REPORT

UNSATURATED SOIL MODELING AND ECOLOGICAL RISK ASSESSMENT FOR SOILS UNDER IRRIGATION

Cameco Resources Smith Ranch-Highlands Facility

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EXECUTIVE SUMMARY

Cameco's Smith Ranch-Highland (SRH) facility uses a Land Application operation to manage waste water from the In-Situ Recovery process through irrigation and evapotranspiration. The purpose of this report is to provide a soil modeling and ecological risk assessment leading to operation recommendations designed to be protective of the environment. This work primarily focused on selenium (Se) in the waste water.

The project was split into four technical tasks:

1. Field data collection and analysis
2. Data compilation
3. Unsaturated soil modeling
4. Screening-level ecological risk assessment (SLERA).

Key conclusions from these tasks are provided below.

1. Golder compiled the historical data from the irrigation areas on the site for parameterization and calibration of the unsaturated soil flow model. The key data gaps were: site specific meteorological data prior to 2010, non-spatially and temporally coincident soil/porewater and soil/vegetation data, and lack of total metals data applicable to certain ecological risk pathways.
2. The 2011 Se concentrations in the irrigator water, soils, and vegetation demonstrate similar trends to those observed previously. Irrigator 1A soil concentration remains low (0.4 to 0.5 mg/kg at 6 to 12 and 0 to 6 inches depth, respectively) and are below the Wyoming Department of Environmental Quality (WDEQ) (2012a) soil standard of 0.95 mg/kg. The average vegetation concentration remain at elevated levels (21.1 mg/kg in 2011 compared to 18.8 mg/kg in 2010).
3. Se concentrations in the Irrigator 2 irrigation water have decreased markedly since 2009 when the new water treatment operations began. Irrigator 2 discharges in 2011 contained an average Se concentration of 0.014 mg/L, below the WDEQ Permit 603 (WDEQ 1987) permitted limit of 0.1 mg/L. The Se concentrations measured in the vegetation have mirrored this trend, with concentrations currently below the reference level of 0.5 mg/kg (as proposed in Sharmasarkar and Vance, 2002). Soil Se concentrations continue to be very low for the Irrigator 2 area (0.27 mg/kg in 2011).
4. Due to the importance of soil hydraulic properties to the unsaturated zone soil modeling analysis and risk analysis, additional soil data were collected and analyzed. Twelve test pits were excavated in the two irrigator areas as well as in the location of a potential future irrigator. Samples from the pits were analyzed for particle size distribution with hydrometer and specific gravity. As a result, it was concluded that the predominant material in the root zones is silt. Roots from vegetation were generally concentrated in the upper 6 to 12 inches of the soil profiles.
5. Unsaturated zone soil modeling was used to estimate soil and pore-water metal concentrations in the root zone over the life span of the land application. HYDRUS-1D was used in this study. The modeling focused on Se concentrations. The output of the model was used as inputs to the ecological risk assessment. After model calibration to

observed soil and porewater concentrations at both existing irrigator locations, the following predictive cases were analyzed for both existing irrigator locations:

- Base case: Average climate, silt, irrigation with waste water;
- Wet climate, silt, irrigation with waste water;
- Dry climate, silt, irrigation with waste water;
- Average climate, silt, irrigation with clean water;
- Average climate, 3 ft. silt and 3 ft. sand, irrigation with waste water; and
- In addition, the base case was analyzed for a new irrigator location.

The base case predictive simulations for Irrigators 1A and 2 predict that shallow (0-12-inch depth) soil Se concentrations will reduce with time while deeper soil concentrations will continue to slowly increase. Predicted Se concentration in the soil decreases over time at shallow depths when irrigating with clean water but deeper soil concentrations will still continue to slowly increase.

These predicted results were very sensitive to the soil adsorption distribution coefficient and vegetation root uptake assumptions and less sensitive to soil type (within the range of observed shallow soil types) and climate.

1. The Screening Level Ecological Risk Assessment (SLERA), based on simplifying assumptions, analyzes risks associated with Se at the Irrigator. 1A and 2 areas of the Smith Ranch-Highlands facility using current measured data and future modeled soil concentrations after irrigation with mine process water. In this SLERA, Golder evaluated the potential for risk to plants, soil invertebrates, and wildlife from Se in the irrigation water, both currently and up to 10 years in the future. This analysis suggests that:
   a. Currently in the Irrigator 1A area, there is the potential for risk to herbivorous birds, small herbivorous mammals, and larger herbivorous mammals. There is no current risk potential for plants, soil invertebrates, insectivorous birds and mammals, carnivorous birds and mammals, and cattle. Currently in the Irrigator 2 area, there is the potential for risk to plants and small herbivorous mammals. There is no current risk potential for soil invertebrates, herbivorous birds, insectivorous birds and mammals, carnivorous birds and mammals, and large herbivorous mammals, including cattle.
   b. For both of the irrigation areas, there is no future risk potential for any of the wildlife groups that could feed at the Site. There is potential for future risk to plants. However since there has been no documentation of effects to plants during recent vegetation sampling events and the risk potential is very slight, it is likely that there is minimal potential for risk to plants in the irrigation areas from Se.
   c. For the potential new irrigator area, 1B, there is no future potential risk via any of the identified ecological risk pathways.
   d. Since the maximum future predicted soil concentration (at any depth and climate scenario) is 0.75 mg/kg dry weight in the area of Irrigator 1 and 1.01 mg/kg at Irrigator 2 (both well below the 1.45 mg/kg threshold), the soil Se concentrations are predicted to attenuate, without additional soil remediation, to concentrations that are not expected to accumulate in plants or earthworms to potential risk levels.

2. The maximum calculated soil Se concentration protective of wildlife was 1.45 mg/kg dry weight. For the base case for Irrigator 2 (worst case location) this can be correlated with an average irrigation concentration of 0.4 mg/L. Therefore the WDEQ Permit 603 limit of 0.1 mg/L for Se in irrigation water is conservatively protective for this site.
3. Risk refinement is warranted if average Se soil concentrations exceed 1.45 mg/kg and/or average irrigation concentrations exceed 0.4 mg/L. These limits are site-specific and based on observed risk pathways but additional analyses may be warranted if WDEQ standards or permitted limits are exceeded (Se soil concentrations of 0.95 mg/kg and/or irrigation concentrations of 0.1 mg/L). The steps that can be taken in the event that a less conservative risk assessment is warranted are:
   a. Reduce the number of assumptions made in the SLERA e.g., by collection of co-located earthworms and soil and vegetation data that would allow the calculation of a site-specific earthworm Se concentration and plant uptake factor for Se, given the soil properties in the irrigation area. This would provide a more realistic estimation of future concentrations of Se in soil invertebrates and vegetation than the use of general uptake models.
   b. Reduce the number of assumptions used in the unsaturated soil modeling, e.g., by determining site-specific saturated hydraulic conductivity and soil water characteristic curves for the silt and sand. Additional efforts could also focus on calibrating flow with the soil-atmosphere model using measured soil moisture if additional data on soil moisture are collected.

Based on these conclusions it is recommended that:

1. Monitoring of the water, soil, and biota continue in order to confirm that the predictions in this report are accurate. Soil analysis should include the total fraction of metals. WDEQ standards for irrigation water quality and soil concentrations of Se are conservatively protective compared to the risk-based goals developed in this report. However, they provide a guide for the Se concentration levels at which alternate management practices, analyses, or monitoring could be considered.
2. If concentrations in any media are found to be greater than those predicted in the SLERA, additional exposure calculations could be performed to refine these estimates for potential toxicity.
3. Alternate management practices, to be considered in the event that risk-based levels are exceeded, be conceptually evaluated. These could include: Rotation of irrigator locations to allow natural attenuation to reduce loadings at any individual location, and adjustments to brine fraction in effluent to irrigators resulting in a higher volume/lower concentration irrigator water.
4. Vegetation harvesting and disposal be re-assessed because the highest current potential ecological risk is from current vegetation samples. The modeling of future soil concentrations of Se yielded soil values that are not expected to accumulate to toxic plant concentrations. Until this 'drop' occurs, vegetation harvesting and disposal continues to be a viable mitigation strategy.
5. Soil remediation is not required. The maximum predicted future soil concentration (at any depth and climate scenario and irrigator location) are low enough that concentrations are not expected to accumulate in plants or earthworms to 'toxic' levels, so soil remediation is not required on the basis of ecological risk analyses.

Soil samples were collected by Cameco in September and October 2010 following a sampling protocol developed in response to comments issued by the WDEQ on Cameco's 2007-2008 Annual Report for the SRH facility. The addendum to this report evaluates the SLERA conclusions presented in the main report in the light of these additional data.

In this unique dataset, the mean annual sampling results and the mean Se(VI) and Se(IV) concentrations for all depths and sites under irrigation are all lower than the maximum calculated soil Se concentration protective of all potentially present wildlife receptors. Total Se exceeded this risk-based concentration goal at both irrigators at 0-2 inches depth but not at the 2-4 ft depth.

Considering the 0-2-inch depth total Se data which exceed the maximum calculated soil Se concentration protective of wildlife receptors:

- Three risk pathways potentially could be re-evaluated: surficial soil, soil invertebrates, and small mammals The risk via these pathways could be re-assessed based on a correlation between total Se and previously measured Se values but this approach would be very speculative because of the assumption that the ratio of total Se and AB-DTPA-analyzed Se concentrations could be extrapolated in time, despite that fact that they were collected at different depths and times of year.
- If Se enters the food chain primarily by way of plant uptake, then use of Total Se concentrations for all receptor pathways may exaggerate ecological risk.
- Since the speciation data were collected close to the end of the irrigation season, they represent an accumulation of Se over the year, and would be an over- estimate of what animals are exposed to during the other months.
- Uptake of Se into plants, earthworms, and small mammals will likely not be limited to exposures experienced in the uppermost 2 inches of soil, which is the depth at which the measured total Se exceeded the maximum risk-based concentration goal.

If further analyses of the speciation data were to be pursued, possible approaches include:

1. Comparison of analytical methods used historically and in the speciation analyses by splitting samples next August, when sampling is typically undertaken;
2. Sampling of earthworm Se to assess whether SLERA assumptions, for the riskiest identified pathway, are overly conservative; and
3. Revision of soil modeling and SLERA analyses assuming that historical data are translated by the ratio of concentrations observed in the annual sampling and speciation datasets (noting that this approach is flawed).

