constituents (i.e. benzene, toluene, ethylbenzene, and xylene [BTEX] and polycyclic aromatic hydrocarbons [PAHs]). Metals can also be present in petroleum products, but they are generally not found at high enough concentrations to provide a significant health risk (Magaw et al., 1999) and therefore metals are not addressed in this report.

The approach presented herein is consistent with a screening-level risk assessment and used a conservative approach to determine potential risks to receptors by comparing exposure levels of petroleum hydrocarbons from a site to petroleum hydrocarbon threshold levels protective of livestock. Although threshold values for the protection of livestock have been developed by some agencies (e.g., Canadian Council of Ministers of the Environment [CCME] and Alberta Environment), these values are either region-specific or cover limited constituents of petroleum hydrocarbons. In this study, a more generalized approach was used to develop conservative threshold values such as TRVs (i.e., toxicity values) and RBSLs (i.e., guidelines) for petroleum hydrocarbons that can be used to characterize risks to livestock across a variety of conditions.

3. Conceptual Site Model

A conceptual site model (CSM) identifies complete and potentially complete exposure pathways and receptors to be considered in a risk assessment. If no complete significant pathway(s) exist for exposure of livestock to petroleum hydrocarbons, a screening-level risk evaluation for livestock is not necessary. By definition, if there is little to no significant exposure to a potentially toxic compound, there is little to no likelihood of significant unacceptable risk to the receptor from that compound. A CSM was developed as presented in Figure 1 to assess the potential for exposures to livestock and the need for a risk evaluation. Components of a CSM generally include receptor evaluation and exposure pathway evaluation, which are described below.

3.1 Receptor Evaluation

Livestock that are potentially vulnerable to toxic effects of petroleum hydrocarbons include animals that could ingest significant quantities of soil, water, and/or food in oil-contaminated areas. Access to the contaminated areas is key; cattle, sheep, goats, and horses that forage in pasture areas are more likely to be potential receptors, while species that are raised in more confined and controlled conditions, such as chickens or pigs, would have less chance of exposure to petroleum hydrocarbons. Outside of the United States, other types of livestock animals may also be exposed to petroleum compounds, such as camels, llamas, oxen, etc. It was assumed that exposures to these receptors would be similar to those of typical livestock in the United States based on similarities in body weights and feeding habits.

3.2 Pathway Evaluation

The pathways by which livestock could be exposed to petroleum hydrocarbons are incidental soil ingestion, water ingestion, and direct ingestion, inhalation, dermal absorption, and plant ingestion. Based on available information, the primary exposure pathways considered significant in the exposure model as show in the CSM (Figure 1) included incidental soil ingestion, water ingestion, and direct petroleum product ingestion. Inhalation, dermal absorption, and plant ingestion were considered minor pathways for petroleum hydrocarbons (CCME 2000). The exposure pathways listed above are described in more detail below.

3.2.1 Soil Ingestion

Soil can comprise a substantial proportion of the livestock diet. Livestock may consume soil inadvertently during grazing (Zach and Mayoh 1984; CCME 2000) or may intentionally ingest salty-tasting soil (Coppock *et al.* 1995). According to the CCME (2000), cattle are exposed to petroleum hydrocarbons primarily through consumption of contaminated soils, particularly during grazing. The authors state that the majority of petroleum hydrocarbon exposure in cattle is due to ingestion of surface soils.

3.2.2 Water Ingestion

Chronic exposure through drinking water can be a significant exposure pathway for livestock (CCME 2000). The amount of water ingested by cattle varies according to age, physiological status (growth, fattening, pregnancy, lactation), diet composition, breed, size, and, for all animals, temperature (Agriculture and Agri-Food Canada 2001; National Research Council [NRC] 1988).

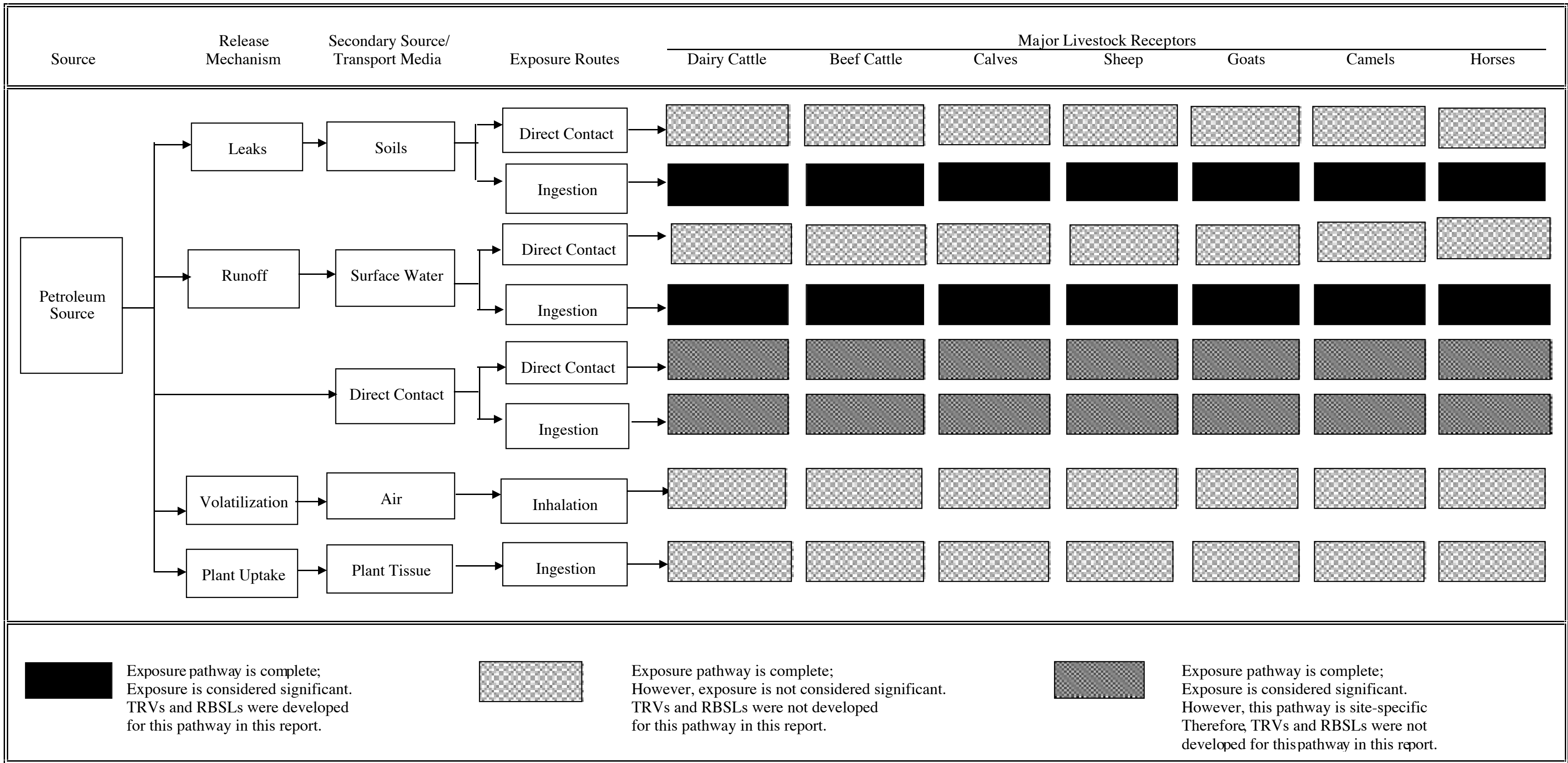

Figure 1. Conceptual Site Model for Livestock Exposed to Petroleum Hydrocarbons

3.2.3 Direct Ingestion

Cattle may directly ingest crude oil and other petroleum compounds from pools of oil formed by leaking pipelines or storage tanks (Edwards and Zinn 1979; Coppock *et al.* 1995; CCME 2000) due to curiosity (particularly in young calves; Edwards 1985*b*), or to add salt to their diet (Edwards 1985*b*, Coppock *et al.* 1995). Reported cases include steers consuming petroleum distillate, drinking from a slush pit, and drinking petroleum from puddles near a tank battery (Edwards and Zinn 1979). Oil and natural gas industry guidance (API 1997) and many regulatory agencies (e.g., the Railroad Commission of Texas 1993) stress the importance of removing free-oil accumulations on the ground that animals could potentially ingest.

3.2.4 Dermal Absorption

Dermal absorption of petroleum hydrocarbons in livestock is considered a minor exposure pathway because of their thick coats (CCME 2000). While methods are available to assess dermal exposure to humans, data necessary to estimate dermal exposure are generally not available for livestock or wildlife (EPA 1993). Additionally, dermal exposure has been shown to be negligible for most terrestrial mammals (EPA 2000).

3.2.5 Inhalation

According to CCME (2000), inhalation of petroleum hydrocarbons is also a minor exposure pathway for livestock. Inhalation of petroleum hydrocarbons was assumed to be negligible for two reasons: (1) due to the assumed presence of vegetation on grazing lands, exposure of contaminated surface soils to winds and resulting aerial suspension of contaminated dust particulates would be minimized, and (2) most volatile organic compounds (VOCs)—the contaminants most likely to present a risk through inhalation—get rapidly diluted and dispersed in ambient air, making significant exposure to VOCs through inhalation unlikely. In situations where inhalation exposure is believed to be more significant, evaluation of this pathway should be considered.

3.2.6 Plant Ingestion

Exposure to petroleum hydrocarbons through ingestion of plants is considered a minor pathway (CCME 2000). The authors explain that although the ingestion rates of plants are high for livestock, plants are considered a minor contributor to this proportion, due to the limited phytoaccumulation (i.e., a process by which plants accumulate contaminants into roots and above ground shoots or leaves) potential of petroleum hydrocarbons (CCME 2000; Alberta Environment 2001*a*).

