

CHARACTERIZING RISKS TO LIVESTOCK FROM PETROLEUM HYDROCARBONS

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ABSTRACT

Livestock may be exposed to 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 was developed to assess whether complete and significant exposure pathways exist at a given site. To estimate potential risks, 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; and polycyclic aromatic hydrocarbons were developed for a variety of livestock receptors. The TRVs and RBSLs developed for this framework were comparable to human health RBSLs and other published livestock guidelines.

INTRODUCTION

Consumption of petroleum hydrocarbons by livestock has been found to lead to a range of health problems, including neurotoxicity (5, 21), fetal toxicity (5), damage to the gastrointestinal tract (6), respiratory system, kidney, and liver (5, 6, 7, 26, 36). Petroleum ingestion has also been linked to anorexia (10), lethargy (8, 26), and fatal poisoning in cattle (9, 10, 26).

The purpose of this paper is to provide guidance on how to evaluate risks to livestock from exposure to petroleum hydrocarbons. This paper addresses the following:

- Determining whether livestock should be included in a risk evaluation and
- Estimating risk of petroleum hydrocarbons exposure to livestock.

The approach used to characterize risks to livestock from petroleum hydrocarbons exposure was divided into two steps. The first step included evaluation of the potential for exposure through the development of a conceptual site model. The second step included development of Toxicity Reference Values (TRVs) and Risk-Based Screening Levels (RBSLs) for the protection of livestock.

This paper focuses 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 cause significant health risks (23); therefore metals are not addressed in this paper.

The approach presented herein was 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 paper, 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.

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 livestock from exposure to petroleum hydrocarbons, a screening-level risk evaluation for livestock is not necessary. By definition, if there is no or insignificant exposure to a potentially toxic compound, there is little to no likelihood of significant unacceptable risk to the receptor from that compound. A CSM should be developed to assess the potential for exposures to livestock and the need for a risk evaluation. Components of a CSM include receptor evaluation and exposure pathway evaluation, which are described below.

Receptor Evaluation

Livestock that are potentially vulnerable to toxic effects of petroleum hydrocarbons include animals that could ingest significant quantities of contaminated soil, water, and/or food in oil-impacted areas. Access to the contaminated areas is key; cattle, sheep, and goats that forage in a pasture area 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 U.S., other types of livestock animals may also be exposed to petroleum compounds, such as camels, llamas, oxen, etc. It is assumed that exposures to these receptors would be similar to those of typical livestock in the U.S. based on similarities in body weights and feeding habits.

Pathway Evaluation

The primary pathways by which livestock could be exposed to petroleum hydrocarbons include incidental soil ingestion, water ingestion, and direct ingestion and were considered significant in the exposure model.

- Soil can comprise a substantial proportion of the diet of cattle and sheep. Livestock may consume soil inadvertently during grazing (4, 39) or may intentionally ingest salty-tasting soil (5).
- Chronic exposure through drinking water can also be a significant exposure pathway for livestock (4), although the amount of water ingested by cattle varies according to age, physiological status, breed, size, and, for all animals, temperature (1, 27).
- Livestock may ingest petroleum hydrocarbons directly from pools of oil from leaking pipelines or storage tanks (4, 5, 10). Cattle may directly ingest crude oil and other petroleum compounds due to curiosity (particularly in young calves; [8]) or to add salt to their diet (5, 8). Since the industry standard is to recover or remove all pooled oils resulting from spills or leaks, direct ingestion was not evaluated in this paper.

Minor exposure pathways for livestock to petroleum hydrocarbons include inhalation, dermal absorption, and plant ingestion (4).

- Exposure via inhalation 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 is minimized and 2. Most volatile organic compounds (VOCs), the contaminants most likely to present a risk through inhalation, are rapidly diluted and dispersed in ambient air, making significant exposure to volatile organic compounds through inhalation unlikely.
- Dermal absorption of petroleum hydrocarbons in livestock was considered a minor exposure pathway due to their thick coats (4). While methods are available to assess dermal exposure to humans, data necessary to estimate dermal exposure are generally not available for livestock or wildlife (12). Dermal exposure has been shown to be negligible for most terrestrial mammals (15).
- Although the ingestion rates of plants are high for livestock, plants were 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 (4).