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Addendum

1.0 INTRODUCTION

Cameco's Smith Ranch-Highland (SRH) facility uses a Land Application operation to manage waste water from the In-Situ Recovery process through irrigation and evapotranspiration. The purpose of this report is to provide a soil modeling and ecological risk assessment leading to operation recommendations designed to be protective of the environment. This report describes data collection and analysis that follows up on a number of different projects Golder has performed for Cameco and its Land Application operation. In previous work, Golder has seen increased loading of salts, most notably Se, in the soils and vegetation under irrigation. The current work is focused on predicting the type of ecological receptors and related potential risks associated with a proposed increase in irrigation intensity using water now being treated to lower Se levels than has been the case historically.

The SRH facility extracts and purifies uranium from the uranium-bearing rock formations *in situ*, and disposes of mine process water via deep well injection, evaporation ponds, or land application through irrigation. The two irrigation areas consist of 58 acres for the Irrigator 1 area and 116 acres for the Irrigator 2 area. Both irrigation areas are fenced and will be fenced for the duration of mining activities. These areas have been used intermittently for disposal of mining bleed and restoration water since 1989 (Shepherd Miller 1996). The bleed water is removed from the ground to maintain a hydraulic cone of depression for uranium extraction. After uranium and radium-226 are removed from the bleed water, the treated water is retained in storage ponds and then sent to the irrigation areas. Restoration water (groundwater used for dilution of bleed water) is produced after uranium production has ceased for the year to reduce the concentrations of radionuclides and trace metals in the groundwater (Levy and Kearney 1999). Se and other inorganic compounds in the mine process waters are naturally dissolved in the groundwater brought to the surface for uranium extraction. Data have been collected from abiotic and biotic media in the irrigation areas since 1986, when baseline conditions for the Site were established. The Irrigator 1 area has not been irrigated since 2003. However, Site conditions have been evaluated to assess the potential for risks from Se if irrigation were to begin again at this location or another, previously unused, irrigator location.

2.0 DATA COMPILATION AND DATA GAPS

2.1 Data Compilation and Data Gaps

Golder compiled the historical data from the irrigation site for parameterization and calibration of the unsaturated soil flow model. This dataset consisted of electronic files provided by Cameco and data collected and analyzed by Golder in Fall 2008 and 2011, and Spring 2012. A complete list of all data considered in this evaluation is provided in Table 1.

Data input to the unsaturated flow model and relevant data gaps are summarized as follows:

- **Meteorological data** – Daily precipitation and temperature data was collected by Cameco from November 2010 through February 2012 and used for parameterization of the model.
  - **Data Gap:** Site-specific meteorological data from earlier than November of 2010 was not identified. Earlier data was accounted for by identifying a correlation with a nearby climate station (i.e., Casper Natrona International Airport, WY, Climate Station: USW 00024089); the derived relationship was used to infer site conditions from 1948 to 2012. See Section 3.4 for details.
- **Irrigation recharge data** – Irrigation recharge data was provided by Cameco in electronic format. Data included the volume of water applied on a monthly basis and monthly irrigation water quality for Irrigator 1A (August 1989 to September 2004) and Irrigator 2 (September 1995 to July 2011) during the months the respective irrigators were operating. This information was used for calibration of the model.
  - **Data Gap** none identified.
- **Irrigation method and area** – Irrigation method was reported in the original permit applications and area was calculated from the known radius of the respective irrigators. This information was used for parameterization of the model.
  - **Data Gap:** none identified.
- **Soil concentration data** – Soil concentration data was reported annually from 14 locations at Irrigator 1A (1990 to 2011) and 16 locations at Irrigator 2 (1995 to 2011) from between 0 to 6 and 6 to 12 inches depth. The soil samples collected in 1986 and 1993 were considered to represent baseline for Irrigators 1A and 2, respectively. The annual soil Se concentration used in the model calibration corresponded to the average of the 16 samples collected from a given depth interval. This information was used for calibration and parameterization of the model. Average annual soil Se concentrations obtained from Irrigator 1A were used in conjunction with the average annual soil pore water concentration data to obtain an estimate of the soil to water partition coefficient (Kd). This parameter is discussed further at the end of this section.

  Background soil Se concentrations were collected on an annual basis for both Irrigators over the same time period as the soil samples were collected. The collection location for the background samples is not reported in the soil chemistry data files. It was additionally noted through the course of the data review that background soil Se concentrations were elevated above the irrigated soil concentrations for the Irrigator 1 background sites in 2001 and 2003.
  - **Data Gap:** Soil concentration data was collected at a maximum depth of 1 foot, whereas the soil pore water data was collected at a minimum depth of 2 feet. Therefore, the data are not spatially coincident.

- **Soil pore water concentration –** Soil pore water data was collected annually for Irrigator 1A, and was reported as the average of three lysimeter samples collected from soil within the irrigated area from 1991 to 2003. No pore water concentration data was reported from 2004 on. Lysimeter samples were collected from 2, 4, and 6 foot depth intervals for all years stated above except 2000 through 2003, for which concentrations were reported for the 6 foot depth interval only. This information was used for calculation of the soil to water partition coefficient, which was used for model parameterization and calibration.
  - **Data Gap:** Soil pore water concentration data were reported for Irrigator 1A only. Additionally, as stated above, soil pore water data was collected at a minimum depth of 2 feet, whereas the soil concentration data was collected at a maximum depth of 1 foot.
- **Soil type, soil porosity, permeability, and grain size distribution –** Soil-related variables were defined, in part, during permitting activities, and were either collected by Golder staff or inferred when the data were otherwise unavailable. Soil-type was well-defined in various permit applications for both irrigators. Soil permeability and grain-size distribution were defined for Irrigator 1A during the original permitting activities, however the locations and depths of these data were not well-defined. Samples were collected by Golder staff in September 2008 from Irrigator 1A area; they were analyzed for particle size distribution (PSD) (Golder Associates, 2009). Additional samples were collected from both of the irrigated areas, as well as from Irrigator 1B, a potential future irrigator location, by Golder staff in June of 2012 and evaluated for grain-size distribution.
  - **Data Gap:** Soil permeability was not identified for Irrigator 2, but was inferred from observations at Irrigator 1A. This was considered a reasonable inference based on similarity in soil-type between the two locations. Porosity was not identified for either of the irrigated areas, but was inferred based on soil-type.
- **Vegetation concentration data –** Vegetation concentration data was reported annually as composite samples for four quadrants in the Irrigator 1A area (1990 to 2011) and for Irrigator 2 area (1998 to 2011).
  - **Data Gap:** none identified.

The uncertainty associated with determination of K_d, the soil to water partition coefficient, is likely the main contributor of uncertainty to the unsaturated zone model parameterization and calibration, as it guides the output of the model for future predictions related to Se concentrations available for plant uptake. Calculation of the partition coefficient from solid-phase and aqueous-phase concentrations is valid in fully-saturated environments, where equilibrium can be assumed and conditions are not affected by hysteresis, as is not the case in the unsaturated zone. Although this calculation, when applied to the unsaturated zone, does not represent a true partition coefficient, it is likely still a valid way to estimate pore water Se concentrations as a function of soil Se concentrations. Table 2 presents the minimum and maximum values of K_d, as calculated from the minimum and maximum values of the measured soil and pore water Se concentrations, according to Equation 1 (Freeze and Cherry, 1979):

$$K_d = \frac{Se_{soil}}{Se_{pore\ water}}$$

Equation 1

Table 2: Bracketed Range of Partition Coefficient Values

	Soil Se Concentration (Se_{soil})	Pore Water Se Concentration ($Se_{pore\ water}$)	Partition Coefficient $K_d = Se_{(soil)} / Se_{(porewater)}$
Units	mg/kg	mg/L	cm^3/mg
Minimum	0.113	0.025	0.00034
Maximum	1.07	0.331	0.043

The K_d ultimately incorporated into the model calculations was based on the above range in calculated values (based on empirical data), and professional judgment based on a conceptual model which relates the temporal Se concentrations in the irrigation water, pore water, and soil. Figures 1 and 2 show the Se concentration trends at Irrigators 1A and 2. These figures demonstrate that pore water Se concentrations reflect the changes in irrigation water Se concentrations, whereas the soil Se concentrations are more constant throughout time with only slight increases observed during periods of higher applied Se concentrations. The relatively small change in temporal soil concentrations is likely due to sorption limitations controlled by the soil and water composition(s), and/or removal of pore water Se by other sources (possibly by the vegetation). Figures 1 and 2 additionally demonstrate that the Se concentration in the harvested vegetation accumulates to concentrations far in excess of the soil Se concentrations. This observation is suggestive of continual uptake of pore water Se by the vegetation and/or mass concentration between media.

A secondary factor affecting the removal of pore water Se by vegetation is the build-up of salts (including Na, Mg, and Ca) in the soils, which can inhibit the growth of vegetation. To assess salt loading in the irrigated soils, SAR values are calculated through time according to Equation 2:

$$SAR = \frac{Na(\frac{meq}{L})}{\sqrt{\frac{Ca(\frac{meq}{L})+Mg(\frac{meq}{L})}{2}}} \qquad \text{Equation 2}$$

Shepherd Miller (1996) reported that a SAR value of 3 is the maximum value accepted with no restrictions in the state of Wyoming (for an electrical conductivity of less than or equal to 700 μomhos/cm). Calculated SAR values for Irrigator 1A ranged from 0.8 to 9.4 during the period of operation, and reported an overall average of 1.9. The maximum value of 9.4 was measured in the first year after irrigation began (1989) and the second highest value (4.7) was measured the following year (1990). The maximum SAR value between 1991 and 2004 (end of operation) was at 2.5. Calculated SAR values for Irrigator 2 ranged from 0.8 to 1.8 during the current period of operation (1995 through 2011).

2.2 Summary of Se Concentration Trends Observed in 2011

The 2011 Se concentrations in the irrigator water, soils, and vegetation demonstrate continued similar trends to those observed in 2010. Although Irrigator 1A is no longer operating, the soil concentration remains low (0.4 to 0.5 mg/kg at 6 to 12 and 0 to 6 inches depth, respectively) and are below the WDEQ (2012a) soil standard of 0.95 mg/kg. The average vegetation concentration remain at elevated levels (21.1 mg/kg in 2011 compared to 18.8 mg/kg in 2010). Vegetation Se concentrations showed a marked decrease from 2003 through 2008, following discontinuation of Irrigator 1A operations, but have increased from 2008 onward. The concentrations observed in the 2011 vegetation samples are not as high as the maximum observed (concentrations were as high as 30 mg/kg in 2002), but they continue to approach the maximum concentrations previously observed.