3.3 Summary of the CSM for Livestock

If the CSM can identify any complete and significant exposure pathway(s) for livestock receptors at a site, then the next step would be to conduct a screening-level risk assessment. However, another factor to consider in determining whether there is need to assess livestock risks is the size of the contaminated area or release relative to the size of the grazing area. This is referred to as a site use factor (explained further in the following section). A small affected area (e.g. less than one acre) is unlikely to result in significant risks to herds of livestock and may not warrant a screening-level risk assessment (Texas Natural Resource Conservation Commission [TNRCC] 2000 and Pennsylvania Department of Environmental Protection [PADEP] 1998). Cumulative risks can be estimated for livestock receptors exposed to petroleum hydrocarbons via multiple exposure pathways (for example, via soil ingestion and water ingestion at a site).

A screening-level risk assessment uses a conservative approach to determine any potential risk to receptors exposed to contaminants at a site which includes comparing exposure levels of contaminants from a site to appropriate threshold values (i.e., toxicity values and guidelines). To characterize potential risks to livestock, petroleum hydrocarbon exposure levels from a site can be compared to petroleum hydrocarbon threshold levels protective of livestock.

As explained earlier, the approach described in this report is general, not site-specific. Therefore, threshold values were developed for the primary exposure pathways: 1) drinking water ingestion, and 2) incidental soil ingestion. Although, direct ingestion was also considered a significant exposure pathway (Figure 1), site-specific parameters are required to develop threshold values for this pathway and therefore, were not addressed in this report.

4. Toxicity Reference Values and Risk-Based Screening Levels

A Toxicity Reference Value (TRV) is a daily dose of a chemical expressed in milligrams of chemical per kilogram of body weight of the livestock receptor per day (mg/kg-bw/day) and represents a concentration associated with an effect level or threshold. TRVs were developed for the protection of livestock at the population level (i.e., herd) of ecological organization and are generally doses at or below which no adverse health effects (e.g., mortality, growth, and reproduction) to the indicator species are expected, even if exposure occurs over an extended duration. TRVs for livestock in this report were developed from the exposure assumptions in Table 1 and available toxicological data presented in Table 2.

Risk-Based Screening Levels (RBSLs) are threshold concentrations in site media (e.g. soil, water, and air) at or below little-to-no likelihood of significant unacceptable risks to livestock are expected. RBSLs were developed based on a food-web model integrating livestock exposures and TRVs. In this framework, livestock RBSLs were developed for complete and significant exposure pathways, which included drinking water RBSLs expressed in milligrams per liter (mg/L) and soil RBSLs expressed in milligrams per kilogram (mg/kg). The following sections describe the exposure and effects assessments used in this report to develop livestock TRVs and RBSLs for complete and potentially significant exposure pathways.

4.1 Exposure Assessment

As discussed previously, the main exposure pathways for cattle, sheep, goats, camels, horses, and other potential livestock receptors are incidental soil ingestion, water ingestion, and direct ingestion. Direct ingestion of chemicals is generally not addressed in a food-web model; however, this pathway should be assessed on a site-specific basis if considered potentially complete. Exposures are generally measured by estimating the intake rates for livestock in kilograms per day (kg/day) or liters per day (L/day) and converting them to doses.

Dose calculation models provide a method of conservatively estimating exposure through the food chain. To ensure conservatism in the overall exposure estimates, it is recommended that the lesser of either the 95% upper confidence limit (UCL) of the mean concentration or the maximum detected concentration in site media (i.e., soil and water) be selected to represent the exposure point concentration (EPC). As dose estimation through modeling generally requires conservative exposure assumptions, exposures measured through modeling tend to be overestimated when compared with actual exposures. The equation used to calculate daily ingested petroleum hydrocarbon dose for livestock was as follows:

$$Dose = \frac{[(IRsoil \times Csoil) + (IRwater \times Cwater)] \times SUF}{BW} \qquad \text{Equation 1}$$

Where:

Dose	=	estimated daily dose of petroleum related hydrocarbons from ingestion (mg/kg-bw/day)
IRsoil	=	amount of soil incidentally ingested per day in dry weight (kg/day)
IRwater	=	amount of water ingested per day (L/day)
Csoil	=	concentration of constituent in soil or sediment (mg/kg dry weight)
Cwater	=	concentration of constituent in water (mg/L)
SUF	=	site use factor (unitless)
BW	=	body weight (kg)

Table 1. Exposure Assumptions for Livestock

Parameter	Dairy Cattle		Beef Cattle		Calves		Sheep		Goats		Camels		Horses	
	Data	Source	Data	Source	Data	Source	Data	Source	Data	Source	Data	Source	Data	Source
Body Weight (kg)	540	NRC, 2001; average of the range 400 to 680 kg. See footnote 1.	454	Lyons et al., 1999. See footnote 1.	50.0	NRC, 2000; average weight of growing calves; range is 25 - 75 kg. See footnote 1.	56.7	Lyons et al., 1999. See footnote 1.	29.5	Lyons et al., 1999; based on Spanish goats.	600	Average body weight from a general web-based search and from Gihad et al., 1989.	550	Environment Canada 1999; mid-range weight. See footnote 1.
Composition of Diet														
Estimated percent soil	0.179	Percentage of dry matter intake; most conservative value; Abrahams and Thornton 1994. See footnote 2.	0.188	Percentage of dry matter intake; most conservative value; Kennedy and Strenge 1992. See footnote 2.	0.188	Percentage of dry matter intake; most conservative value; Kennedy and Strenge 1992. See footnote 2.	0.300	Conservative assumption. See footnote 2.	0.300	Conservative assumption. See footnote 2.	0.300	See footnote 3.	0.300	based on best professional judgement and on similar feeding habits as sheep.
Estimated percent forage	0.821	Calculated; assuming main food item	0.812	Calculated; assuming main food item	0.812	Calculated; assuming main food item	0.700	Calculated; assuming main food item	0.700	Calculated; assuming main food item	0.700	Calculated; assuming main food item	0.700	Calculated; assuming main food item
Food Ingestion Rate - Total														
kg/day dry matter (dw)	13.5	Lyons et al., 1999; 2.5 % of bodyweight. See footnote 3.	11.4	Lyons et al., 1999; 2.5 % of bodyweight. See footnote 3.	1.25	Lyons et al., 1999; 2.5 % of bodyweight. See footnote 3.	1.98	Lyons et al., 1999; 3.5 % of bodyweight. See footnote 3.	1.18	Lyons et al., 1999; 4 % of bodyweight. See footnote 3.	6.07	Gihad et al., 1989; based on a diet of hay.	13.8	OMAFRA 1999*b* ; 2.5% of body weight.
kg/kg body weight-day (dw)	0.0250	Calculated	0.0250	Calculated	0.0250	Calculated	0.0350	Calculated	0.0400	Calculated	0.0101	Calculated	0.0250	Calculated
Soil Ingestion Rate (kg/day)														
Soil (dw)	2.42	Calculated. See footnote 4.	2.13	Calculated. See footnote 4.	0.235	Calculated. See footnote 4.	0.595	Calculated. See footnote 4.	0.354	Calculated. See footnote 4.	1.82	Calculated. See footnote 4.	4.13	Calculated. See footnote 4.
Water Ingestion Rate (L/day)														
summer estimate	95.0	Agriculture Canada, 2002. Summer estimate of water ingestion for milking cows. See footnote 5.	86.0	Agriculture Canada, 2002. Summer estimate of water ingestion for finishing cattle. See footnote 5.	36.0	Agriculture Canada, 2002. Summer estimate of water ingestion for calves. See footnote 5.	14.0	Agriculture Canada, 2002. Summer estimate of water ingestion for sheep.	10.0	IAEA, 1994; maximum of range.	16.5	Gihad et al., 1989. See footnote 6.	42.0	Environment Canada 2003; maximum of range.
winter estimate	77.0	Agriculture Canada, 2002; estimates for milking cows. See footnote 5.	55.0	Agriculture Canada, 2002; estimates for finishing cattle. See footnote 5.	23.0	Agriculture Canada, 2002; estimates for calves. See footnote 5.	3.60	Agriculture Canada, 2002; estimates for sheep.	5.00	IAEA, 1999; minimum of range.	NA	--	15	Environment Canada 2003; minimum of range.
Home Range	--	See footnote 6.	--	See footnote 6.	--	See footnote 6.	--	See footnote 6.	--	See footnote 6.	NA	See footnote 6.	NA	See footnote 6.
Site Use Factor (SUF)[b]	1.00	Conservative assumption	1.00	Conservative assumption	1.00	Conservative assumption	1.00	Conservative assumption	1.00	Conservative assumption	1.00	Conservative assumption	1.00	Conservative assumption

%	Percent.
kg	Kilograms.
kg/day	Kilograms per day.
kg/kg bw-day	Kilogram per kilogram body weight per day.
dw	Dry weight.
ww	Wet weight.
m^2	Meter squared.
m^3/day	Meter cubed per kilogram body weight per day.
L/day	Liters per day.
--	Not available.
a	Dry weight ingestion rate converted to wet weight using the formula from Sample and Suter, 1994: wet weight = dry weight / (1-fraction of moisture content).
b	SUFs = Site Area/Home Range; however, in this ERA, SUF was assumed to be 1.

Notes:

1 Body weights for cattle vary depending on region, breed, age, and lactation period.
Dairy cattle: 400 - 680 kg (NRC 2001), 480 kg - noted as an underestimate (Ng et al., 1982)
Beef cattle: 230 kg (Stair *et al.* , 1995), 250-460 kg (Khan *et al.,* 1995), 454 kg (Lyons *et al.,* 1999), 542 kg (NRC 2000; 1991 slaughter weight)
Calves: 236 kg (Stickney *et al.,* 2001), 50-60 kg (Upadhyay and Swarup 1994), 25 - 75 kg small breeds, 45 - 75 kg large breeds (NRC 2000)
Sheep: 37.6 kg for ewes (Floris *et al.,* 2000).
Goats: 12.5 - 13.5 kg (Bose *et al.,* 2001) and 31.7 kg (Lyons *et al.,* 1999; Angora goats).
Horses: ranged from 500 - 600 kgs (Environment Canada 1999).