Another factor to be considered in determining whether there is need to assess livestock risks at a given site, in addition to a pathway analysis, is the size of the contaminated area or release relative to the size of the grazing area; is referred to as a site use factor (SUF). 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 be conducted (Texas Natural Resource Conservation Commission [37] and Pennsylvania Department of Environmental Protection [31]).

EXPOSURE ASSUMPTIONS

As discussed previously, the main exposure pathways for cattle, sheep, goats, and camels are incidental soil ingestion and water ingestion. Exposures are generally measured by estimating the intake rates in kilograms per day (kg/day) or liters per day (L/day) that livestock might ingest and converting this to a dose. Equation 1 was used to calculate daily ingested petroleum hydrocarbon dose for livestock.

$$\text{Dose} = \{[(\text{IR}_{\text{soil}} * \text{C}_{\text{soil}}) + (\text{IR}_{\text{water}} * \text{C}_{\text{water}})] * \text{SUF}\} \div \text{BW} \quad \text{Equation 1}$$

where:

| | |
|-----------------------|---|
| Dose = | estimated daily dose of petroleum related hydrocarbons from ingestion (mg/kg body weight/day) |
| IR _{soil} = | amount of soil incidentally ingested (kg (dry weight)/day) |
| IR _{water} = | amount of water ingested per day (L/day) |
| C _{soil} = | concentration of constituent in soil or sediment (mg/kg dry weight) |
| C _{water} = | concentration of constituent in water (mg/L) |
| SUF = | site use factor (unitless) |
| BW = | body weight (kg) |

Recommended exposure assumption parameters are presented in Table 1. Conservative assumptions are made in all cases. For example a Site Use Factor (SUF) of 1 is assumed, meaning that all of the soil and water ingested by livestock daily comes from contaminated sources.

TOXICITY 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 paper were developed from the 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 which 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 include drinking water RBSLs expressed in milligrams per liter (mg/L) and soil RBSLs expressed in milligrams per kilogram (mg/kg).

The assessment endpoints used in developing TRVs were based on survival, reproductive, developmental and growth endpoints of the herd population. The measurement endpoints used to quantify the assessment endpoints were preferably based on chronic no-observable adverse effect levels (NOAELs). If NOAELs were not available or reported, the lowest-observable adverse effects levels (LOAELs) were extrapolated to develop NOAELs using an uncertainty factor (UF) of 10 following EPA guidelines (14).

The following sections describe the development of TRVs and drinking water RBSLs and soil RBSLs for the protection of livestock from exposure to petroleum hydrocarbons, including crude oil, BTEX, and PAHs, for the major exposure pathways discussed in the CSM section.

Crude Oil

Most of the toxicity studies available for crude oil effects on livestock were based on lethal endpoints. However, a study conducted by Stober in 1962 (36) evaluated sublethal toxicity endpoints and therefore, was selected to develop TRVs for this paper. The toxicity endpoints in Stober's study were based on chronic LOAELs for fresh crude oil in cattle, based on altered rumen function, loss of appetite, decreased liver function, increased eosinophil number, hypomagnesemia, 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 by administering fresh (i.e., unweathered) whole crude oil in its diet for a treatment period of 127 days (36). The chronic LOAEL was reported as 2.5 milliliters per kilogram body weight (ml/kg-bw/day; [36 as cited in 5]) which was converted into a dose expression using the specific gravity value of 0.843 grams per milliliter (g/ml) reported in Stober (36) resulting in a chronic LOAEL of 2,108 mg/kg-bw/day. Using an UF of 10, the chronic LOAEL was extrapolated to a chronic NOAEL and a TRV of 211 mg/kg-bw/day and this TRV for whole fresh crude oil was used to develop RBSLs for all types of livestock and are presented in Table 3.