Se concentrations in the Irrigator 2 irrigation water have decreased markedly since 2009 when the new water treatment operations began. Irrigator 2 discharges in 2011 contained an average Se concentration of 0.014 mg/L, below the WDEQ (2012b) standard of 0.2 mg/L. The Se concentrations measured in the vegetation have mirrored this trend, although a slight increase was observed in 2011 relative to the 2010 concentrations. The concentrations are currently below the reference level of 0.5 mg/kg (as proposed in Sharmasarkar and Vance, 2002). Soil Se concentrations continue to be very low for the Irrigator 2 area (0.27 mg/kg in 2011).

3.0 UNSATURATED SOIL MODELING TO SIMULATE LAND APPLICATION OF WASTE WATER

3.1 Introduction

This section presents a field investigation and subsequent unsaturated soil-atmosphere modeling analyses". The objective of the modeling is to estimate soil and pore-water metal concentrations in the root zone over the life span of the land application. HYDRUS-1D, a groundwater model developed by the Department of Environmental Sciences, University of California (Simunek et. al., 2009), was used in this study. The modeling focused on Se (Se) concentrations. The output of the model was used to assess future ecological risk.

3.2 Field Investigation

Due to the importance of soil hydraulic properties to the unsaturated zone soil modeling analysis and risk analysis, additional soil data were collected and analyzed, as described below. On May 9, 2012 and June 6, 2012 Golder completed excavation of test pits at the SRH facility near Glenrock Wyoming. The locations of the test pits are shown in Figure 3. The May 9, 2012 activities included the excavation of four hand-dug test pits within Irrigator 2 with depths ranging from 1 to 1.5 feet below ground surface. The June 6, 2012 activities included the excavation of eight test pits with the use of a Caterpillar 450E excavator, provided by Cameco, with depths ranging from 6 to 6.8 feet. Four of these test pits were located within the inactive Irrigator 1A and four were located within the permitted, but unused, Irrigator 1B. Test pit logs including soil characteristics, excavation photographs, visual estimate of root density, and other notable observations are presented in Appendix A.

Samples of each soil unit encountered were collected from each test pit. Select samples were submitted to Golder's geotechnical laboratory in Lakewood, CO for PSD with hydrometer and specific gravity. The results of the PSD and specific gravity testing are summarized in Table 3. The PSDs are shown on Figure 4. The data in this figure include two samples collected previously for Irrigator 2 (Golder, 2009). The individual lab results are provided in Appendix B.

Table 3: Geotechnical Laboratory Results

Sample Number	Sample Depth	Grain Size Distribution % Finer	% Finer	% Finer	Specific Gravity
	(ft)	3/4"	#4	#200	
IRR2-2-1	0-0.5'	100	100	57	2.65
IRR2-2-2	0.5-0.85'	100	100	32	2.70
IRR2-2-4	1.35'	100	100	45	2.70
IRR2-4-1	0-1.5'	100	100	72	2.68
IRR1A-1-1	0-2.4	100	100	78	2.78
IRR1A-1-3	4.4-6.2	100	100	21	2.74
IRR1A-3-1	0-2.9	100	100	78	2.73
IRR1A-3-2	2.9-3.4	100	100	24	2.71
IRR1B-3-1	0-3.8	100	100	75	2.75
IRR1B-3-3	5.25-6	100	100	19	2.73
IRR1B-4-1	0-6.6	100	100	77	2.76
IRR2-1-1	0-1	100	100	75	2.70

Based on the test pits and the subsequent laboratory analysis, the soil near the surface is predominantly silt (identified as clay in the field based on physical properties, not grain size). Some layers of sand were also encountered. The shallowest sand encountered was present at a depth of 2.9 feet, which is below the typical root zone. In addition, Shepherd Miller (Shepherd Miller 1996) encountered clay from surface to 15 foot depth in three cores and 2 to 4.5 feet of clay over sand in three cores. The sand ranged from 2.5 to 11 feet thick. Considering all of the samples described in this section, the predominant material is silt. Roots from vegetation were generally concentrated between zero to 5 and zero to 8 inches depth in the soil profiles. Root depth details are provided later.

3.3 Soil Properties

Soil properties were estimated by identifying analog soils from the SoilVision™ (Fredlund 2004) database for the silt and sand encountered in the test pits. The PSD of soil samples from the site were used to identify analog soil samples from the database. Data quality and representativeness for the analog materials were then evaluated to choose one sample each as analogs for the silt and sand. The soil water characteristic curve (SWCC) and saturated hydraulic conductivity were estimated using the analog samples. Figure 5 provides the PSD for the silt samples and the analog (SV-10804) while Figure 6 provides the same for the sand (analog is SV-11320). Figure 7 provides the SWCC for the silt analog while Figure 8 provides the SWCC for the sand analog. Assuming a van Genuchten model to describe water retention (van Genuchten, 1980), the fitted parameters for the SWCC and the saturated hydraulic conductivity for each analog are provided on these figures.

3.4 Climate Data

The climate data required for input to the soil model are precipitation and parameters used to calculate potential evapotranspiration (PET) (wind speed, relative humidity, temperature, and solar radiation). Weather data from the mine site were available from November 2010 through February 2012. In addition, climate data for the nearby station at the Casper Airport (Station ID 481570) was obtained from the National Oceanic and Atmospheric Administration, National Weather Service Hydrologic Data Systems Group (NOAA NWS). Climate data for Casper are available from 1948 through 2012. The data include precipitation and maximum and minimum air temperatures. Long-term climate data for the site including precipitation and PET was calculated using the Casper data. Factors for precipitation and PET were calculated based on overlapping periods of record to adjust the long-term climate data available at Casper. PET was calculated for Casper using minimum and maximum air temperatures and the Hargreaves (1985) model (Hargreaves et al. 1985) as included in the Food and Agriculture Organization of the United Nations (FAO) irrigation paper (Allen et al. 1998). Figure 9 shows the relationship between precipitation at the site and Casper. Figure 10 shows the relationship between calculated PET at the site and Casper. PET was divided into evaporation and transpiration using the Ritchie and Burnett equation (Ritchie and Burnett 1971).

Based on 10-year running sums for precipitation, the 10-year average, dry, and wet periods were identified as summarized below-:

- Average 10-year period (2002 – 2011): 97.56 inches total precipitation;
- Wet 10-year period (1978 – 1987): 116.22 inches total precipitation;
- Dry 10-year period (1952 – 1961): 82.99 inches total precipitation.

These three sets of data were used to bracket likely future conditions for the modeling analysis and risk assessment.

3.4.1 Irrigation Data

The irrigation data required for input to the soil model are the irrigation rate, duration, and metals concentrations. Two areas have been used in the past to manage waste water, Irrigator 1A and Irrigator 2. Waste water was applied to Irrigator 1A from August 1989 to September 2004. Waste water was applied to Irrigator 2 from September 1995 to the present. Data on the historical irrigation practices were supplied by Cameco and are summarized in Section 2.1. For the soil-atmosphere model, daily irrigation was added to the daily precipitation while the metal concentration in the irrigated water was adjusted appropriately for days in which precipitation was recorded.

Future irrigator water quantity and quality were provided by Cameco operations on the basis of assumed future operations. It was estimated that 400 gallons per minute wastewater would be applied at each irrigator, over a 6-month period per year, with an average 0.05 mg/L Se concentration. Assumptions built into this estimate include: reverse-osmosis recovery of 75%, purge pond flow mass balance assuming a 45-inch/year evaporation rate, and pre-treatment concentrations based on a range of conditions covering Mine Unit C pre-restoration/post-mining concentrations as well as restoration target values for that mine unit.

3.5 Vegetation Data

For the soil-atmosphere model, three inputs were required to simulate transpiration by vegetation: root distribution with depth; leaf area index (LAI), which is the ratio of leaf area to ground area; and the water uptake parameters defining the relationship of transpiration with soil suction.

Root distribution with depth was defined using the data collected from the test pits. Figure 11 provides the root density with depth for each test pit. The relationship for roots observed at test pit location IRR2-2, which approximates the range observed and show that most roots occur between zero and 6 inch depths, was used for the model. LAI throughout the year was defined based on a grass ecosystem in an arid climate in Nevada. The maximum LAI was 0.63, typical for grasses. The water uptake parameters defined in the model were the default parameters in HYDRUS-1D available for pasture.

3.6 Model Selection

Transport modeling was completed using the public domain numerical soil-atmosphere software HYDRUS-1D. HYDRUS-1D solves a modified Richard's equation for liquid flow and a one-dimensional convection-dispersion equation for heat flow (Simunek et al. 2009). The governing equations are solved numerically using Galerkin-type linear finite element schemes. The HYDRUS-1D model code is widely accepted by the professional community for evaluating variably-saturated flow and transport processes.

3.7 Model Setup

Based on conditions observed during the field investigation, silt was the predominant soil type. Therefore the base case model consists of silt to a depth of 6 feet, which is beyond the effective depth of evaporation and transpiration given the climate, vegetation, and soil type. Therefore, water simulated as draining from the soil profile can be assumed to be net infiltration where net infiltration is defined as water that infiltrates deep into the soil and is not returned to the atmosphere through evaporation or transpiration. The top boundary condition of the model is atmospheric input with daily precipitation and evaporation. As described earlier, irrigation was added to recorded precipitation with the concentration adjusted to account for precipitation. The bottom boundary condition was defined as free drainage, which is equivalent to a unit vertical hydraulic gradient.

Prior to model calibration (described in the next section), a model was completed to condition the soil profile to the atmosphere. This provided initial conditions of soil moisture equilibrated to typical precipitation and PET, for the calibrated model. For each irrigator, the 20 years of climate preceding irrigation were applied prior to initiation of irrigation. In addition, background soil concentrations were available for Irrigator 1. The average background concentration of Se in the soil (excluding two outlier values) was input to the calibration model as an initial condition. Table 4 provides a summary of the background soil concentrations. The background soil concentration was used to calculate an equilibrium pore water concentration, which was input as an initial condition.

Table 4: Summary of Background Se Soil Concentrations

Depth Interval	Average mg/kg	Minimum mg/kg	Maximum mg/kg
0 to 6 inches	0.045	0.0078	0.095
6 to 12 inches	0.028	0.0040	0.082

Note: these data do not include two anomalous high values reported for Irrigator 1 background sites in 2001 and 2003

3.8 Model Calibration

Model calibration is required in order to obtain site-specific values for the partitioning and reaction behavior of metals in the unsaturated zone. For the purposes of this assessment, only transport of Se was simulated. A calibrated model was developed for Irrigator 1A, which has the longest period of data. Data used for the calibration included pore water concentrations from lysimeters and soil concentrations through time. For the purposes of calibration, the parameters adjusted to match the measured pore water and soil concentrations include:

- the adsorption isotherm coefficient (Kd), which defines the partitioning between pore water and soil;
- the zero order rate constant for the dissolved phase, which approximates pore water Se losses (for example by microbially-mediated volatilization);
- the zero order rate constant for the solid phase, (modeled as a small effect); and
- the first order rate coefficient for nonequilibrium adsorption, which approximates soil Se losses (for example by microbially-mediated volatilization).