2 Percent soil ingested varies depending on region, breed, age, lactation period, season, amount of grazing vegetation, and wind.
Cattle: 2-14 % for dairy cattle (Healy 1968); 4-14 % for dairy cattle (Fries *et al.,* 1982); 1.2-18.8% for range cattle (Zach and Mayoh 1984); 0.2-17.9% for beef or dairy cattle (Thornton and Abrahams 1983);
17.9% maximum recorded for cattle (Abrahams and Thornton 1994); 18.8 % (Kennedy and Strenge 1992).
Sheep: Up to 14% (Zach and Mayoh 1984) and up to 30 % (Thornton and Abrahams 1983).
camels and horses: most conservative % soil ingested of all the livestock receptors was used (i.e., sheep = 30%) as no value were available for camels and horses.

3 Other sources of ingestion rates:
Dairy cattle: 10 kg/d dry matter (Ng *et al.,* 1982), 16.1 kg/d dry matter (IAEA 1994)
Beef cattle: 10 kg/d dry matter (Ng *et al.,* 1982), 7.2 kg/d dry matter (IAEA 1994)
Calves: 1.9 kg/d dry matter (IAEA 1994)
Sheep: 1.6 kg/d dry matter (Ng et al., 1982), 1.3 kg/d dry matter (IAEA 1994)
Goats: 1.3 kg/d dry matter (IAEA 1994)
horses: 13 - 25 kg/day (Environment Canada 1999).

4 Other sources of soil ingestion rates for cattle:
0.5 - 1.2 kg/day with a high of 2.2 kg/day (Zach and Mayoh 1984), 0.72-2.56 (Fries et al. , 1982), 0.1-1.5 kg/d (Mayland et al., 1977), 0.1-0.72 kg/d (McKone and Ryan 1989), 0.4 kg/d (McKone 1994).
Camels: would be expected to ingest large quanitities of sand as they obtain their food from desert terrains.

5 Other sources of water ingestion rates for cattle:
Cattle: 30.3-56.8 L/day (Fairies et al., 1998), up to 100 L/day (CCME 2000), 50–100 L/d for dairy cows, 20-60 L/d for beef cattle, 5-15 L/d for calves (IAEA 1994).
Sheep: 5-8 L/d for dairy sheep (IAEA 1994).
Camels: are known to go without drinking water for days (maximum of 30 days) and then drink large quantities of water at one time.

6 Depends on the livestock ranch or grazing area.

Table 2. Toxicity Studies for Mammals Exposed to Petroleum Hydrocarbons

Animal	Compound	Route	Final Dose[a]	Duration	Effect	Endpoint	Source
Calf	sweet crude oil	oral	8.0 ml/kg-bw/day	7-14 days	Mortality	LD80	Rowe 1972 and 1973 *in* Coppock *et al.* 1995
Calf	sweet crude oil	oral	37 ml/kg-bw/day	immediate	Mortality	LD100	Rowe 1972 and 1973 *in* Coppock *et al.* 1995
Calf	sour crude oil	oral	8.0 ml/kg-bw/day	16-23 days	Mortality	LD100	Rowe 1972 and 1973 *in* Coppock *et al.* 1995
Calf	kerosene	oral	8.0 ml/kg-bw/day	9-23 days	Mortality	LD100	Coppock *et al* . 1995
Cow	weathered oil	oral	7.3 g/kg-bw	26 days	Liver, GI, hematological, neurological effects	LOAEL	Stober 1962 *in* Coppock *et al.* 1995
Cow	**unweathered oil**	**oral**	**2.5 ml/kg-bw/day**	**127 days**	**Liver, GI, hematological, neurological effects**	**LOAEL**	**Stober 1962 in Coppock et al. 1995**
			2,108 mg/kg-bw/day			**LOAEL**	**converted to a dose using Equation 3 in text.**
			211 mg/kg-bw/day			**NOAEL**	**Extrapolated from LOAEL using UF of 10**
Cow	unweathered oil	oral	2.1-4.2 g/kg-bw	26 days	Liver, GI, hematological, neurological effects	LOAEL	Stober 1962 *in* Coppock *et al.* 1995
Cow	Venezuela crude	oral	4.0 mg/kg-bw	26 days	Liver, GI, hematological, neurological effects	LOAEL	Stober 1962 *in* Coppock *et al.* 1995
Cow	bunker "C" oil	oral	>1.1 g/kg-bw/day	26 days	Liver, GI, hematological, neurological effects	LOAEL	Stober 1962 *in* Coppock *et al.* 1995
Rat	**benzene**	**oral**	**357 mg/kg-bw/day**	**84 weeks; 5 days a week**	**Hematological effects and decreased body weight.**	**LOAEL**	**Maltoni et al. 1983 in Stickney et al. 2001**
			35.7 mg/kg-bw/day			**NOAEL**	**Extrapolated from LOAEL using UF of 10**
Mouse	benzene	oral	263.6 mg/kg-bw/day	6-12 days of gestation period	Based on growth and development effects.	LOAEL	Nawrot and Stapels 1979 *in* Sample et al. 1996
			26.36 mg/kg-bw/day			NOAEL	Extrapolated from LOAEL using UF of 10
Mouse	benzene	oral	8 mg/kg-bw/day	28 days	Based on hematological effects.	LOAEL	Hsieh *et al.* 1988 *in* Alberta Environment 2001
			0.8 mg/kg-bw/day			NOAEL	Alberta 2001; extrapolated from LOAEL using UF of 10
Rat	**toluene**	**oral**	**223 mg/kg-bw/day**	**13 weeks; 5 days a weeks**	**Based on hepatic/renal effects.**	**NOAEL**	**NTP 1989 in IRIS/EPA 2003**
Mouse	toluene	oral	260 mg/kg-bw/day	6-12 days of gestation period	Based on growth and development effects.	LOAEL	Nawrot and Stapels 1979 *in* Sample et al. 1996
Rat	toluene	oral	446 mg/kg-bw/day	13 weeks; 5 days a weeks	Based on hepatic/renal effects.	LOAEL	NTP 1989 *in* Alberta Environment 2001
			44.6 mg/kg-bw/day			NOAEL	Alberta 2001; extrapolated from LOAEL using UF of 10
Rat	**ethylbenzene**	**oral**	**291 mg/kg-bw/day**	**182 days**	**Based on hepatic/renal effects.**	**LOAEL**	**Wolf et al., 1956 in IRIS/EPA 2003**
			29.1 mg/kg-bw/day			**NOAEL**	**Extrapolated from LOAEL using UF of 10**

Table 2. Toxicity Studies for Mammals Exposed to Petroleum Hydrocarbons (continued)

Animal	Compound	Route	Final Dose[a]	Duration	Effect	Endpoint	Source
Rat	**xylene**	**oral**	**179 mg/kg-bw/day**	**103 weeks; 5 days/week**	**Based on growth and development effects.**	**NOAEL**	**NTP 1986 in IRIS/EPA 2003**
Mouse	xylene	oral	2.1 mg/kg-bw/day	6-15 days of gestation period	Based on growth and development effects.	NOAEL	Marks et al., 1982 *in* Sample et al., 1996
Rat	xylene	oral	357 mg/kg-bw/day	103 weeks; 5 days/week	Based on growth and development effects.	LOAEL	NTP 1986 *in* Alberta Environment 2001
			35.7 mg/kg-bw/day			NOAEL	Extrapolated from LOAEL using UF of 10
Rat	**naphthalene**	**oral**	**50 mg/kg-bw/day**	**6-15 days of gestation period**	**Increased maternal lethargy and slow breathing**	**LOAEL**	**Navarro et al., 1991**
			5 mg/kg-bw/day			**NOAEL**	**Extrapolated from LOAEL using UF of 10**
Rat	naphthalene	oral	150 mg/kg-bw/day	6-15 days of gestation period	Reduced body weights and reduced water consumption	LOAEL	Navarro et al., 1991
			15 mg/kg-bw/day			NOAEL	Extrapolated from LOAEL using UF of 10
Mouse	**benzo(a)pyrene**	**oral intubation**	**10 mg/kg-bw/day**	**7-16 days of gestation**	**Reduced preganancy rates decreased percentage of viable liter**	**LOAEL**	**MacKenzie and Angevine, 1981**
			1 mg/kg-bw/day			**NOAEL**	**Extrapolated from LOAEL using UF of 10**
Mouse	benzo(a)pyrene	oral intubation	16.67 mg/kg-bw/day	single dose (studied for 8-10 months)	Gastrointentinal papilloma	acute LOAEL	Bock and King, 1981
			0.167 mg/kg-bw/day			chronic NOAEL	Extrapolated from acute LOAEL using UF of 100
Rat	dibenz(a,h)anthracene	injected	0.2 mg/kg-bw/day	15 days	Reduced growth rate and gastroinstestinal effects	acute LOAEL	Haddow et al., 1937
			0.002 mg/kg-bw/day			chronic NOAEL	Extrapolated from acute LOAEL using UF of 100

Note: bolded studies were seleted as approriate to develop toxicity values for livestock.

IRIS	Integrated risk information system	UF	Uncertainty factor.
LD	Lethal dose.	g/kg-bw	Grams per kilogram body weight.
LOAEL	Lowest observable adverse effects level.	mg/kg-bw	Milligrams per kilogram body weight.
NOAEL	No observable adverse effects level.	mg/kg-bw/day	Milligrams per kilogram body weight per day.
NTP	National Toxicology Program.	ml/kg-bw/day	Milliliters per kilogram body weight per day.
		a	After adjustment dosing times.

4.2 Exposure Assumptions

The following sections describe the input parameters used in the dose model (Equation 1) above. Exposure assumptions used in the development of TRVs and RBSLs in this report are presented in Table 1.

4.2.1 Body Weight

Body weights are available in various literature sources. Cattle and other livestock can range in size depending on their production value (e.g., dairy or beef cattle) and age (e.g., calves, growing cattle, finishing cattle, mature cows or bulls), as well as their location (e.g., livestock from third world countries tend to be smaller). In this approach, parameters have been provided for three subsets of the cattle receptor: dairy cattle, beef cattle, and calves. The average cattle body weights were taken from the NRC reports on nutrient requirements for dairy cattle and calves (NRC 2001, 2000).