Livestock RBSLs were calculated by rearranging the standard hazard quotient (HQ) equation used for estimating risks to human health and other ecological receptors (13). Instead of estimating a HQ associated with a chemical concentration in water or soil using the toxicity and exposure assumptions above, this equation estimates a protective drinking water or soil concentration associated with a target HQ of 1. RBSLs for livestock were calculated using Equation 2.

$$HQ = \text{Dose} \div \text{TRV} \quad \text{Equation 2a}$$

Substituting Equation 1 for Dose:

$$HQ = (\text{IR} * \text{C} * \text{SUF}) \div \text{BW} \div \text{TRV}$$

Assuming a target HQ = 1; SUF = 1; and rearranging Equation 2, C becomes defined as the corresponding RBSL:

$$\text{RBSL} = (1 * \text{BW} * \text{TRV}) \div \text{IR} \quad \text{Equation 2b}$$

Where:

- 1 = target hazard quotient (unitless);
RBSL = risk-based screening levels for water (milligrams per liter) or soil (milligrams per kilogram);
IR = ingestion rate for water (liters per day) or soil (kilograms per day);
BW = body weight (kilograms)
TRV = toxicity reference value (milligrams per kilogram body weight per day)

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. TRV and RBSLs developed based on whole fresh or unweathered crude oil can be used to evaluate fresh spills. However, as weathered crude oil is generally less toxic than unweathered crude oil, TRV and RBSLs for unweathered crude oil can also be used for evaluating weathered spills.

Benzene, Toluene, Ethylbenzene, and Xylene (BTEX)

There were no BTEX toxicity values available in literature for livestock. However, BTEX toxicity values were available for small mammals (Table 2) and TRVs for livestock were developed based on these studies, extrapolated to a dose that would be protective of livestock.

The TRV developed for benzene was based on a toxicity study conducted by Maltoni et al. in 1983 (as cited in 34) where rats were administered oral doses of benzene five 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 and extrapolated to a chronic NOAEL resulting in a value of 35.7 mg/kg-bw/day. As there was a significant difference in body weight between test-species (e.g., rat weighing 0.35 kg [32]) and livestock, a scaling factor (SF) to allometrically adjust for the difference in body weights (11, 31) was used as described in Sample and Arenal (33). The benzene TRVs developed for livestock based on chronic NOAELs are presented in Table 4 and range from 5.6 mg/kg-bw/day (camels) to 12 mg/kg-bw/day (goats).

The TRV developed for toluene was based on a toxicity study conducted by the National Toxicology Program (NTP) in 1989 (as cited in 16) where rats were administered oral doses of toluene five 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 which was further adjusted for the dosing schedule resulting in a value reported as 223 mg/kg-bw/day (a LOAEL of 625 mg/kg-bw/day was also reported in this study). The chronic NOAEL was further adjusted to account for differences in body weight between rats and livestock. Toluene TRVs for developed livestock are presented in Table 4 and range from 35 mg/kg-bw/day (camels) to 74 mg/kg-bw/day (goats).

The TRV developed for ethylbenzene was based on a toxicity study conducted by Wolf et al. in 1956 (as cited in 16) where rats were administered oral doses of ethylbenzene five 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 which was further adjusted for the dosing schedule resulting in a value reported as 291 mg/kg-bw/day. The chronic LOAEL was extrapolated to a chronic NOAEL resulting in a value of 29.1 mg/kg-bw/day which is further adjusted for differences in body

weight between rats and livestock. Ethylbenzene TRVs developed for livestock are presented in Table 4 and range from 4.5 mg/kg-bw/day (camels) to 9.6 mg/kg-bw/day (goats).

The TRV developed for xylene was based on a toxicity study conducted by NTP in 1986 (as cited in 16) where rats were administered oral doses of xylene five 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 which was further adjusted for the dosing schedule resulting in a value reported as 179 mg/kg-bw/day. The chronic NOAEL was further adjusted for differences in body weight between rats and livestock. Xylene TRVs developed for livestock are presented in Table 4 and range from 28 mg/kg-bw/day (camels) to 59 mg/kg-bw/day (goats).

For the protection of livestock, BTEX RBSLs were developed using the same approach as described earlier for whole crude oil RBSLs and results are presented in Table 5.

Polycyclic Aromatic Hydrocarbons (PAHs)

There were no toxicity values available for PAHs for livestock. However, PAH TRVs were available for small mammals. Therefore, similar to TRVs developed for BTEX, PAH TRVs for livestock were developed based on small mammal toxicity (Table 2) values extrapolated to a dose that would be protective of livestock. Several PAH toxicity studies on small mammals were reviewed and appropriate studies were selected to develop TRVs for livestock. Due to the limited availability of suitable data, two TRVs were recommended, one for low molecular weight (LMW) PAHs and one for high molecular weight (HMW) PAHs.