Adjusting these parameters was effective in obtaining a reasonable calibration to pore water and soil concentrations for Se. In addition, the maximum passive root uptake was permitted in the modeling. Table 5 provides the calibrated parameters. The calibrated Kd value shown in this table (9.6E-4 cm^3/mg) falls in the range of observed values calculated as described in Section 2.1 (3.4E-4 to 4.3E-2 cm^3/mg).

Table 5: Calibrated Parameters for Irrigator 1A

Adsorption Isotherm Coefficient (Kd)	Zero Order Rate Constant, Dissolved Phase	Zero Order Rate Constant, Solid Phase	1st Order Rate Coefficient for Nonequilibrium Sorption
cm^3/mg	mg/cm^3/day	1/day	1/day
9.6E-04	2E-07	1E-12	1E-03

Figures 12 through 14 provide the results from the calibrated model for Irrigator 1A compared to the measured soil and pore water concentrations. Figure 12 shows the depth-averaged, measured Se concentration in soil compared to the average simulated Se concentration over the same depth intervals, from surface to a depth of six inches, and from six to twelve inches depth between 1989 and 2011. The simulated Se concentrations fall within the range of average observed concentrations. Figure 13 shows the minimum and maximum measured Se concentration in soil which shows a much wider range in the measured data. Over a shorter time period (1993 to 2003) soil pore water concentration data are available for Irrigator 1A. These data are compared to model-predicted values in Figure 14. This figure shows the simulated Se concentrations in pore water are within the range of measured concentrations, although the yearly variation in concentrations are not simulated. The overall model calibration is considered appropriate to predict Se concentrations in soil to be used for the risk assessment.

Figures 15 and 16 provide a comparison of measured and simulated Se concentrations in the soil for Irrigator 2 using the calibrated parameters developed for Irrigator 1A. The simulated Se concentrations are within the range of measured concentrations. The simulated Se concentrations in soil from surface to six inches depth are generally greater than the measured concentrations. This is conservative because simulations completed to predict Se concentrations in the future will similarly over-estimate shallow soil Se concentrations. The match between simulated and measured concentrations at Irrigator 2 is considered appropriate to predict Se concentrations in soil to be used for the risk assessment.

3.9 Predictive Simulations

Future irrigation is expected at one or more irrigators over a ten-year period. In order to predict Se concentration in the soil, a base case model was developed that represents the most likely conditions expected for irrigation. The base case model consists of six feet of silt with an average 10-year climate set and irrigation applied at 400 gallons per minute and 0.05 mg/L Se concentration (Cameco 2012). In addition to the base case model, additional simulations were completed to evaluate the sensitivity of the predicted Se concentration in soil to various input parameters. The simulations listed below were completed for both Irrigator 1A and Irrigator 2.

- Base case: Average climate, silt, irrigation with waste water;
- Wet climate, silt, irrigation with waste water;
- Dry climate, silt, irrigation with waste water;
- Average climate, silt, irrigation with clean water; and
- Average climate, 3 ft silt and 3 ft sand, irrigation with waste water.

For each simulation listed above, the initial conditions were defined by the final conditions from the calibrated models. In addition to the simulations listed above, an additional simulation was completed using the background soil and water concentrations discussed earlier and irrigating with waste water to simulate the use of a new area for irrigation, such as Irrigator 1B.

3.10 Results and Recommendation

Figures 17 through 27 provide the predicted Se concentration in soil for the models described above. Note the Se concentration applied for the predictive simulations (0.05 mg/L) is relatively low compared to the concentration of Se applied in the waste water for both irrigators in the past.

Predicted future Se concentration in soil ranges from 0.1 to 1 mg/kg for all of the simulations except for those for the new irrigator, which is similar to the measured concentrations from Irrigator 1A and Irrigator 2. The base case predictive simulations for Irrigators 1A and 2 predict that shallow (0-12 inch depth) soil Se concentrations will reduce with time while deeper soil concentrations will continue to slowly increase. Based on comparing simulations using different climate sets (average, dry, wet), predicted Se concentration in the soil is relatively insensitive to climate. Predicted Se concentration is sensitive to the simulated soil properties based on comparing results from the base case simulation and the simulation with three feet of sand under three feet of silt. The predicted Se concentration in the soil decreases over time at shallow depths when irrigating with clean water. However, deeper portions of the profile are relatively unaffected compared to the base case simulation, likely due to the low hydraulic conductivity of the silt. Predicted Se concentration in the soil is very similar for Irrigator 2 compared to Irrigator 1A except that Se concentrations near the surface are higher for Irrigator 2. This is a direct result of using the final concentrations from the calibrated model for Irrigator 2, which showed higher concentrations near the surface. If a new irrigation area is used, predicted Se concentration in the soil gradually increases from the background level to concentrations similar to Irrigator 1A and 2 over the simulated 10-year period.

If significantly, higher Se loadings than those modeled here are applied in the future, then more detailed analyses may be warranted. Further work for this project could include deriving site-specific adsorption distribution coefficients by measuring co-located porewater and soil concentrations, and saturated hydraulic conductivity and soil water characteristic curves for the silt and sand. As shown by the sensitivity simulations using silt and sand, the predicted results are sensitive to material properties.

Additional efforts could also focus on calibrating flow with the soil-atmosphere model using measured soil moisture. This was beyond the scope of the current effort. If calibration of flow is considered, additional data on soil moisture may be necessary.

4.0 SCREENING-LEVEL ECOLOGICAL RISK ASSESSMENT

4.1 Introduction

This report section details a screening-level ecological risk assessment (SLERA) for Se at the Irrigator 1A, 1B, and 2 areas of the Smith Ranch-Highlands facility (see Figure 28 and background information in Section 2.1) using current measured data and future modeled soil concentrations after irrigation with mine process water. In this SLERA, Golder evaluated the potential for risk to plants, soil invertebrates, and wildlife from Se in the irrigation water, both currently and up to 10 years in the future.

4.1.1 Background Information

This SLERA evaluates the potential for risk from Se to plants, soil invertebrates, and wildlife that may inhabit the two irrigation areas through the next 10 years of mining operations from water used in irrigation. The mine is expected to cease operations after 10 more years of operations, based on discussions with the mine operator. Results from this SLERA should be used to establish the need for further risk evaluation with additional Site data, if warranted. Alternatively, results of this conservative SLERA can be used to directly support remedial actions in lieu of a more comprehensive risk assessment should this be desired by the client.

This SLERA utilizes the results of limited empirical soil and vegetation sampling data, and future modeling of the fate of Se in the irrigation water applied to Site soil, as presented in earlier report sections. These data are used to evaluate whether Se in the irrigation water may result in potential adverse ecological effects. Given the screening nature of this assessment and the predictive nature of the analyses regarding chemical fate, transport and exposure, generally conservative assumptions are used throughout the analysis to ensure it errs on the side of receptor protection.

This SLERA Section is organized as follows:

- Section 4.2: Problem Formulation: including a discussion of the environmental setting, existing data, potential receptors, assessment endpoints, and the preliminary conceptual site model (CSM);
- Section 4.3: Exposure Assessment: including a summary of the hydrogeochemical fate model, model results for Se concentration in soil given the expected concentrations of Se in the irrigation water, and information on biota and wildlife uptake of Se from the soil, and vegetation through direct and food chain pathways;
- Section 4.4: Effects Assessment: includes an evaluation of toxicity reference values (TRVs) for ecotoxicity of Se to various site receptors;
- Section 4.5: Risk Characterization: the evaluation of measured (current conditions) and predicted (future conditions) soil concentrations with ecological soil screening levels and comparison of predicted food chain exposure with TRVs. This section also summarizes and discusses the key uncertainties of this SLERA ;
- Section 4.6: Calculated Protective Soil Concentration for Wildlife;

- Section 4.7: Conclusions and Recommendations: summarizes the key findings from the SLERA.

4.2 Problem Formulation

This section presents a description of the existing data for the irrigation area, a discussion of the environmental setting including the potential ecological receptors evaluated in the SLERA and a preliminary CSM which illustrates how the potential ecological receptors could be exposed to Se in irrigation water. The issues we are evaluating in this SLERA are:

- Evaluate current potential risk from Se to plants, soil invertebrates, and wildlife from soil and vegetation data that have been collected in each of the irrigation areas.
- Evaluate future predicted potential risk from Se to plants, soil invertebrates, and wildlife from geochemical modeling of soil concentrations given a future concentration of 0.05 mg/L of Se in the irrigation water in each irrigation area.
- Given the estimated wildlife doses of Se, calculate a "safe" concentration of Se in the soil that can be used to predict a "safe" concentration of Se in the irrigation water for birds and mammals that may feed in the irrigation areas.

4.2.1 Environmental Setting

The irrigation areas (see Figure 28) occur in an otherwise undisturbed rangeland supporting a native grassland community (Shepherd Miller 1996) in the Northwestern Great Plains Ecoregion (USEPA 2011). The climate is generally semi-arid, with annual precipitation approximately 12 inches per year and approximately 32 inches per year of net evaporation (Power Resources 1995). The yearly average minimum and maximum temperatures are about 31.5 and 61.5 °F (WRCC 2008), with an average minimum of 12.4 °F in December and an average maximum of 91.1 °F in July.

4.2.2 Existing Site Data

Existing analytical data for the Site were compiled by Golder from historical documentation provided by Cameco. For the Irrigator 1A area, irrigation water data for Se, arsenic, barium, boron, uranium, and radium-226 have been collected several months per year since 1989. Soil data for the same constituents generally were collected from 14 locations once per year from 1990 through 2006. Background soil data for both the 0-6 inch and 6-12 inch depths were collected from one location from 1996 through 2006. The soil samples were analyzed for boron, arsenic, and Se after extraction from the soil with aluminum-bicarbonate diethylene triamine pentaacetic acid (AB-DTPA), which provides a concentration of metals that is correlated with plant uptake (Carter and Gregorich 2007). Note that this is not the same as the total metal concentration, as is the basis for ingestion by wildlife. However, it is used in this SLERA to represent the amount of Se currently in the soil since we do not have other historical site data. Please see Addendum—Selenium Speciation Data for further information on this. Vegetation concentrations for Se, arsenic, barium, boron, uranium, and radium-226 were collected from the same locations as soil samples then composited for each quadrant that the samples are located in (i.e., NE, NW, SW, SE).as well as one sample in a background location annually in June from 1991 through 2010 and analyzed for total concentrations of the same metals as the irrigation water. There has been good general concordance between the ABDTPA-extractable Se in the top 12 inches of soil with vegetation concentrations at the site.