- Dairy Cattle – Ng *et al.* (1982) cited a 1979 value of 480 kg for dairy cows, noting that individual cows from dairy herds were larger than their proposed value, as mature weights of dairy cattle vary from 400 kg for small breeds to over 680 kg for large breeds (NRC 2001). However, an average value of 540 kg was used in this report.
- Beef Cattle – The Texas Agricultural Extension Service (Lyons *et al.* 1999) cited an estimated average live weight of 454 kg (1,000 lbs) for beef cattle. Other literature values included 230 kg (Stair *et al.* 1995) and 250 kg to 460 kg (Khan *et al.* 1995). The NRC (2000) indicated that the current population of beef cattle in the United States varied considerably in biological type, and slaughter weight ranged from 399 kg to 644 kg. The average steer slaughter weight in 1991 was 542 kg (NRC 2000). The Texas value of 454 kg was used in this report as it fell within the range of all the available values.
- Calves – The average calf body weight used in this report was also from NRC (2000). The range presented was 25 kg to 75 kg for small and large breeds. Other values in the literature were 236 kg (Stickney *et al.* 2001) and 50 kg to 60 kg (Upadhyay and Swarup 1994). The midpoint of the range weights in the NRC (2000), 50 kg, was used for calf body weight.

Sheep and goat body weights were from the values cited by the Texas Agricultural Extension Service (Lyons *et al.* 1999) for sheep (56.7 kg) and Spanish goats (29.5 kg). The sheep body weight used was slightly larger than the only other value identified for sheep, 37.6 kg for ewes (Floris *et al.* 2000). Other values for goats identified in the literature were 12.5 to 13.5 kg (Bose *et al.* 2001) and 31.7 kg (Lyons *et al.* 1999; Angora goats).

Exposures to camels were evaluated to address potential risks to livestock outside of the United States. Body weights can vary depending on the camel type (i.e., dromedary, bactrian, or llamas). An average body weight of 600 kg was used in this report (based on various internet sources; e.g., http://www.arab.net/camels/ and http://www.oaklandzoo.org/atoz/azarabcamel.html and a study by Gihad *et al.* 1989).

Horse body weights can also vary depending on the breed. Environment Canada (1999) cited body weights between 500 kgs and 600 kgs. The mid-point range of 550 kgs was used in this report (Table 1). Other studies have indicated that horse body weights can be estimated in kgs with a simple formula (Ontario Ministry of Agriculture and Food [OMAFRA] 1999*a*) using heartgirth circumference, body length, and an adjustment factor. Horse body weight used in this report were within the range of body weights reported in OMAFRA (1999*a*) and calculated using the formula (i.e., 45.5 kgs to 591 kgs).

4.2.2 Dietary Composition

For screening-level risk assessment purposes, livestock was assumed to obtain all nutrients from forage material. As some receptors, beef cattle in particular, may consume store-bought feed in substantial dietary proportions, this component of the daily dose model (Equation 1) may result in overestimates of risk and may be an area of refinement in secondary tiers of analysis.

4.2.3 Food Ingestion Rate

Conservative food ingestion rates for beef cattle, sheep, and Spanish goats were derived using intake factors from the Texas Agricultural Extension Service (Lyons *et al.* 1999). The daily food intakes as dry matter (i.e., dry weight) for grazers like dairy cattle, beef cattle, and calves, were estimated as 2.5% of their body weight; and for intermediate feeders like sheep and goats, were estimated at 3.5% and 4% of body weights, respectively. The food ingestion rates calculated in dry weight were 13.5, 11.4, 1.25, 1.98. 1.18 kg/day for dairy cattle, beef cattle, calves, sheep, and goats, respectively (Table 1). These values were comparable to other values found in the literature sources. Ng *et al.* (1982) cited values of 10, 10, and 1.6 kg/day dry matter for dairy cattle, beef cattle, and sheep respectively. The International Atomic Energy Agency (IAEA 1994) cited expected (mean) values of 16.1, 7.2, 1.9, 1.3, and 1.3 kg/day for dairy cows, beef cattle, calves, dairy sheep, and dairy goats, respectively.

For camels fed whole hay, a food ingestion rate of 6.07 kg/day dry matter reported by Gihad *et al.* (1989) was used in this report.

Horses generally consume 2.5 % of their body weight in dry matter daily (OMAFRA 1999*b*). The food ingestion rate for horses calculated in dry weight was 13.8 kg/day. Other food ingestion rates reported in literature included 13 kg/day to 25 kg/day (Environment Canada 1999). Note that although horses and cows are grazers, horses can consume up to 70% more forage than cows of similar body size because the difference in their digestion process (Lyons *et al*., 1999).

4.2.4 Incidental Soil Ingestion Rate (*IRsoil*)

Soil ingestion rates (*IRsoil*) were derived by multiplying the literature values of percentage soil found in the diet by the total daily food ingestion rate. Percentages of soil in the diet of dairy cattle, beef cattle, calves, sheep, and goats were from Thornton and Abrahams (1983) and Abrahams and Thornton (19994). An extensive review of the literature sources produced values for cattle soil ingestion that included 2% to 14% (Healy 1968) and 4% to 14% (Fries *et al.* 1982) for dairy cattle; 1.2% to 18.8% for range cattle (Zach and Mayoh 1984); 0.2% to 17.9% (Thornton and Abrahams 1983) for range or beef cattle; maximum recorded value of 17.9% in agricultural cattle (Abrahams and Thornton 1994), and 18.8% for calves and beef cattle (Kennedy and Strenge 1992). The maximum soil dietary percentage of 17.9% (Thornton and Abrahams 1983; Abrahams and Thornton 1994) was used for the generation of conservative threshold values: for dairy cattle and 18.8% (Kennedy and Strenge 1992) was used for calves and beef cattle. The soil dietary percentages resulted in the following values for incidental soil ingestion rates (in dry weight): 2.42 kg/day for dairy cattle, 2.13 kg/day for beef cattle, and 0.235 kg/day for calves. Literature values for incidental soil ingestion rates for cattle were similar and included 0.5 kg/day to 1.2 kg/day with a high of 2.2 kg/day (Zach and Mayoh 1984), 0.72 kg/day to 2.56 kg/day (Fries *et al.,* 1982), 0.1 kg/day to 1.5 kg/day (Mayland *et al.* 1977), 0.1 kg/day to 0.72 kg/day (McKone and Ryan 1989), and 0.4 kg/day (McKone 1994).

The only soil intake value identified in the literature for sheep was an upper-end estimate of 30% of dietary intake (Thornton and Abrahams 1983) that resulted in an incidental soil ingestion rate of 0.595 kg/day. Values were unavailable for goats, therefore, the percent soil intake was extrapolated to goats, assuming similar food consumption rates and grazing behavior which resulted in an incidental soil ingestion rate (in dry weight) of 0.354 kg/day.

Soil ingestion rates for camels could not be found. Camels tend to eat plants and other items found in the desert terrain. As a result, it can be assumed that camels may consume significant quantities of sand/soil. To be conservative, the percent of soil ingested by camels was assumed to be the maximum percent soil ingested of all the livestock receptors (i.e., sheep). Therefore, a calculated soil ingestion rate (in dry weight) of 1.82 kg/day for camels was used in this report.

Soil ingestion rates could not be found for horses. As explained earlier, horses tend to digest food rapidly. Horses may consume more food than cows of similar size and, subsequently, may consume more soil. Therefore, conservatively, the percent of soil ingested by horses was assumed to be the maximum percent soil ingested of all the livestock receptors (i.e. sheep; Table 1). The calculated soil ingestion rate (in dry weight) of 4.13 kg/day for horses was used in this report.

4.2.5 Water Ingestion Rate (*IRwater*)

Water ingestion rates for dairy cattle, beef cattle, calves, and sheep were taken from estimates provided by Agriculture and Agri-food Canada (2002). Values varied seasonally, and for this reason, summer and winter estimates are provided. These values (summer/winter) were as follows: 95/77 L/day for dairy cattle; 86/55 L/day for beef cattle (finishing cattle); 36/23 L/day for calves; and 14/3.6 L/day for sheep. For goats, the daily water intake was 10/5 L/day from IAEA (1994). Additional ranges presented in the literature included 50 L/day to 100 L/day for dairy cattle, 20 L/day to 60 L/day for beef cattle, 5 L/day to 15 L/day for calves, 5 L/day to 8 L/day for sheep (IAEA 1994), 56.8 L/day for cattle (Fairies *et al.* 1998), and up to 100 L/day for cattle (CCME 2000).

For camels, one study (Gihad *et al.* 1989) on the daily water ingestion rates reported 16.5 L/day which was used in this report (no specific summer and winter drinking water intakes were available). Note that camels can go for days without drinking water (maximum of 1 month) and can drink large volumes of water at one time.

Daily water intake for horses were reported in Environment Canada (1999) and ranged from 15 L/day to 42 L/day. As no specific summer and winter water intake rates were available for horses, the lower limit of the range (i.e., 15 L/day) was used as the winter water ingestion rate and the upper end of the range (i.e., 42 L/day) was used as the summer water ingestion rate.

4.2.6 Site Use Factor (SUF)

The SUF represents the fraction of the exposure area for the receptor represented by the contamination area and is a unitless factor generally calculated by dividing the contamination area by the home or foraging range of the receptor. Because any evaluation of risk to livestock would be focused on protecting a particular population or herd, the effective grazing area of the herd in question would substitute for the home range and this value would be site specific. The RBSLs presented herein were calculated assuming a default SUF of 1 (i.e., the contamination area is as large as the effective grazing area) for exposure via each of the significant exposure pathways (i.e., SUF for exposure via drinking water ingestion and SUF via incidental soil ingestion). As mentioned earlier, the size of the contaminated area is an important factor in determining the overall need to conduct a risk assessment.