The TRV developed for LMW PAHs was based on a toxicity study conducted by Navarro et al. in 1991 (30) where rats were administered oral doses of naphthalene during days 6 to 15 of gestation (a critical life stage). The chronic LOAEL was calculated to be 50 mg/kg-bw/day based on increased maternal lethargy and slow breathing in rats. Using an UF of 10, the chronic LOAEL was extrapolated to a chronic NOAEL for LMW PAH resulting in a value of 5 mg/kg-bw/day which was further adjusted using a SF to account for differences in body weight between rats and livestock. The LMW PAH TRVs developed for livestock are presented in Table 6.

The TRV developed for HMW PAHs was based on a toxicity study conducted by MacKenzie and Angevine in 1981 (24) where mice were administered oral doses of benzo(a)pyrene during 7 to 16 days of gestation (a critical life stage). The chronic LOAEL was calculated to be 10 mg/kg-bw/day based on reduced pregnancy rates and decreased percentage of viable mice litter. Using an UF of 10, the chronic LOAEL was extrapolated to a chronic NOAEL resulting in a value of 1 mg/kg-bw/day which was further adjusted using a SF to account for differences in body weight between mice (0.03 kg; [32]) and livestock. The HMW PAH TRVs for developed for livestock are presented in Table 6.

For the protection of livestock, PAH RBSLs were developed using the same approach as whole crude oil RBSLs described earlier and are presented in Table 6.

AVAILABLE GUIDELINES

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. However, there are some limitations and differences in the development of these guidelines from the threshold values developed in this paper which are described below.

The Canada-Wide Standards (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 four fractions of crude oil (4). These guidelines present levels considered protective of human and environmental health under four generic land uses: agricultural, residential, commercial, and industrial. TRVs for livestock were also developed based on Stober's study (35) 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 2b resulting 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. The differences and limitations in the CWS (4) include the following:

1. Only TRVs and drinking water RBSLs for livestock were developed and not soil RBSLs;
2. Threshold values were not developed for BTEX and PAHs;
3. Threshold values were developed only for one livestock receptor (i.e. cattle);
4. 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 assumes that livestock can be equally exposed by all five potentially complete exposure pathways. However, as discussed in the sections above on the CSM, the dermal, inhalation, and food ingestion 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 generalized approach an AF of 1 would be appropriate with recommendation to use site-specific AFs as warranted to evaluate multiple exposure pathways;
5. The fractionation approach used by CCME is not necessarily applicable or appropriate at all sites. In this paper toxicity values were only 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; and
6. It should be noted that there is 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).

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 (2, 3). 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. The differences and limitations in Alberta Environment (2, 3) include the following:

1. TRVs for crude oil fractions were adopted from CCME and therefore, also used an allocation factor of 0.2 (see above for explanation);
2. 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. This is overly protective, as an AF of 0.2 was already used for the TRV;

3. Threshold values were not developed for PAHs;
4. Threshold values were developed only for one livestock receptor (i.e. cattle);
5. The fractionation approach used by CCME is not necessarily applicable or appropriate at all sites (see above for explanation);
6. 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; and
7. 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

SUMMARY

As mentioned above, 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 paper for soil ingestion in livestock are comparable to the recommended human health risk-based screening levels (RBSLs) for sites impacted with crude oils. The recommended 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 (25). Similarly, a comparable TPH screening level of 10,000 parts per million (ppm) was previously recommended for groundwater and plants (18).

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 the protection of livestock. 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.