For the Irrigator 2 area, the same general data were collected. Irrigation water data for Se, arsenic, barium, boron, uranium, and radium-226 have been collected several months per year since 1995. Soil data were collected from 16 locations once per year from 1993 through 2011. Again, the boron, arsenic, and Se concentrations were determined after AB-DTPA extraction and are not total soil concentrations. Vegetation samples were collected in the same locations as soil samples then composited for each quadrant that the samples are located in (i.e., NE, NW, SW, SE).as well as one sample in a background location annually in August from 1993 through 2011 and analyzed for total concentrations of the same metals as the irrigation water. There has been good general correlation between the AB-DTPA-extractable Se in the top 12 inches of soil with vegetation concentrations at the site.

4.2.3 Potential Ecological Receptors

Receptors are defined as any entity (plant or animal) that may have contact with an environmental exposure media (soil, etc.) through one or more defined pathways of exposure (discussed in Section 1.3 below). Potential plant receptors at the Cameco Site are largely grasses and shrubs. Plant surveys in the irrigation areas have documented the presence of the following species (Shepherd Miller 1996, Golder 2010), primarily native cool season perennial grasses (Power Resources 1993, 1995):

- Smooth brome (*Bromus inermis*);
- Japanese brome (*Bromus japonicas*);
- Western wheatgrass (*Agropyron smithii*);
- Intermediate wheatgrass (*Agrypyron intermedium*);
- Crested wheatgrass (*Agropyron crestatum*);
- Kentucky bluegrass (*Poa pratensis*);
- Alfalfa (*Medicago sativa*);
- Blue grama (*Bouteloua gracilis*); and
- Cheatgrass (*Bromus tectorum*).

Other plant species potentially present in the area include shrubs, such as sagebrush (*Artemisia sp.*). Based on collection of plants for Se concentration monitoring (see Section 2.1), roots are generally limited to the 0-6-inch depth in the irrigation areas. However, deeper soils also are evaluated in this SLERA since small mammals can access deeper soils through burrowing activities, and because it is possible that surficial soils could be removed by Cameco in the future, thus exposing the deeper soils to receptor species.

Potential animal receptors in the vicinity of the Site were determined from a detailed publication by the Wyoming Game and Fish Department (Orabona et al. 2009) which shows species presence by area of the state including a Site survey for birds conducted by the US Fish and Wildlife Service (Ramirez and Rogers 2000). Receptors also were selected to represent different feeding guilds and to ensure the SLERA evaluates appropriate surrogate receptors for the various food chain pathways. General bird and mammal species representing different feeding guilds that may occur in the area around the Site include:

- Ground-dwelling herbivorous bird: greater sage grouse (*Centrocercus urophasianus*);
- Insectivorous / invertivorous birds: American robin (*Turdus migratorius*), red-winged blackbird (*Agelaius phoeniceus*), western meadowlark (*Sturnella neglecta*), lark bunting (*Calamospiza melanocorys*);
- Carnivorous birds: burrowing owl (*Athene cunicularia*), Swainson's hawks (*Buteo swainsoni*);
- Small herbivorous mammals: deer mouse (*Peromyscus maniculatus*), prairie vole (*Microtus ochrogaster*), desert cottontail (*Sylvilagus audubonii*);
- Small insectivorous / invertivorous mammals: Merriam's shrew (*Sorex merriami*), masked shrew (*Sorex cinereus*);
- Large herbivorous mammals: pronghorn antelope (*Antilocapra americana*) mule deer (*Odocoileus hemionus*), domestic livestock;
- Carnivorous mammals: coyote (*Canis latrans*), red fox (*Vulpes vulpes*);
- Reptiles: bullsnake (*Pituophis catenifer sayi*), greater short-horned lizard (*Phrynosoma hernandesi*); and
- Amphibians: tiger salamander (*Ambystoma mavortium*), American bullfrog (*Rana catesbeiana*).

The potential federal threatened and endangered species that could occur at the Site (USFWS 2012) is the Greater sage-grouse, which is a candidate avian species that occurs in sagebrush communities. The greater sage-grouse is included as the surrogate species for a ground-dwelling herbivorous bird feeding guild.

A surrogate species was selected for each feeding guild for evaluation in this SLERA. These species were those either most likely to occur near the Site given known habitat conditions or hypothesized to have the highest exposures to Se in Site soils and biota, since smaller animals generally have higher body-weight normalized food ingestion rates. In addition to the greater sage grouse, the birds selected as surrogate receptor species for the SLERA were the American robin and the burrowing owl. The robin is a standard risk species due to its ubiquitous distribution, and the burrowing owl was selected since it may have a higher soil ingestion rate and a larger normalized food ingestion rate compared to other avian carnivores, such as a hawk or eagle. Since burrowing owls also have a smaller home range than hawks (EPA 1999), they could spend a higher proportion of their time feeding at the Site. The mammals selected as surrogate species were the deer mouse, Merriam's shrew, mule deer, cow, and coyote. They were chosen based on their likely presence near the Site and overall availability of exposure data. Reptiles may occur in the area, but are not evaluated further in this SLERA due to a lack of established toxicity data. The SLERA for birds and mammals are expected to be protective of reptiles that may occur in the irrigation area. Amphibians are not expected to occur at the Site given the lack of water bodies in the irrigation area and nearby, and are not evaluated further.

4.2.4 Assessment Endpoints

Assessment endpoints are explicit statements of the environmental values to be protected at a Site and are operationally defined by an ecological entity and its attributes (EPA 1998). Examples of ecological entities include a species, community of species, or functional group of species (e.g., vegetation-eating organisms), among others (EPA 1998). The second element of establishing assessment endpoints for an ecological risk assessment is identification of the characteristic of the ecological entity that is important to protect and that is potentially at risk, such as reproductive success (EPA 1998). The assessment endpoints established for this SLERA are as follows:

- Protection of the richness and abundance of terrestrial plants and soil invertebrates against chemical impacts to their survival, growth, and reproduction as a result of exposure to water from irrigation; and
- Protection of the richness and abundance of terrestrial birds and mammals against chemical impacts to their survival, growth, and reproduction as a result of exposure to water from irrigation and subsequent environmental accumulation.

Assessment endpoints typically cannot be directly quantified, so one or more representative measures are usually identified. There are three types of measures typically used (USEPA 1998): (1) measures of effect (e.g., toxicity data), (2) measures of exposure (e.g., soil or vegetation data), and (3) measures of ecosystem and receptor characteristics (e.g., species abundance). In this SLERA, data for the Site are only available to evaluate the first two of these measures. However, the assessment endpoints articulated above do specifically incorporate protection of species richness and abundance through the selection of conservative soil screening levels and TRVs that are protective of survival, growth, and reproductive success. It should be noted that although migratory birds could utilize the site for part of the year, this assessment is focused on potentially resident species that could have long-term exposures. The exposures of the resident species should be greater than any of the transient species, and hence will be protective of migratory birds.

In summary, measures of exposure for the SLERA include predicted concentration data for Se in the irrigation water and soil (presented previously in Section 2.0), as well as predicted concentrations of Se in plants and soil invertebrates using literature-derived soil Se uptake factors. Measures of ecological effects in this SLERA include toxicity data for plants and soil invertebrates, and chronic (i.e., long-term exposures) toxicity data for Se derived from the scientific literature. The USEPA Ecological Soil

Screening Levels (EcoSSLs) provide existing regulatory TRVs developed specifically for screening assessments and were a key source of TRVs in this SLERA. A search of recent published terrestrial plant and animal literature was performed by Golder to investigate any additional studies of Se toxicity to support updating TRVs.

4.2.5 Conceptual Site Model

Figure 28 shows the CSM detailing pathways of Se exposure for biota within both the Irrigator 1A, 1B, and 2 irrigation areas of the Site. Irrigation water from mining processes generally will be applied to the irrigation areas from May to October at an average of 400 gallons per minute. When irrigation occurs, mine process water is applied aerially onto the soil and plant surfaces. Localized and transient ponding of the irrigation water may occur on occasion. Se in the irrigation water is available for plant uptake, soil invertebrate uptake, bird and small/large mammal uptake via soil ingestion and dietary pathways. Pathways of exposure for these receptors are depicted in Figure 28 and include incidental surface soil ingestion, irrigation water ingestion, ingestion of plant material growing and potentially accumulating metals from irrigation water / soil, ingestion of soil invertebrates (e.g., earthworms) that may accumulate Se from the soil and become a food source, and ingestion of small mammals that occur in the irrigation area and have potentially accumulated Se from ingestion of soil and plants.

Given the focus of existing Site data on permit compliance activities there is an understandable lack of site-specific biomonitoring data to support site-specific food chain modeling for representative species that could be present at the Site. The herbivorous animals assumed to be potentially exposed to soil and vegetation in the irrigation areas are small mammals (deer mouse), large mammals (mule deer), livestock (cattle), and birds (sage grouse). The animals that may consume soil invertebrates are represented by a robin and Merriam's shrew, while carnivorous mammals (coyote) and birds (burrowing owl) are assumed to consume small mammals living at the Site. Livestock occur near the Site, but have incomplete current exposure pathways to Site forage because the Site is currently fenced. However, they are evaluated herein to investigate the potential impact if the fencing was not intact in locations or should it be removed in the future. Large grazers (pronghorn, mule deer) are not fenced out at this time. This assessment used a conservative assumption that these animals only forage on the irrigation are, while acknowledging that a typical mule deer home range consists of about 2,780 acres (EPA 1999), which is much larger than the irrigated area.

To evaluate conservative worst-case exposures, the representative animal in each feeding guild is assumed to eat 100% of one food source only (e.g., a carnivorous mammal [coyote] is assumed to only eat small mammals [mice] and incidental soil and irrigation water). Omnivorous animals are not evaluated in this SLERA since their exposures will be lower than that of the feeding guilds evaluated using conservative exposure assumptions.