4.3 Effects Assessment

The assessment endpoints used in developing TRVs were based on survival, reproductive, development and growth endpoints of the herd community. The measurement endpoints used to quantify the assessment endpoints were preferably based on chronic no-observable adverse effect levels (NOAELs). For unavailable or unreported NOAELs, the lowest-observable adverse effects levels (LOAELs) were extrapolated to develop NOAELs using an uncertainty factor of 10 following EPA guidelines (EPA 1999):

$$chronicNOAEL = \frac{chronicLOAEL}{UF} \qquad \text{Equation 2}$$

Where:

chronicLOAEL	=	chronic lowest observable adverse effects level in milligrams per kilogram body weight per day (mg/kg-bw/day)
chronicNOAEL	=	chronic no-observable adverse effects level in milligrams per kilogram body weight per day (mg/kg-bw/day)
UF	=	uncertainty factor = 10; unitless

Two of the complete and potentially significant exposure pathways identified in the CSM (Figure 1) for livestock included incidental soil ingestion and drinking water ingestion. Minor exposure pathways included dermal contact and inhalation, which do not contribute significantly to overall exposure. Therefore, drinking water and soil RBSLs were developed for the protection of livestock from exposure to petroleum hydrocarbons, including crude oil, BTEX, and PAHs based on the exposure assumptions described above and presented in Table 1, and using TRVs which are discussed below.

4.4 Crude Oil

TRVs and RBSLs developed for livestock receptors exposed to whole crude oil are described below and presented in Table 3.

4.4.1 Development of Crude Oil TRVs for Livestock

Toxicity studies available for crude oil effects on livestock are summarized in Table 2. Most of the toxicity endpoints in the studies listed in Table 2 were based on lethal endpoints. However, a study conducted by Stober in 1962 evaluated sublethal toxicity endpoints and therefore, was selected to develop TRVs for this report. The toxicity endpoints in Stober's study were based on chronic LOAELs for fresh and weathered crude oil in cattle, particularly on altered rumen function, loss of appetite, decreased liver function, increased eosinophil (i.e. a type of white blood cell) number, hypomagnesemia (which can lead to heart and kidney problems), apathy, and emaciation.

The crude oil TRV for the protection of livestock was based on a toxicity test performed on a 4-month-old cow administered fresh (i.e., unweathered) crude oil in its diet for a 127-day treatment period (Stober 1962). The chronic LOAEL was reported as 2.5 ml/kg-bw/day (Stober 1962 as cited *in* Coppock *et al.* 1995) which was converted into a dose expression using the specific gravity value reported (Stober 1962) as follows:

$$chronicLOAEL(\text{ml/kg} - \text{bw/day}) \times \text{sg(g/ml)} \times 1000 = chronicLOAEL(\text{mg/kg} - \text{bw/day}) \qquad \text{Equation 3}$$

Where:

chronicLOAEL	=	chronic lowest observable adverse effects level
sg	=	specific gravity of fresh crude oil = 0.843 g/ml
1,000	=	conversion factor for grams to kilograms
ml/kg-bw/day	=	milliliters per kilogram body weight per day
mg/kg-bw/day	=	milligrams per kilogram body weight per day
g/ml	=	grams per milliliter.

Based on Equation 3, the chronic LOAEL for fresh crude oil (unweathered) was 2,108 mg/kg-bw/day, which was extrapolated to a chronic NOAEL using Equation 2 resulting in a TRV of 211 mg/kg-bw/day. As shown in Table 3, this TRV of 211 mg/kg-bw/day for whole fresh crude oil was used to develop RBSLs for all types of livestock.

In recent studies, subchronic effects of crude oil on cattle (Dziwenka *et al,* 2002) and sheep (Coppock *et al*. 2002) were reported. In these studies, cattle and sheep were orally administered crude oil at doses that were similar or higher than those listed in Table 2. It can be assumed that toxicity values developed, based on these recent studies, would be similar or less conservative than the values developed in this report (i.e., based on Stober's [1962] study). Therefore, crude oil TRV for livestock based on Stober's study (1962) is used in this report.

Table 3. Whole Fresh Crude Oil TRVs and RBSLs for Livestock

			Drinking Water Exposure		Soil Exposure	
Receptor	BW (kg)	TRV (mg/kg bw/day)	IR_{water} (L/day)	dw-RBSL (mg/L)	IR_{soil} (kg/day)	soil-RBSL (mg/kg)
Dairy Cattle	540	211	95.0	1,199	2.42	47,151
Beef Cattle	454	211	86.0	1,114	2.13	44,894
Calves	50.0	211	36.0	293	0.235	44,894
Sheep	56.7	211	14.0	855	0.595	20,095
Goat	29.5	211	10.0	622	0.354	17,583
Camel	600	211	16.5	7,673	1.82	69,522
Horses	550	211	42.0	2,763	4.13	28,133

Note:

dw-RBSL = $(TRV \times BW) / IR_{water}$

soil-RBSL = $(TRV \times BW) / IR_{soil}$

Where:

dw-RBSL	Drinking water risk-based screening level.
soil-RBSL	Soil risk-based screening level.
TRV	Toxicity reference value.
BW	Body weight; from Table 1.
IR_{water}	Water ingestion rate during summer; from Table 1.
IR_{soil}	Soil ingestion rate; from Table 1.
kg	Kilograms.
L/day	Liters per day.
mg/L	Milligrams per liter.
mg/kg	Milligrams per kilogram.
mg/kg bw/day	Milligrams per kilogram body weight per day.

4.4.2 Development of Crude Oil Drinking Water RBSLs and Soil RBSLs for Livestock

Livestock screening levels are risk-based and are developed based on the standard hazard quotient (HQ) equation used for estimating risks to human health and other ecological receptors (EPA 1997).

$$HQ = \frac{Dose}{TRV} \qquad \text{Equation 4a}$$

Substituting Equation 1 for "*Dose*" in Equation 4a:

$$HQ = \frac{\left[(IRsoil \times Csoil) + (IRwater \times Cwater)\right] \times SUF}{BW \times \ TRV} \qquad \text{Equation 4b}$$

or

$$HQ = \frac{(IR \times C) \times SUF}{BW \times TRV} \qquad \text{Equation 4c}$$

To calculate RBSLs for a single media (i.e., drinking water or soil), Equation 4c was rearranged as shown in Equations 5a and 5b. Instead of estimating a HQ associated with a chemical concentration in water or soil using the toxicity and exposure assumptions presented in Table 1, Equations 5a and 5b estimated a protective drinking water or soil concentration associated with a target HQ of 1.

Assuming target HQ = 1; SUF = 1; and rearranging Equation 4c, "*C*" becomes defined as the corresponding RBSL.

Drinking water-RBSLs for livestock were calculated using the following equation:

$$dwRBSL = \frac{1 \times BW \times TRV}{IRwater} \qquad \text{Equation 5a}$$

Where:

1	=	target hazard quotient; unitless
dwRBSL	=	drinking water RBSL in milligrams per liter (mg/L)
IRwater	=	water ingestion rate in liters per day (L/day); to be conservative, the summer *IRwater* value from Table 1 is used.
BW	=	Body weight in kilograms (kg)
TRV	=	Toxicity reference value in milligrams per kilogram body weight per day (mg/kg-bw/day)

Incidental soil ingestion RBSLs for livestock were calculated using the following equation:

$$soilRBSL = \frac{1 \times BW \times TRV}{IRsoil} \qquad \text{Equation 5b}$$

Where:

1	=	target hazard quotient; unitless
soilRBSL	=	soil RBSL in milligrams per kilogram dry weight (mg/kg)
IRsoil	=	soil ingestion rate in kilograms per day (kg/day)
BW	=	body weight in kilograms (kg)
TRV	=	toxicity reference value in milligrams per kilogram body weight per day (mg/kg-bw/day)

Based on the equations above and the TRV developed for whole fresh crude oil, drinking water RBSLs and soil RBSLs were calculated for a variety of livestock receptors and presented in Table 3. Drinking water RBSLs ranged from 293 mg/L (calves) to 7,673 mg/L (camels) and soil RBSLs ranged from 17,583 mg/kg (goats) to 69,522 mg/kg (camels).

In a screening-level risk assessment for a site, these RBSLs can be directly compared to crude oil concentrations, generally expressed as total petroleum hydrocarbon (TPH), at that site. Because the TRV for crude oil was developed based on whole fresh or unweathered crude oil, and weathered crude oil is generally less toxic (United States Fish and Wildlife Service [USFWS] 1998), TRVs and RBSLs for unweathered crude oil can be used for evaluating fresh spills and can be considered a conservative screening value for weathered spills.

4.5 Benzene, Toluene, Ethylbenzene, and Xylene (BTEX)

TRVs and RBSLs developed for livestock receptors exposed to BTEX are described below and presented in Tables 4 and 5.

4.5.1 Development of BTEX TRVs for Livestock

BTEX toxicity values were unavailable in literature for livestock. However, BTEX toxicity values were available for small mammals and are presented in Table 2. BTEX TRVs for livestock were developed based on small mammal toxicity studies and extrapolated to a dose that would be protective of livestock. In this report, where available, toxicity studies reported in EPA's Integrated Risk Information System (EPA/IRIS 2003) were used to develop TRVs for BTEX.