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Table 1. Exposure Assumptions for Livestock Used in the Development of Toxicity and Screening Values

| Parameter | Dairy Cattle | | Beef Cattle | | Calves | | Sheep | | Goat | | Camel | |
|----------------------------|--------------|---|-------------|---|--------|---|-------|---|-------|---|-------|---|
| Body Weight (kg) | 540 | a | 454 | b | 50.0 | c | 56.7 | b | 29.5 | b | 600 | d |
| Percent soil diet (%) | 17.9 | e | 18.8 | f | 18.8 | f | 30.0 | g | 30.0 | h | 30.0 | h |
| Percent forage in diet (%) | 82.1 | i | 81.2 | i | 81.2 | i | 70.0 | i | 70.0 | i | 70.0 | i |
| Food IR dw (kg/day) | 13.5 | j | 11.4 | j | 1.25 | j | 1.98 | j | 1.18 | j | 6.07 | d |
| Soil IR dw (kg/day) | 2.42 | k | 2.13 | k | 0.235 | k | 0.595 | k | 0.354 | k | 1.82 | k |
| Water IR (L/day) | 95.0 | l | 86.0 | l | 36.0 | l | 14.0 | l | 10.0 | m | 16.5 | d |
| SUF | 1 | n | 1 | n | 1 | n | 1 | n | 1 | n | 1 | n |

kg= kilograms.
 kg/day = kilograms per day.
 L/day = liters per day.
 IR = ingestion rate.
 NA = not available.
 SUF = site use factor.
 dw = dry weight.
 ww = wet weight.
 % = percent.

a = average of range (29).
 b = from (22).
 c = average range of growing calves (28).
 d = average body weight (from web-based search and 17).
 e = most conservative literature value available (38).
 f = most conservative literature value available (20).
 g = most conservative literature value available (38).
 h = based on similar feeding habits as sheep.
 i = calculated; assuming main food item in diet.
 j = calculated in dry weight based on 2.5 % of body weight of dairy cattle, beef cattle, and calves; 3.5 % body weight of sheep; and 4% body weight of goats (22).
 k = calculated based on percent soil in diet and Food IR.
 l = estimated Water IR during summer (1).
 m = estimated Water IR during summer (19).
 n = conservative assumption.

Table 2. Toxicity Studies Available for Petroleum Hydrocarbons

| Test Species | Chemical/Compound | Final Dose | Exposure Duration | Effect | Endpoint | Source |
|--------------|-------------------|------------|-------------------------------|--|----------|---|
| Cow | Crude oil | 211 | 127 days | liver, GI, hematological, and neurological effects | NOAEL | (36) Maltoni et. al., 1983 (as cited in 16) |
| Rat | Benzene | 357 | 84 weeks | hematological effects and decreased body weight | LOAEL | a |
| Rat | Benzene | 35.7 | NA | NA | NOAEL | NTP, 1989 (as cited in 16) |
| Rat | Toluene | 223 | 13 weeks | hepatic/renal effects | NOAEL | Wolf et. al., 1956 (as cited in 16) |
| Rat | Ethylbenzene | 291 | 182 days | hepatic/renal effects | LOAEL | 16) |
| Rat | Ethylbenzene | 29.1 | NA | NA | NOAEL | a |
| Rat | Xylene | 179 | 103 weeks | growth and development effects | NOAEL | NTP, 1986 (as cited in 16) |
| Rat | Naphthalene | 50 | Days 6-15 of gestation period | maternal lethargy and slow breathing | LOAEL | (30) |
| Rat | Naphthalene | 5 | NA | NA | NOAEL | a |
| Mouse | Benzo(a)pyrene | 10 | Days 7-16 of gestation period | decreased pregnancy rates and reduced viable liter | LOAEL | (24) |
| Mouse | Benzo(a)pyrene | 1 | NA | NA | NOAEL | a |

Final dose = in milligrams per kilogram body weight per day (mg/kg-bw/day); see text for details.

GI = gastrointestinal.

NOAEL = no-observable-adverse-effects-level in mg/kg-bw/day.

LOAEL = lowest-observable-adverse-effects-level in mg/kg-bw/day.

a = extrapolated from the LOAEL study using an uncertainty factor of 10.

NA = not available.