4.3 Exposure Assessment

The potential for adverse exposure to Se of plants and animals at the Site was evaluated two ways. First, measured (i.e., current conditions) or modeled (future scenario) soil concentrations of Se were compared with readily available regulatory risk-based ecological benchmarks (i.e., Ecological Soil Screening Levels, EcoSSLs). Where exceedances of these benchmarks were identified, additional Se exposure evaluations were undertaken for wildlife receptors to assess intake from all Se ingestion exposure pathways. Ingestion pathways are considered the primary exposure routes to soil-based contaminants. Other routes such as inhalation and skin contact are considered secondary pathways that typically contribute significantly less to total exposure (EPA 2005).

The remainder of this section summarizes the data and calculations used to estimate model data used in the wildlife exposure evaluations, including how concentrations were estimated in irrigation water, soil, and wildlife foods. Finally, a summary is provided of how wildlife doses were estimated using these concentrations for the wildlife receptors previously identified.

4.3.1 Irrigation Water Se Concentrations

The concentrations of Se in the irrigation water have been monitored since irrigation operations began in the 1990s. Se has varied from 0.01 to 2.25 mg/L in the irrigation water. The most recent measurements were 0.646 mg/L in the Irrigator 1A area (from July 2003) and 0.01 mg/L in the Irrigator 2 area (from July 2011). Cameco expects the future concentration of Se in the irrigation water to stay at or below 0.05 mg/L. For the purposes of this SLERA, future soil Se concentrations and irrigation water concentrations for drinking were estimated based on an irrigation water Se concentration of 0.05 mg/L.

4.3.2 Soil Concentrations of Se

Sampling of soils and vegetation from the Irrigator 1A and Irrigator 2 areas has occurred since prior to the start of mining activities in 1983. The most recent sampling results from 2011 were used to represent current concentrations of Se in the soil for the Irrigator 2 area, while the last measured soil value for the Irrigator 1A area was in 2010 (Table 6). As mentioned previously, the Se concentrations have been measured as the AB-DTPA-extractable fraction. Although this may represent the plant bioavailable fraction, this may not represent the Se available to wildlife after ingestion. These measurements were available for the 0-6-inch and 6-12-inch soil depths for 14 locations in the Irrigator 1A irrigation area and for 16 locations in the Irrigator 2 irrigation area. The maximum and 95% upper confidence limit (UCL) of the mean concentrations were used to estimate current conditions across the Irrigator 2 area. For plants, the use of the maximum concentration is most applicable for screening-level assessments since plants are not mobile and can theoretically be exposed to a maximum soil concentration in a "hot spot" area. Since animals that are able to move around the Site are exposed to an averaged concentration over a larger area, the use of the 95% UCL of the mean concentration is appropriate to conservatively estimate their exposures.

Table 6: Historic Se Soil Concentration in Irrigator1A and Irrigator 2 Areas

Soil Depth	95% UCL [A] (mg/kg dw) / Distribution Used	Maximum (mg/kg dw)
Irrigator 1A		
0-6 inches	-[C]	0.05
6-12 inches	-[C]	0.30
Irrigator 2 [B]		
0-6 inches	0.85 / 95% Chebyshev	1.4
6-12 inches	0.315 / Normal	0.48

Notes: dw = dry weight
A) 95% Upper Confidence Limit calculated using ProUCL v. 4.1
B) Value is AB-DTPA extractable Se, not the total fraction
C) 95% UCL was not calculated for Irrigator 1A due to the limited availability of data

The modeling results, as described in Section 3.0, were used to assess potential future risk over the next 10 years of irrigation. The results for soil porewater concentration and adsorbed concentrations of Se on soil particles were combined to determine the total soil concentration of Se for comparison to EcoSSLs (and for use in estimating food chain uptake). The following equation was used:

$$Total\ Soil\ Se = (Sorbed\ Se \times CF1) + (porewater\ Se \times density\ water \times soil\ moisture \times CF2)$$

Equation 3

Where:

Total Soil Se:	Total concentration in soil (mg/kg dry weight)
Sorbed Se:	Model derived concentration of Se adsorbed onto soil particles (mg Se / mg soil [dry weight])
CF1:	Conversion factor, 1,000,000 mg soil / 1 kg soil
Porewater Se:	Model derived Se concentration in soil porewater (mg Se / mL porewater)
Water density:	Conversion factor (adjusts volume to weight), 1 mL water / 1 g water
Soil moisture:	Model derived soil moisture (%, g water / g soil [assumed dry weight])
CF2:	Conversion factor, 1,000 g soil / 1 kg soil

Using this equation, the maximum total soil concentration over the next 10 years was calculated and used in the SLERA for each of the soil depth profiles (0-6 inches, 6-12 inches, 12-18 inches, 18-24 inches, and 24-36 inches) for each of the climate scenarios modeled (see Section 3.4). The climate scenarios include dry climate, average climate, wet climate, no Se in the irrigation water, and an alternate soil column assumption in which a sand layer existed in purely silty soil. For Irrigator 1Aarea, an additional scenario of no current soil Se was included to evaluate Se behavior in the soil if an additional irrigation area, such as Irrigator 1B, were to be utilized in the future. Tables 7a and 7b summarize the maximum modeled soil concentration over the next 10 years by soil depth interval for the climate scenarios considered for the Irrigator 1A and Irrigator 2 areas, respectively. Even though the rooting depth of the grasses observed in both irrigation areas was largely in the 0-6 inch depth, the other depths were investigated to evaluate accumulations at depth that could be encountered by burrowing animals or deep rooted plants.

Table 7a: Modeled 10-Year Total Se Soil Concentration in Irrigator 1A Area

Soil Depth, Climate	Average (mg/kg dw)	Maximum (mg/kg dw)
0-6 inch		
Average climate	0.3216	0.5908
Wet climate	0.2578	0.4493
Dry climate	0.2863	0.5439
Average climate w/o irrig. Se	0.1766	0.2914
Silt and Sand	0.3632	0.7485
New irrigation	0.2085	0.4671
6-12 inch		
Average climate	0.3546	0.4972
Wet climate	0.3402	0.4803
Dry climate	0.3708	0.4851
Average climate w/o irrig. Se	0.2983	0.4897
Silt and Sand	0.2416	0.3320
New irrigation	0.1211	0.1994
12-18 inch		
Average climate	0.3925	0.4340
Wet climate	0.3824	0.4311
Dry climate	0.4152	0.4586
Average climate w/o irrig. Se	0.3536	0.4288
Silt and Sand	0.3280	0.4073
New irrigation	0.1305	0.2258
18-24 inch		
Average climate	0.4237	0.5095
Wet climate	0.4160	0.4771
Dry climate	0.4275	0.5213
Average climate w/o irrig. Se	0.4048	0.4702
Silt and Sand	0.4325	0.4900
New irrigation	0.1313	0.2359
24-36 inch		
Average climate	0.4378	0.5483
Wet climate	0.4408	0.5364
Dry climate	0.4296	0.5591
Average climate w/o irrig. Se	0.4327	0.5349

Soil Depth, Climate	Average (mg/kg dw)	Maximum (mg/kg dw)
Silt and Sand	0.5039	0.5973
New irrigator, such as Irrigator 1B	0.1290	0.2339

Notes: Model descriptions are provided in Section 3.9

Table 7b: Modeled 10-Year Total Se Soil Concentration in Irrigator 2 Area

Soil Depth, Climate	Average (mg/kg dw)	Maximum (mg/kg dw)
0-6 inch		
Average climate	0.4732	0.7746
Wet climate	0.3898	0.6678
Dry climate	0.4213	0.7063
Average climate w/o irrig. Se	0.3259	0.6235
Silt and Sand	0.5698	1.007
6-12 inch		
Average climate	0.3573	0.4994
Wet climate	0.3463	0.4911
Dry climate	0.3775	0.4766
Average climate w/o irrig. Se	0.3011	0.4815
Silt and Sand	0.3455	0.5311
12-18 inch		
Average climate	0.3722	0.4196
Wet climate	0.3675	0.4184
Dry climate	0.3921	0.4429
Average climate w/o irrig. Se	0.3344	0.3805
Silt and Sand	0.4452	0.5987
18-24 inch		
Average climate	0.3971	0.4887
Wet climate	0.3926	0.4594
Dry climate	0.3961	0.4959
Average climate w/o irrig. Se	0.3795	0.4509
Silt and Sand	0.5490	0.6462
24-36 inch		
Average climate	0.3911	0.5050
Wet climate	0.3974	0.4984
Dry climate	0.3819	0.5121
Average climate w/o irrig. Se	0.3866	0.4926
Silt and Sand	0.4811	0.5927

Notes: Model descriptions are provided in Section 3.9

4.3.3 Estimated Se Concentrations in Wildlife Food Chain Compartments

No co-located samples of soil and plants or soil with other biota have been collected to provide a site-specific data on Se uptake from the Site soil into wildlife food chain compartments. Accordingly, concentrations of Se in wildlife foods were estimated based on measured or modeled future concentrations. Estimated food chain concentrations were based on published studies from the scientific literature covering a range of soil conditions.

The EPA's EcoSSL guidance document (EPA 2007b) identifies models for evaluating the uptake of Se from soil into plants, earthworms, and small mammals (Table 8). For plants, the model for estimating Se uptake is as reported by Betchel Jacobs (1998), which predicts plant concentrations of Se from total soil concentrations of Se. The earthworm Se uptake model used was from Sample et al. (1998a), which predicts earthworm Se concentrations from total soil Se concentrations. The small mammal Se uptake was estimated using the model by Sample et al. (1998b), which predicts small mammal tissue concentrations based on total soil concentrations. The estimated concentrations in these wildlife foods were used as input parameters to the wildlife dose model discussed below.

Table 8: Uptake Equations for Se

Soil to Plants	Soil to Invertebrates	Soil to Small Mammals
ln(Cp)=1.104 x ln(Cs) -0.677	ln(Ce)=0.733 x ln(Cs) -0.075	ln(Cm)=0.3764 x ln(Cs) -0.4158

Notes: ln = natural logarithm
Cp = plant concentration (mg/kg dry weight)
Cs = soil concentration (mg/kg dry weight)
Ce = earthworm (soil invertebrate) concentration (mg/kg dry weight)
Cm = small mammal concentration (mg/kg dry weight)

4.3.4 Estimated Wildlife Doses

The total wildlife receptor exposures to Se in the irrigation areas represent the sum of several potential consumption pathways which will vary by receptor. These consumption exposures include the following pathways:

- Ingestion of forbs / vegetation;
- Ingestion of soil invertebrates (e.g., earthworms);
- Ingestion of small mammals;
- Incidental ingestion of soil while feeding; and
- Ingestion of irrigation water.