Benzene: The TRV for benzene was based on a toxicity study conducted by Maltoni *et al.* in 1983 (as cited *in* Stickney *et al.* 2001) where rats were administered oral doses of benzene 5 times a week for 84 weeks. The chronic LOAEL reported was 500 mg/kg-bw/day (NOAEL was not available) based on hematological effects and changes in body weight in the rats. The chronic LOAEL was adjusted for the dosing schedule (i.e., 5 days a week), which resulted in a value of 357 mg/kg-bw/day. To develop benzene TRVs for this report, the chronic LOAEL reported above was extrapolated to a chronic NOAEL using Equation 2 and resulted in a value of 35.7 mg/kg-bw/day. A significant difference in body weight between the test-species (e.g., rat weighing 0.35 kg; from Sample *et al.* 1996) and livestock requiring a scaling factor to allometrically adjust for the difference in body weights (Sample 1996; EFA 1998) following Equation 6 below (Sample and Arenal 1999). The calculated benzene TRVs for livestock based on chronic NOAELs are presented in Table 4 and range from 5.55 mg/kg-bw/day (camels) to 11.8 mg/kg-bw/day (goats).

$$SF = \left(\frac{BWtestspecies}{BWlivestock}\right)^{1/4}$$ Equation 6

Where:

SF	=	scaling factor (unitless)
BWtest species	=	body weight of test species in kilograms (kg)
BWlivestock	=	body weight of livestock receptor in kilograms (kg)

Toluene: The TRV for toluene was based on a toxicity study conducted by the National Toxicology Program (NTP) in 1989 (as cited *in* EPA/IRIS 2003). Rats were administered oral doses of toluene 5 times a week for 13 weeks. The chronic NOAEL reported was 312 mg/kg-bw/day based on liver and kidney changes in male rats, and was further adjusted for the dosing schedule. This resulted in a value reported as 223 mg/kg-bw/day (a LOAEL of 625 mg/kg-bw/day was also reported in this study). To develop toluene TRVs for this report, the chronic NOAEL reported above was adjusted for differences in body weight between rats and livestock using Equation 6. The calculated toluene TRVs for livestock are shown in Table 4 and range from 34.6 mg/kg-bw/day (camels) to 73.6 mg/kg-bw/day (goats).

Ethylbenzene: The TRV for ethylbenzene was based on a toxicity study conducted by Wolf *et al.* in 1956 (as cited *in* EPA/IRIS 2003). Rats were administered oral doses of ethylbenzene 5 days a week for 182 days. The chronic LOAEL reported was 408 mg/kg-bw/day (NOAEL was not available) based on histopathologic changes in liver and kidney in rats and was further adjusted for the dosing schedule, resulting in a value reported as 291 mg/kg-bw/day. To develop ethylbenzene TRVs for this report, the chronic LOAEL reported above was extrapolated to a chronic NOAEL using Equation 2 resulting in a value of 29.1 mg/kg-bw/day which was further adjusted for differences in body weight between rats and livestock using Equation 6. The calculated ethylbenzene TRVs for livestock are presented in Table 4 and range from 4.53 mg/kg-bw/day (camels) to 9.62 mg/kg-bw/day (goats).

Xylene: The TRV for xylene was based on a toxicity study conducted by NTP in 1986 (as cited *in* EPA/IRIS 2003). Rats were administered oral doses of xylene 5 times a week for 103 weeks. The chronic NOAEL reported was 250 mg/kg-bw/day (a LOAEL of 500 mg/kg-bw/day was also reported in this study) based on decreased body weight and decreased survival and was further adjusted for the dosing schedule resulting in a value reported as 179 mg/kg-bw/day. To develop xylene TRVs for this report, the chronic NOAEL reported above was further adjusted for differences in body weight between rats and livestock using Equation 6. The calculated xylene TRVs for livestock are presented in Table 4 and range from 27.8 mg/kg-bw/day (camels) to 58.9 mg/kg-bw/day (goats).

Table 4. Benzene, Toluene, Ethylbenzene, and Xylene (BTEX) TRVs for Livestock

	Test Species								Livestock TRVs (mg/kg-bw/day)						
								Receptor:	Dairy Cattle	Beef Cattle	Calves	Sheep	Goat	Camel	Horse
	Endpoint		Adjustments[a]	Adjusted Endpoint	NOAEL	$BW_{test\ species}$		$BW_{livestock}$ (kg):	540	454	50.0	56.7	29.5	600	550
Chemical	(mg/kg-bw/day)		(unitless)	(mg/kg-bw/day)	(mg/kg-bw/day)	(kg)	Study	SF (unitless):	0.16	0.17	0.29	0.28	0.33	0.16	0.16
Benzene	500	LOAEL	0.714	357	35.7	0.350	b		5.70	5.95	10.3	10.0	11.8	5.55	5.67
	NA	NOAEL	--	--	--	--			--	--	--	--	--	--	--
Toluene	625	LOAEL	--	--	--	--			--	--	--	--	--	--	--
	312	NOAEL	0.714	223	223	0.350	c		35.6	37.1	64.5	62.5	73.6	34.6	35.4
Ethylbenzene	408	LOAEL	0.714	291	29.1	0.350	d		4.65	4.86	8.43	8.17	9.62	4.53	4.63
	NA	NOAEL	--	--	--	--			--	--	--	--	--	--	--
Xylene	500	LOAEL	--	--	--	--			--	--	--	--	--	--	--
	250	NOAEL	0.714	179	179	0.350	e		28.5	29.8	51.7	50.1	58.9	27.8	28.4

Note:
TRV for Livestock = NOAEL * SF

Where:

TRV	Toxicity reference value
NOAEL	No observable adverse effect level.
SF	Scaling factor; from Sample and Arenal 1999 = $(BW_{test\ species} / BW_{livestock})^{1/4}$
$BW_{livestock}$	Body weight for livestock; from Table 1
$BW_{test\ species}$	Body weight for test species (i.e. rat); from Sample et al., 1996.
kg	Kilograms.
mg/kg-bw/day	Milligrams per kilogram body weight per day.
BTEX	Benzene, Toluene, Ethylbezene, and Xylene.
LOAEL	Lowest observable adverse effect level.
NA	Not available.
--	Not applicable.

a Adjusting for dosing schedule of 5 days per week (i.e. 5/7 = 0.71).
b Maltoni *et al.* 1983 *in* Stickney *et al.* 2001; from Table 2.
c NTP 1989 *in* IRIS/EPA 2003; from Table 2.
d Wolf et al., 1956 *in* IRIS/EPA 2003; from Table 2.
e NTP 1986 *in* IRIS/EPA 2003; from Table 2.

4.5.2 Development of BTEX Drinking Water RBSLs and Soil RBSLs for Livestock

BTEX RBSLs for the protection of livestock were developed using the same approach as described earlier for crude oil RBSLs (Section 3.4.1). BTEX drinking water RBSLs were developed using Equation 5a and BTEX soil RBSLs were developed using Equation 5b for livestock. The calculated RBSLs are presented in Table 5. Drinking water RBSLs ranged from 14.3 mg/L (calves) to 202 mg/L (camels) for benzene; from 89.5 mg/L (calves) to 1,259 mg/L (camels) for toluene; from 11.7 mg/L (calves) to 165 mg/L (camels) for ethylbenzene; and from 71.7 mg/L (calves) to 1,009 mg/L (camels) for xylene. Soil RBSLs ranged from 756 mg/kg (horses) to 2,198 mg/kg (calves) for benzene; from 4,719 mg/kg (horses) to 13,715 mg/kg (calves) for toluene; from 617 mg/kg (horses) to 1,794 mg/kg (calves) for ethylbenzene; and from 3,782 mg/kg (horses) to 10,990 mg/kg (calves) for xylene.

4.6 Polycyclic Aromatic Hydrocarbons (PAHs)

TRVs and RBSLs developed for livestock receptors exposed to PAHs are described below and presented in Tables 6 and 7.

4.6.1 Development of PAH TRVs for Livestock

Toxicity values were available for PAHs for livestock. However, PAH TRVs for small mammals were available and are shown in Table 6. Similar to BTEX, PAH TRVs for livestock were developed based on small mammal toxicity values (Table 2) extrapolated to a dose that would be protective of livestock. PAH toxicity studies on small mammals were reviewed and appropriate studies were selected to develop TRVs for livestock. The limited availability of suitable data allowed for the selection of only two TRVs, one for low molecular weight (LMW) PAHs and one for high molecular weight (HMW) PAHs. LMW PAHs are defined as PAHs with less than or equal to 3 rings and with molecular weight less than or equal to 192 atomic mass units (amu) (National Oceanic and Atmospheric Administration [NOAA] 2000). Parent LMW PAHs include naphthalene, acenaphthylene, acenaphthene, fluorene, anthracene, and phenanthrene. HMW PAHs are defined as PAHs with greater than or equal to 4 rings and with molecular weight greater than or equal to 202 amu (NOAA 2000). Parent HMW PAHs include pyrene, fluoranthene, benz(a)anthracene, chrysene, benzo(a)pyrene, perylene, benzo(e)pyrene, benzo(b) fluoranthene, benzo(j)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, indeno(1,2,3-cd)pyrene, and dibenz(a,h)anthracene.

The TRV for LMW PAHs was based on a toxicity study conducted by Navarro *et al.* in 1991. Rats were administered oral doses of naphthalene during 6 to15 days of gestation. The chronic LOAEL was calculated as 50 mg/kg-bw/day based on increased maternal lethargy and slow breathing in rats. To develop LMW PAH TRVs for this report, the chronic LOAEL was extrapolated to a chronic NOAEL using Equation 2 which resulted in a value of 5 mg/kg-bw/day; this was further adjusted for differences in body weight between rats and livestock using Equation 6. The calculated LMW PAH TRVs for livestock are shown in Table 6 and range from 0.777 mg/kg-bw/day (camels) to 1.65 mg/kg-bw/day (goats). Of all the LMW PAHs, naphthalene is considered the most toxic to mammals. Therefore, risks estimated for livestock exposed to other LMW PAHs at a site using the LMW PAH TRV developed in this report would be considered conservative.