Table 3. Whole Fresh Crude Oil TRVs and RBSLs Developed for the Protection of Livestock

| Livestock | TRV (mg/kg-bw/day) | Drinking Water-RBSL (mg/L) | Soil-RBSL (mg/kg) |
|------------------|-------------------------------|---------------------------------------|------------------------------|
| Dairy cattle | 211 | 1,199 | 47,151 |
| Beef cattle | 211 | 1,114 | 44,894 |
| Calves | 211 | 293 | 44,894 |
| Sheep | 211 | 855 | 20,095 |
| Goats | 211 | 622 | 17,583 |
| Camels | 211 | 7,673 | 69,522 |

mg/kg-bw/day = milligrams per kilogram body weight per day.
 mg/L = milligrams per liter.
 mg/kg = milligrams per kilogram.
 RBSL = risk-based screening level.
 TRV = toxicity reference value.

Table 4. BTEX TRVs Developed for the Protection of Livestock

| Livestock | TRVs (mg/kg-bw/day) | | | |
|------------------|----------------------------|----------------|---------------------|---------------|
| | Benzene | Toluene | Ethylbenzene | Xylene |
| Dairy cattle | 5.70 | 35.6 | 4.65 | 28.5 |
| Beef cattle | 5.95 | 37.1 | 4.86 | 29.8 |
| Calves | 10.3 | 64.5 | 8.43 | 51.7 |
| Sheep | 10.0 | 62.5 | 8.17 | 50.1 |
| Goats | 11.8 | 73.6 | 9.62 | 58.9 |
| Camels | 5.55 | 34.6 | 4.53 | 27.8 |

mg/kg-bw/day = milligrams per kilogram body weight per day.
 BTEX = benzene, toluene, ethylbenzene, and xylene.
 TRV = toxicity reference value.

Table 5. BTEX RBSLs Developed for the Protection of Livestock

| Livestock | Drinking Water-RBSLs (mg/L) | | | | Soil-RBSLs (mg/kg) | | | |
|------------------|------------------------------------|----------------|--------------------------|---------------|---------------------------|----------------|--------------------------|---------------|
| | Benzene | Toluene | Ethyl benzene | Xylene | Benzene | Toluene | Ethyl benzene | Xylene |
| Dairy cattle | 32.4 | 202 | 26.4 | 162 | 1,273 | 7,946 | 1,039 | 6,367 |
| Beef cattle | 31.4 | 196 | 25.6 | 157 | 1,266 | 7,901 | 1,033 | 6,331 |
| Calves | 14.3 | 89.5 | 11.7 | 71.7 | 2,198 | 13,715 | 1,794 | 10,990 |
| Sheep | 40.5 | 253 | 33.1 | 203 | 953 | 5,949 | 778 | 4,767 |
| Goats | 34.8 | 217 | 28.4 | 174 | 982 | 6,129 | 802 | 4,911 |
| Camels | 202 | 1,259 | 165 | 1,009 | 1,492 | 11,412 | 1,492 | 9,144 |

mg/L = milligrams per liter.
 mg/kg = milligrams per kilogram.
 BTEX = benzene, toluene, ethylbenzene, and xylene.
 RBSLs = risk-based screening levels.

Table 6. PAH TRVs and RBSLs Developed for the Protection of Livestock

| Livestock | TRVs (mg/kg-bw/day) | | Drinking Water-RBSLs (mg/L) | | Soil-RBSLs (mg/kg) | |
|--------------|------------------------|-------------|--------------------------------|-------------|-----------------------|-------------|
| | LMW PAHs | HMW PAHs | LMW PAHs | HMW PAHs | LMW PAHs | HMW PAHs |
| Dairy cattle | 0.798 | 0.160 | 4.53 | 0.907 | 178 | 35.7 |
| Beef cattle | 0.833 | 0.167 | 4.40 | 0.880 | 177 | 35.5 |
| Calves | 1.45 | 0.289 | 2.01 | 0.402 | 308 | 61.5 |
| Sheep | 1.40 | 0.280 | 5.68 | 1.14 | 133 | 26.7 |
| Goats | 1.65 | 0.330 | 4.87 | 0.974 | 138 | 27.5 |
| Camels | 0.777 | 0.155 | 28.3 | 5.65 | 256 | 21.2 |

mg/L = milligrams per liter.
mg/kg = milligrams per kilogram.
mg/kg-bw/day = milligrams per kilogram body weight per day.
LMW = low molecular weight.
HMW = high molecular weight.
PAHs = polycyclic aromatic hydrocarbons.
RBSLs = risk-based screening levels.
TRV = toxicity reference value.