The wildlife exposure parameters used (Table 9) were readily available from risk assessment guidance documents (federal, state) and from other researchers (EPA 1993, 1999; Sample et al. 1997; USACHPPM 2004; WA DOE 2007). Allometric equations were used to predict food ingestion rates based on organism body weight where empirical data were lacking. Where certain exposure parameter data specific to a Site receptor was lacking, exposure data for a related surrogate was used. For example, no soil ingestion data are available for the sage grouse; therefore, soil ingestion data for turkeys, another mostly herbivorous ground-bird, were used (Beyer et al. 1994). Cow forage consumption was assumed at 37.5 lbs. / day (dry weight) based on a cow weighing 1250 lbs. (Carter 2008), and eating up to 6.8% of their diet as soil based on data for bison (Beyer 1994).

Table 9: Wildlife Exposure Data

Receptor	Value	Source
Food Ingestion Rate (kg dw / kg-d)		
Sage Grouse	0.04014	Sample et al. 1997
Robin	0.207	WA DOE 2007
Burrowing Owl	0.113	EPA 1999 (Allometric based on Nagy 1987)
Deer Mouse	0.1616	USACHPPM 2004 (Allometric for rodents, Nagy 1987)
Merriam's Shrew	0.0416	EPA 1999 (Allometric based on Nagy 1987)
Mule Deer	0.0219	Sample et al. 1997
Cow	0.02998	Carter 2008
Coyote	0.1455	EPA 1999
Soil Ingestion Rate (kg dw / kg-d)		
Sage Grouse	0.00373	Beyer 1994 (adapted from similar species)
Robin	0.0215	WA DOE 2007
Burrowing Owl	0.01693	USACHPPM 2004
Deer Mouse	0.00323	Beyer 1994 (adapted from similar species)
Merriam's Shrew	0.001	Beyer 1994 (adapted from similar species)
Mule Deer	0.00044	Beyer 1994 (<2% of FIR)
Cow	0.00203	Beyer 1994 (adapted from similar species)
Coyote	0.00407	EPA 1999
Water Ingestion Rate (L / kg-d)		
Sage Grouse	0.04014	EPA 1999 (allometric based on body weight)
Robin	0.1373	EPA 1999 (allometric based on body weight)
Burrowing Owl	0.1103	EPA 1999 (allometric based on body weight)
Deer Mouse	0.1450	EPA 1999 (allometric based on body weight)
Merriam's Shrew	0.1464	EPA 1999 (allometric based on body weight)
Mule Deer	0.06437	EPA 1999 (allometric based on body weight)
Cow	0.05251	EPA 1999 (allometric based on body weight)
Coyote	0.07653	EPA 1999 (allometric based on body weight)
Body Weight (kg)		
Sage Grouse	1.4 – 2.9	Cornell 2012
Robin	0.0773	EPA 1993
Burrowing Owl	0.15	EPA 1999
Deer Mouse	0.022	USACHPPM 2004

Receptor	Value	Source
Merriam's Shrew	0.02	EPA 1999
Mule Deer	59-74	Sample et al. 1997
Cow	567	Carter 2008
Coyote	13.13	EPA 1999

Notes: dw = dry weight

The model used to estimate the wildlife receptor dose of Se is as follows:

$$Dose = AUF \text{ x } ([Biota\ conc. \text{ x } Bb \text{ x } FIR] + [Soil\ conc. \text{ x } Bs \text{ x } SIR] + [Water\ conc. \text{ x } Bw \text{ x } WIR])$$

Equation 4

Where:

AUF: Area use factor (unitless). Irrigated area (acres) divided by animal home range (acres). A value of 1.0 was conservatively used for this screening assessment for all species.

Biota conc: Concentration of Se in the ingested biota (plants, earthworms, or small mammals) (mg chemical / kg biota – dry weight).

FIR: Food ingestion rate (kg biota [dry weight] per kg body weight per day).

Bb: Bioavailability (unitless) of Se from biota ingested). A value of 1.0 was conservatively used for this screening assessment for all species.

Soil conc. Concentration of Se estimated in the soil (mg chemical / kg soil – dry weight).

SIR: Incidental soil ingestion rate (kg soil [dry weight] per kg body weight per day).

Bs: Bioavailability (unitless) of Se from soil. A value of 1.0 was conservatively assumed for this screening assessment.

Water conc.: Concentration of Se in the irrigation water (mg/L).

Bw: Bioavailability (unitless) of Se from water. A value of 1.0 was conservatively assumed for this screening assessment.

WIR: Water ingestion rate (L per kg body weight per day).

4.4 Effects Assessment

The first determination of possible effects for ecological receptors at the Site is accomplished by making a comparison of predicted soil concentrations to risk-based regulatory benchmarks. The risk-based benchmarks for Se are represented by the EPA EcoSSLs (EPA 2007). The EcoSSLs (Table 10) are used as a first screen for Se to determine the potential for toxicity to plants, soil invertebrates, birds, and mammals. These are conservative values meant to be protective for all potential exposures based on a range of reported effect concentrations from the scientific literature. The EcoSSLs for birds and mammals for Se represent the lowest soil screening value from each of the feeding guilds considered: herbivores, insectivores, and carnivores.

Table 10: EPA EcoSSLs for Se (mg/kg – dry weight of soil)

Plants	Soil Invertebrates	Birds	Small Mammals
0.52	4.1	1.2	0.63

Notes: EPA (2007)

In the case where an exceedance of an EcoSSL for higher trophic receptors (e.g., birds, mammals) occurred based on the exposure concentrations across the soil depth interval and climate scenarios evaluated, a more in-depth food chain dose calculation was performed for wildlife species. As discussed above, the dose, or intake of Se, is based on a combined intake by a wildlife receptor from water, food and soil ingestion pathways.

The TRVs used for evaluating the wildlife food chain pathways were also derived from the EcoSSL (EPA 2007) and correspond to the highest bounded "no observed adverse effect levels (NOAELs) reported in the literature" for toxicity endpoints addressing reproduction, growth, and survival. The use of the NOAEL is conservative and appropriate for a screening level analysis. Further, a search of scientific peer-reviewed literature was performed to identify the existence of any additional recent studies related to terrestrial Se toxicity since the EcoSSL for Se was published in 2007. No additional relevant studies were identified for use in the effects assessment from this search. The NOAEL-based TRVs were therefore used in characterizing risk potential for the wildlife food chain evaluations.

4.5 Ecological Risk Characterization

In this section, the results of the comparisons between screening-level exposure estimates and effects concentrations discussed in Section 1.4 are presented. The resulting quantity is termed a screening quotient (SQ) which provides a measure of the potential for risk that may be posed to wildlife receptors.

Screening quotients are calculated as:

$$\mathbf{SQ} = \frac{\text{Soil Se Concentration (mg/kg dry weight)}}{\text{EcoSSL (mg/kg dry weight)}}$$

Equation 5

OR, for higher trophic level wildlife

$$\frac{\text{Dose (ingested concentration of Se in soil, water, and biota [mg/kg-day])}}{\text{Effects level (TRV [mg/kg-day])}}$$

Equation 6

An SQ less than or equal to a value of 1.0 indicates the exposure from the Site is below or equal to a level generally recognized as "safe" and no further refined risk assessment is necessary. When an SQ has a value greater than 1.0 it indicates that there may be risk potential that should be further evaluated through a more in-depth risk assessment to reduce uncertainties that are unavoidably present in a conservative screening-level assessment. Typically, an in-depth risk assessment involves the collection of additional Site information to refine the estimates of receptor exposure.

4.5.1 Ecological Risk Potential

4.5.1.1 Preliminary Soil Screening (EcoSSL) Comparisons

The EcoSSL values for Se in Site soils was compared to the most recently measured Site soil concentrations (see Table 11) and also to the modeled future Se soil concentrations occurring at depth (see Tables 12a and 12b). Following is a summary of the comparison of maximum current or future predicted soil concentrations to the EcoSSLs for each of the two irrigation areas.

Table 11: Screening Quotients for Comparison of Current Conditions

Soil Depth	Soil Conc.	Plants	Soil Invertebrates	Birds	Small Mammals
Irrigator 1A Area					
0-6 inches		0.10	0.01	0.04	0.08
6-12 inches		0.58	0.07	0.25	0.48
Irrigator 2 Area					
0-6 inches	95% UCL	1.63	0.21	0.71	1.35
	Maximum	2.69	0.34	1.17	2.22
6-12 inches	95% UCL	0.61	0.08	0.26	0.50
	Maximum	0.92	0.12	0.40	0.76

Notes: Values greater than 1.0 are noted with red font

Table 12a: Range of Screening Quotients for Comparison of Future Conditions in Irrigator 1A and 1B to EcoSSLs for the Six Modeled Scenarios

Soil Depth	Area	Soil Conc.	Plants	Soil Invertebrates	Birds	Small Mammals
0-6 inches	Irr.1A	Average	0.34 – 0.70	0.04 – 0.09	0.15 – 0.30	0.28 – 0.58
	Irr.1A	Maximum	0.56 – 1.44	0.07 – 0.18	0.24 – 0.62	0.46 – 1.19
	Irr.1B	Ave. to Max	0.40 – 0.90	0.05 – 0.11	0.17 – 0.39	0.33 – 0.74
6-12 inches	Irr.1A	Average	0.46 – 0.71	0.06 – 0.09	0.20 – 0.31	0.38 – 0.59
	Irr.1A	Maximum	0.64 – 0.96	0.08 – 0.12	0.28 – 0.41	0.53 – 0.79
	Irr.1B	Ave. to Max	0.23 – 0.38	0.03 – 0.05	0.10 -0.17	0.19 – 0.32
12-18 inches	Irr.1A	Average	0.63 – 0.80	0.08 – 0.10	0.27 – 0.35	0.52 – 0.66
	Irr.1A	Maximum	0.78 – 0.88	0.10 – 0.11	0.34 – 0.38	0.65 – 0.73
	Irr.1B	Ave. to Max	0.25 – 0.43	0.03 – 0.06	0.11 – 0.19	0.21 – 0.36
18-24 inches	Irr.1A	Average	0.78 – 0.83	0.10 – 0.11	0.34 – 0.36	0.64 – 0.69

Notes: Values greater than 1.0 are noted with red font

Table 12b: Range of Screening Quotients for Comparison of Future Conditions in Irrigator 2 to EcoSSLs for the Five Modeled Scenarios