Table 5. Benzene, Toluene, Ethylbenzene, and Xylene (BTEX) TRVs and RBSLs for Livestock

		TRV (mg/kg-bw/day)				Drinking Water Exposure					Soil Exposure				
	BW					IR_{water}	dw-RBSL (mg/L)				IR_{soil}	soil-RBSL (mg/kg)			
Receptor	(kg)	Benzene	Toluene	Ethylbenzene	Xylene	(L/day)	Benzene	Toluene	Ethylbenzene	Xylene	(kg/day)	Benzene	Toluene	Ethylbenzene	Xylene
Dairy Cattle	540	5.70	35.6	4.65	28.5	95.0	32.4	202	26.4	162	2.42	1,273	7,946	1,039	6,367
Beef Cattle	454	5.95	37.1	4.86	29.8	86.0	31.4	196	25.6	157	2.13	1,266	7,901	1,033	6,331
Calves	50.0	10.3	64.5	8.43	51.7	36.0	14.3	89.5	11.7	71.7	0.235	2,198	13,715	1,794	10,990
Sheep	56.7	10.0	62.5	8.17	50.1	14.0	40.5	253	33.1	203	0.595	953	5,949	778	4,767
Goat	29.5	11.8	73.6	9.62	58.9	10.0	34.8	217	28.4	174	0.354	982	6,129	802	4,911
Camel	600	5.55	34.6	4.53	27.8	16.5	202	1,259	165	1,009	1.82	1,829	11,412	1,492	9,144
Horse	550	5.67	35.4	4.63	28.4	42.0	74.3	464	60.6	371	4.13	756	4,719	617	3,782

Note:

dw-RBSL = (TRV X BW) / IR_{water}

soil-RBSL = (TRV X BW) / IR_{soil}

Where:

dw-RBSL	Drinking water risk-based screening level.
soil-RBSL	Soil risk-based screening level.
TRV	Toxicity reference value.
BW	Body weight; from Table 1.
IR_{water}	Water ingestion rate during summer; from Table 1.
IR_{soil}	Soil ingestion rate; from Table 1.
kg	Kilograms.
L/day	Liters per day.
mg/L	Milligrams per liter.
mg/kg	Milligrams per kilogram.
mg/kg bw/day	Milligrams per kilogram body weight per day.

The TRV for HMW PAHs was based on a toxicity study conducted by MacKenzie and Angevine in 1981. Mice were administered oral doses of benzo(a)pyrene during 7 to16 days of gestation. The chronic LOAEL was calculated as 10 mg/kg-bw/day based on reduced pregnancy rates and decreased percentage of viable mice liter. To develop HMW PAH TRVs for this report, the chronic LOAEL was extrapolated to a chronic NOAEL using Equation 2 and resulted in a value of 1 mg/kg-bw/day. This chronic NOAEL was further adjusted for differences in body weight between mice (0.03 kg; from Sample *et al.,* 1996) and livestock using Equation 5. The calculated HMW PAH TRVs for livestock are presented in Table 6 and range from 0.155 mg/kg-bw/day (camels) to 0.330 mg/kg-bw/day (goats).

4.6.2 Development of PAH Drinking Water RBSLs and Soil RBSLs for Livestock

PAH RBSLs for the protection of livestock were developed using the same approach as crude oil RBSLs described earlier (Section 3.4.1). PAH drinking water RBSLs were developed using Equation 5a and PAH soil RBSLs were developed using Equation 5b for livestock. The calculated RBSLs are shown in Table 7. Drinking water RBSLs ranged from 2.01 mg/L (calves) to 28.3 mg/L (camels) for LMW PAHs and from 0.402 mg/L (calves) to 5.65 mg/L (camels) for HMW PAHs. Soil RBSLs ranged from 106 mg/kg (horses) to 308 mg/kg (calves) for LMW PAHs and from 21.2 mg/kg (horses) to 61.5 mg/kg (calves) for HMW PAHs.

As LMW PAH RBSLs were developed based on the LMW PAH TRV which was based on naphthalene (one of the most toxic of all the LMW PAHs to mammals), risks estimated for livestock exposed to other LMW PAHs at a site using the RBSLs developed in this report for LMW PAH would be considered conservative.

Table 6. Polycyclic Aromatic Hydrocarbon (PAH) TRVs for Livestock

	Test Species					Receptor:	Livestock TRVs (mg/kg-bw/day)						
							Dairy Cattle	Beef Cattle	Calves	Sheep	Goat	Camel	Horse
	LOAEL	UF	NOAEL	$BW_{test\ species}$		$BW_{livestock}$ (kg):	540	454	50.0	56.7	29.5	600	550
Chemical	(mg/kg-bw/day)	(unitless)	(mg/kg-bw/day)	(kg)	Study	SF (unitless):	0.16	0.17	0.29	0.28	0.33	0.16	0.16
LMW PAH	50	10	5	0.35	[a]		0.798	0.833	1.45	1.40	1.65	0.777	0.794
HMW PAH	10	10	1	0.03	[b]		0.160	0.167	0.289	0.280	0.330	0.155	0.159

Note:
TRV for Livestock = NOAEL from test species* SF for livestock

Where:

TRV	Toxicity reference value
NOAEL	No observable adverse effect level.
SF	Scaling factor; from Sample and Arenal 1999 = $(BW_{test\ species}/ BW_{livestock})^{1/4}$
$BW_{livestock}$	Body weight for livestock; from Table 1 and
$BW_{test\ species}$	Body weight for test species; from Sample et al., 1996.
kg	Kilograms.
mg/kg-bw/day	Milligrams per kilogram body weight per day.
HMW PAH	High molecular weight polycyclic aromatic hydrocarbon; HMW PAHs have ≥ 4 rings and molecular weight ≥ 202 atomic mass units (pyrene to dibenz(a,h)anthracene).
LOAEL	Lowest observable adverse effect level.
LMW PAH	Low molecular weight polycyclic aromatic hydrocarbon; LMW PAHs have ≤ 3 rings and molecular weight 192 atomic mass units (napthalene to phenanthrene).
UF	Uncertainty factor to extrapolate from LOAEL to NOAEL
[a]	Navarro *et al.* 1991; For nphthalne from Table 2.
[b]	McKenzie and Angevine 1981; For benzo(a)pyrene) from Table 2.

Table 7. Polycyclic Aromatic Hydrocarbon (PAH) TRVs and RBSLs for Livestock

Receptor	BW (kg)	TRV (mg/kg-bw/day)		Drinking Water Exposure			Soil Exposure		
				IR_{water} (L/day)	dw-RBSL (mg/L)		IR_{soil} (kg/day)	soil-RBSL (mg/kg)	
		LMW PAH	HMW PAH		LMW PAH	HMW PAH		LMW PAH	HMW PAH
Dairy Cattle	540	0.798	0.160	95.0	4.53	0.907	2.42	178	35.7
Beef Cattle	454	0.833	0.167	86.0	4.40	0.880	2.13	177	35.5
Calves	50.0	1.45	0.289	36.0	2.01	0.402	0.235	308	61.5
Sheep	56.7	1.40	0.280	14.0	5.68	1.14	0.595	133	26.7
Goat	29.5	1.65	0.330	10.0	4.87	0.974	0.354	138	27.5
Camel	600	0.777	0.155	16.5	28.3	5.65	1.82	256	51.2
Horse	550	0.794	0.159	42.0	10.4	2.08	4.13	106	21.2

Note:
dw-RBSL = (TRV X BW) / IR_{water}
soil-RBSL = (TRV X BW) / IR_{soil}

Where:

dw-RBSL Drinking water risk-based screening level.
soil-RBSL Soil risk-based screening level.
TRV Toxicity reference value.
BW Body weight; from Table 1.
IR_{water} Water ingestion rate during summer; from Table 1.
IR_{soil} Soil ingestion rate; from Table 1.
HMW PAH High molecular weight polycyclic aromatic hydrocarbon; HMW PAHs have ≥ 4 rings and molecular weight ≥ 202 atomic mass units (pyrene to dibenz(a,h)anthracene).
LMW PAH Low molecular weight polycyclic aromatic hydrocarbon; LMW PAHs have ≤ 3 rings and molecular weight 192 atomic mass units (napthalene to phenanthrene).
kg Kilograms.
L/day Liters per day.
mg/L Milligrams per liter.
mg/kg Milligrams per kilogram.
mg/kg bw/day Milligrams per kilogram body weight per day.

5. Uncertainty Analysis

Uncertainty plays an important role in risk-based decision-making and needs to be incorporated explicitly into risk characterization. Identifying known sources of uncertainty is more useful than using conservative default assumptions because potential error is made more explicit in the risk management process (Suter, 1993).

The TRVs and RBSLs developed in this report were based on a general approach. Various conservative assumptions were made and may have overestimated the threshold values for the protection of livestock. The following assumptions, uncertainties, and safety factors were made or used in the development of TRVs and RBSLs:

5.1 Exposure Assumptions

Most of the exposure assumptions (Table 1) were based on conservative values from available literature sources. For example, for the composition of livestock diet, maximum soil percentages were selected from all available values which subsequently resulted in high soil ingestion rates.

For livestock receptors where exposure parameters were not available, the most conservative value from the other livestock receptors were used. For example, percentage of soil in the diet of camels and horses were based on the percentage of soil in the sheep diet and was the most conservative value.

Similarly, when calculating drinking water RBSLs for livestock, summer drinking water estimates were used (higher value) instead of the winter drinking water estimates (lower value).

Another conservative assumption made was the use of SUF for both complete and significant exposure pathways (i.e., via drinking water and incidental soil ingestion). SUFs for calculating drinking water RBSL and soil RBSL were set at a value of 1 assuming that the livestock receptor will be present at the contaminated site 100% of the time and feeding exclusively on that particular contaminated site media (i.e., water or soil). In cases where the contamination area, such as from leaks, are smaller than the grazing area of the livestock receptors, an SUF of 1 overestimates the threshold values for the protection of livestock.

5.2 Development of TRVs and RBSLs

Factors such as UFs (Equation 2) and SFs (Equation 6) were used in the development of some of the TRVs for livestock and also contribute to the conservative approach used in this report.

For the protection of livestock, TRVs were developed based on chronic NOAELs. For unavailable NOAELs, LOAELs were extrapolated to NOAELs using an UF of 10 (EPA 1999). Note that toxicity studies for only two of the petroleum hydrocarbons (toluene and xylene) report NOAELs as endpoints. The rest of the petroleum hydrocarbons (crude oil, benzene, ethylbenzene, LMW PAH, and HMW PAH) reported LOAELs as endpoints.

Additionally, due to the lack of toxicity studies available for livestock, TRVs for all the petroleum hydrocarbons except crude oil were developed based on toxicity studies on small mammals. A SF was used to allometrically adjust for the difference in body weight between the test species and the livestock receptors.

For crude oil and LMW PAHs, the TRVs and RBSLs were developed based on more toxic test chemicals, unweathered whole crude oil and naphthalene, respectively. Risks estimated for livestock exposed to weathered crude oil or other LMW PAHs using the TRVs and RBSLs developed in this report for these petroleum hydrocarbons would be considered conservative.

The conservative approach used in this report was confirmed in an external peer-review by Dr. Billy R. Clay (MS, DVM; from the American Board of Veterinary Toxicology), stating specifically that the body weight of calves that may be potentially exposed to petroleum hydrocarbons would weigh more than 50 kgs thereby suggesting that 100 kgs would be more appropriate. Additionally, he stated that water ingestion rates used in this report were also quite high for cattle, thereby suggesting that 50 L/day – 60 L/day would be more appropriate (Clay 2003).

6. Analysis of Other Guidelines for Livestock Protection

TRVs and drinking water and soil quality guidelines (i.e. threshold values) for the protection of livestock exposed to petroleum compounds have been developed by two agencies—Canadian Council of Ministers of the Environment (CCME) and Alberta Environment—which are briefly described below. However, there were some limitations and differences in the development of these guidelines from the threshold values developed in this report and are also described below.

6.1 Canada-Wide Standards (CWS; CCME 2000)

The CWS for petroleum hydrocarbons present TRVs (referred to as *Daily Threshold Effects Dose* or DTED) and drinking water RBSLs (referred to as *Reference Concentration* or RfC) for 4 fractions of crude oil (CCME 2000). These guidelines present levels considered protective of human and environmental health under 4 generic land uses: agricultural, residential, commercial, and industrial. TRVs for livestock were also developed based on Stober's (1962) study resulting in value of 210 mg/kg-bw/day similar to the approach described in this report. Drinking water RBSLs were developed using an equation similar to Equation 5a and resulted in a value of 23 mg/L. Values were only presented for the lighter fractions, recognizing that heavier fractions would bind to soil and not migrate to groundwater/surface water. Direct contact, plant ingestion, and inhalation pathways were not addressed by CCME. These toxicity values and guidelines are presented in Table 8.

Differences/Limitations:

- Only TRVs and drinking water RBSLs for livestock were developed and not soil RBSLs.
- Threshold values were not developed for BTEX and PAHs.
- Threshold values were developed for only one livestock receptor (i.e. cattle).
- One element of their approach was the inclusion of an allocation factor (AF) of 0.2 to adjust toxicity and guideline values. This value was used to account for multiple exposure pathways and media exposure (air, soil, water, food, and consumer products) that could be complete at a given site, whereas the guideline values are for single pathways. The AF of 0.2 assumed that livestock can be equally exposed by all 5 potentially complete exposure pathways. However, as discussed in the sections above on the CSM, dermal and inhalation pathways are expected to be minor and not contribute significantly to overall exposure. Additionally, not all sites will have both water and soil exposures. Therefore, for a general approach an AF of 1 would be appropriate with suggestion to use site-specific AFs as warranted to evaluate multiple exposure pathways.
- The fractionation approach by CCME is not necessarily applicable or appropriate at all sites. In this report, a toxicity value was developed for whole (i.e. fresh) crude oil. As fresh crude oil is more toxic than weathered oil, these values can be considered conservative screening values for weathered products.
- It should be noted that there was an order of magnitude error in calculating the RfC value by CCME and the RFC value should actually be 231 mg/L (this error was acknowledged by CCME; personal communication with Ted Nason, September 10, 2002).

6.2 Alberta Environment (2001)

In 2001, Alberta Environment issued a document that set water RBSLs (referred to as *watering guidelines*) and soil RBSLs (referred to as *soil quality guidelines* or SQG) for petroleum hydrocarbons (crude oil fractions and BTEX) considered to be protective of livestock health (Alberta Environment

2001*a;* 2001*b*). Crude oil TRVs for livestock were not developed specifically for this document but were adopted from CCME (as described above). For BTEX, TRVs were developed using an approach similar to that described in this report based on effects in laboratory animals adjusted by an uncertainty factor. Soil and water RBSLs for crude oil fractions and BTEX were based on these TRVs and exposure parameters with adaptations to Alberta conditions where appropriate. These toxicity values and guidelines are presented in Table 8.

Differences/Limitations:

- TRVs for crude oil fractions were adopted from CCME and therefore, also used an AF of 0.2 (see above for explanation).
- Another element of their approach to calculating soil RBSLs for crude oil fractions was the inclusion of a protection factor of 0.75 to prevent livestock from being exposed to more than 75% of the TRV. Although this may seem protective, as an AF of 0.2 was already used for the TRV, it was likely overly conservative.
- Threshold values were not developed for PAHs.
- Threshold values were developed for only one livestock receptor (i.e. cattle).
- The fractionation approach used by CCME is not necessarily applicable or appropriate at all sites (see above for explanation).
- Two types of water quality guidelines were developed: *exposure point guidelines* for water to which receptors are actually exposed, and *groundwater quality guidelines* to assess acceptable concentrations of chemicals in groundwater.
- Additionally, SQGs for the protection of groundwater (i.e., the concentration of chemical in soil that will not cause unacceptable concentrations in surface water) for livestock were also developed using fate and transport models and Alberta-specific groundwater recharge rates.

Table 8. Other Available Toxicity Values and Guidelines for Livestock

PHCs	Crude Oil Whole	Crude Oil F1 (23.2%)	Crude Oil F2 (21.3 %)	Crude Oil F3 (34.5%)	Crude Oil F4 (18.2%)	BTEX Benzene	BTEX Toluene	BTEX Ethylbenzene	BTEX Xylene	PAHs LMW	PAHs HMW
Canadian Council of Ministers of the Environment (CCME) Toxicity Values and Guidelines (CCME 2000)											
TRV[a] (mg/kg-bw/day)	210	9.74	8.95	14.5	9.64	NA	NA	NA	NA	NA	NA
dw RBSL[b] (mg/L)	231	53.0	49.0	79.0	42.0	NA	NA	NA	NA	NA	NA
soil RBSL (mg/kg)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Alberta Environment Toxicity Values and Guidelines (Alberta 2001*a* ; 2001*b*)											
TRV[c] (mg/kg-bw/day)	210	9.74	8.95	14.5	9.64	0.0800	4.46	2.91	11.9	NA	NA
dw RBSL[d] (mg/L)	1342	62.0	57.0	na	na	0.510	29.0	19.0	76.0	NA	na
gw RBSL[e] (mg/L)	1342	62.0	57.0	na	na	0.510	29.0	19.0	76.0	NA	na
soil RBSL (mg/kg)	9,000	4,000	3,700	6,000	4,000	33.0	1,800	1,200	4,900	NA	na
soil/gwRBSL (mg/kg)	NA	11000	8600	na	na	2.20	2,200	16,000	25,000	NA	na

F Fraction of crude oil.
HMW High molecular weight.
LMW Low molecular weight.
NA Not available.
na Not applicable; not calculated based on their low aqueous solubility and subsurface mobility (Alberta 2001*a* ; 2001*b*).
PAHs Polycyclic aromatic hydrocarbons.
PHCs Petroleum hydrocarbons.
dw RBSL Drinking water risk-based screening level.
soil RBSL Soil risk-based screening level.
TRV Toxicity reference value; referred to as daily threshold effect dose in CCME 2000 and Alberta 2001*a* ; 2001*b* .
mg/kg-bw/day Milligrams per kilogram body weight per day.
mg/kg Milligrams per kilogram.
mg/L Milligrams per liter.
% Percent.

[a] TRV for crude oil fractions are fractions of whole crude oil TRV including allocation factor of 0.2 (see text for details).
[b] Corrected RBSL; CCME reported dwRBSL for crude oil as 23 mg/L (see text for details).
[c] Adapted from CCME 2000.
[d] Exposure point guideleine; calculated using an equation similar to Equation 4b in the text.
[e] Groundwater quality guideline; assumed to be the same as exposure point guidelines for livestock (Alberta 2001*a* ; 2001*b*).
[f] Soil quality guideline; calculated using an equation similar to Equation 4c including a safety factor of 0.75 (see text for details).
[g] Soil quality guideline for the protection of groundwater; based on fate and transport models and Alberta specific data (Alberta 2001*a* ; 2001*b*).

7. Summary

The first step in a livestock risk assessment at a site would be to evaluate the potential for exposure. If no significant and complete exposure pathways exist for petroleum hydrocarbons, there is little to no likelihood of unacceptable risk to livestock from these compounds. Where a complete exposure pathway (or pathways) is determined to exist, the presence or level of risk to livestock from petroleum hydrocarbons depends on several key factors, including exposure route, duration, and dose, chemicals present, species characteristics (i.e., body weight, metabolism, overall health), and factors related to the potential significance of ecological effects, such as the grazing area or range.

The toxicity values and guidelines for crude oil developed in this report for soil ingestion in livestock are comparable to human health risk-based screening levels (RBSLs) for sites affected with crude oils. The suggested RBSLs for human residential and non-residential scenarios are the 95th percentile values (for all exposure pathways) of 2,800 mg/kg and 41,300 mg/kg, respectively (McMillen et al., 2001). Similarly, a comparable TPH screening level of 10,000 parts per million (ppm) was developed for groundwater and plants (Hamilton et al., 1999).

To characterize risks to livestock from petroleum hydrocarbon exposure at a site, drinking water and soil RBSLs developed in this report can be used as screening values for soil, surface water, and groundwater for livestock protection. If the effective size of the contamination is available, site-specific RBSLs can also be developed using SUFs in order to estimate potential risks to livestock from exposure to that particular site. If required, a quantitative risk evaluation could be conducted using the TRVs and exposure factors presented in this report. Additionally, cumulative risks can be estimated for livestock receptors exposed to petroleum hydrocarbons via multiple exposure pathways.

The overall approach used to develop threshold values in this report was conservative (Clay 2003) and it can be assumed that risks calculated using the TRVs and RBSLs from this report would definitely be protective of livestock receptors exposed to petroleum hydrocarbons.

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