Soil Depth	Soil Conc.	Plants	Soil Invertebrates	Birds	Small Mammals
0-6 inches	Average	0.63 – 1.10	0.08 – 0.12	0.27 – 0.47	0.52 – 0.90
	Maximum	1.20 – 1.94	0.15 – 0.25	0.52 – 0.84	0.99 – 1.60
6-12 inches	Average	0.58 – 0.73	0.07 – 0.09	0.25 – 0.31	0.48 – 0.60
	Maximum	0.92 – 1.02	0.12 – 0.13	0.40 – 0.44	0.76 – 0.84
12-18 inches	Average	0.65 – 0.86	0.08 – 0.11	0.28 – 0.37	0.53 – 0.71
	Maximum	0.73 – 1.15	0.09 – 0.15	0.32 – 0.50	0.60 – 0.95
18-24 inches	Average	0.73 – 1.06	0.09 – 0.13	0.32 – 0.46	0.60 – 0.87
	Maximum	0.87 – 1.24	0.11 – 0.16	0.38 – 0.54	0.72 – 1.03
24-36 inches	Average	0.73 – 0.93	0.09 – 0.12	0.32 – 0.40	0.61 – 0.76
	Maximum	0.95 – 1.14	0.12 – 0.14	0.41 – 0.49	0.78 – 0.94

Notes: Values greater than 1.0 are noted with red font

Summary Table: Comparison of Maximum Concentrations of Se From All Soil Depths and Climate Scenarios Compared to EcoSSLs

Current Measured Maximum Soil Se Concentration Exceed the EcoSSL				Future Predicted Maximum Soil Se Concentration Exceed the EcoSSL			
Plants	**Soil Invertebrates**	**Birds**	**Mammals**	**Plants**	**Soil Invertebrates**	**Birds**	**Mammals**
Irrigator 1A Area							
No	No	No	No	Yes	No	No	Yes
Irrigator 1B (new) Area							
No	No	No	No	No	No	No	No
Irrigator 2 Area							
Yes	No	Yes	Yes	Yes	No	No	Yes

Note: Green shading denotes soil concentrations from all depths and climate scenarios less than EcoSSL. Red shading denotes at least one soil concentration from all depths and climate scenarios considered was greater than the EcoSSL.

At the Irrigator 1A area, the current soil Se concentration is below all of the Se EcoSSL values as shown in Table 11 and the summary table above. However, at least one of the future modeled maximum Se concentrations exceeded the Se plant EcoSSL. One of the future modeled maximum concentrations was also above the mammal EcoSSL, however the future modeled average concentration over time was not (see Table 12a).). None of the EcoSSL values were exceeded in the potential new Irrigator 1B area.

For the Irrigator 2 area, there are current measured and future predicted concentrations of Se greater than EcoSSLs, excluding the soil invertebrate EcoSSL (see summary table above, Table 11, and Table 12a).

Since some minor exceedences of the bird and mammal EcoSSLs were identified in each irrigation area, a more in-depth wildlife food chain evaluation was conducted as discussed in the next sections. Note that further refinement of risk potential associated with irrigation water toxicity to plants is not likely to be warranted as discussed further in Section 4.8.1.

4.5.1.2 Bird Food Chain Exposure

Given the exceedances of EcoSSLs identified for birds above, additional food chain uptake evaluations were modeled for bird species representing three feeding guilds that could be present at the site: herbivore, soil invertivore, and carnivore. The potential for risk from these food chain pathway exposures was based on the estimated dietary concentrations discussed in Section 4.3.3 and the food chain model discussed in Section 4.3.4. Bird doses based predicted future soil concentrations of Se were calculated using both the maximum soil concentration and the average soil concentration over time by depth. The results from predicted uptake considering only the maximum soil concentration of Se are summarized in the following table.

Summary Table: Comparison of Maximum Current Measured and Future Predicted Concentrations of Se in the Soil in Irrigator 1A and 2 Areas Compared to Avian Toxicity No Effect Levels

Current Measured Maximum Soil Se Concentration Exceed the Avian TRV			Future Predicted Maximum Soil Se Concentration Exceed the Avian TRV		
Grouse	**Robin**	**Owl**	**Grouse**	**Robin**	**Owl**
Irrigator 1A Area					
Yes	No	No	No	No	No
Irrigator 2 Area					
No	No	No	No	No	No

Note: Green shading denotes soil concentrations from all depths and climate scenarios less than EcoSSL. Red shading denotes at least one soil concentration from all depths and climate scenarios considered was greater than the EcoSSL.

For the Irrigator 1A area, the only risk potential was found for herbivorous birds, such as the sage grouse, from current measured concentrations of Se in plants (Table 13). Plant uptake modeling with future soil concentrations predict that the Se ingestion rates will be lower than avian risk levels (Table 14b). No risk from current or future conditions was predicted for avian soil invertivores, such as the robin, or for avian predators, such as the burrowing owl in the Irrigator 1A area (Tables 13, 14a). Figure 29a shows the screening quotients for each of the climate scenarios by soil depth and species for the Irrigator 1A area.

Table 13: Screening Quotients for Comparison of Current Conditions to Wildlife TRVs Based on Predicted Exposures to Surficial Soils (0-6 inches)

Receptor	Irrigator 1A Area		Irrigator 2 Area	
	Average	**Maximum**	**Average**	**Maximum**
Sage Grouse	3.01	3.79	0.65	0.81
Robin	0.38	0.38	0.65	0.95
Burrowing Owl	0.33	0.33	0.29	0.37
Deer Mouse	24.5	30.8	5.22	6.47
Merriam's Shrew	0.69	0.69	0.25	0.36
Mule Deer	3.52	4.38	0.71	0.88
Cow	0.33	0.42	0.07	0.09
Coyote	0.56	0.56	0.66	0.80

Notes: Values greater than 1.0 are noted with red font

Table 14a: Range of Screening Quotients for Comparison of Future Conditions in Irrigator 1A for Birds for the Six Modeled Scenarios

Soil Depth	Soil Conc.	Herbivore (Sage Grouse)	Soil Invertivore (Robin)	Carnivore (Burrowing Owl)
0-6 inches	Average	0.02 – 0.03	0.25 – 0.37	0.17 – 0.22
	Maximum	0.03 – 0.07	0.31 – 0.61	0.24 – 0.29
6-12 inches	Average	0.02 – 0.04	0.17 – 0.37	0.14 – 0.22
	Maximum	0.02 – 0.05	0.24 – 0.46	0.17 – 0.25
12-18 inches	Average	0.02 – 0.04	0.18 – 0.40	0.15 – 0.23
	Maximum	0.02 – 0.04	0.26 – 0.43	0.18 – 0.24
18-24 inches	Average	0.02 – 0.04	0.18 – 0.41	0.15 – 0.23
	Maximum	0.02 – 0.05	0.27 – 0.47	0.18 – 0.25
24-36 inches	Average	0.02 – 0.05	0.18 – 0.46	0.15 – 0.23
	Maximum	0.02 – 0.05	0.27 – 0.52	0.18 – 0.27

Notes: Values greater than 1.0 are noted with red font

Table 14b: Range of Screening Quotients for Comparison of Future Conditions in Irrigator 1A for Mammals for the Six Modeled Scenarios

Soil Depth	Soil Conc.	Small Herbivore (Mouse)	Soil Invertivore (Shrew)	Large Herbivore (Mule Deer	Large Herbivore (Cow)	Carnivore (Coyote)
0-6 inch	Average	0.14 – 0.25	0.13 – 0.18	0.03 – 0.05	<0.01	0.40 – 0.50
	Maximum	0.20 – 0.48	0.16 – 0.27	0.04 – 0.08	<= 0.01	0.46 – 0.65
6-12 inch	Average	0.11 – 0.25	0.11 – 0.18	0.03 – 0.05	<0.01	0.33 – 0.50
	Maximum	0.15 – 0.33	0.14 – 0.22	0.04 – 0.06	<= 0.01	0.40 – 0.56
12-18 inch	Average	0.11 – 0.28	0.11 – 0.20	0.03 – 0.05	<0.01	0.34 – 0.52
	Maximum	0.17 – 0.30	0.14 – 0.21	0.04 – 0.06	<= 0.01	0.42 – 0.54
18-24 inch	Average	0.11 – 0.29	0.11 – 0.20	0.03 – 0.05	<0.01	0.34 – 0.53
	Maximum	0.17 – 0.34	0.15 – 0.22	0.04 – 0.06	<= 0.01	0.42 – 0.57
24-36 inch	Average	0.11 – 0.33	0.11 – 0.20	0.03 – 0.06	<= 0.01	0.34 – 0.56
	Maximum	0.17 – 0.39	0.15 – 0.24	0.04 – 0.07	<= 0.01	0.42 – 0.60

Notes: Values greater than 1.0 are noted with red font

No risk from current or future predicted soil, water, and biota concentrations is predicted in the Irrigator 2 area for all three avian feeding guilds evaluated (Table 13, 15a). Figure 30a shows the screening quotients for each of the climate scenarios by soil depth and species for the Irrigator 2 area.

Table 15a: Range of Screening Quotients for Comparison of Future Conditions at Irrigator 2 for Birds for the Five Modeled Scenarios

Soil Depth	Soil Conc.	Herbivore (Sage Grouse)	Soil Invertivore (Robin)	Carnivore (Burrowing Owl)
0-6 inches	Average	0.03 – 0.05	0.34 – 0.50	0.21 – 0.26
	Maximum	0.06 – 0.09	0.54 – 0.76	0.27 – 0.34
6-12 inches	Average	0.03 – 0.04	0.32 – 0.38	0.20 – 0.21
	Maximum	0.04 – 0.05	0.44 – 0.48	0.24 – 0.25
12-18 inches	Average	0.03 – 0.04	0.35 – 0.42	0.21 – 0.23
	Maximum	0.04 – 0.05	0.38 – 0.52	0.22 – 0.27
18-24 inches	Average	0.04 – 0.05	0.38 – 0.49	0.22 – 0.26
	Maximum	0.04 – 0.06	0.43 – 0.55	0.24 – 0.27
24-36 inches	Average	0.04 – 0.04	0.38 – 0.45	0.22 – 0.24
	Maximum	0.05 – 0.05	0.45 – 0.52	0.24 – 0.26

Notes: Values greater than 1.0 are noted with red font

Given these results, it is unlikely that adverse effects to birds would occur from future Se exposure in the Irrigator 1A area or current or future exposures in the Irrigator 2 area.

The current potential for risk to herbivorous birds is based on observed plant concentrations of Se several times greater than the plant uptake models predict. This is most likely due to the current soil Se concentrations measuring the AB-DTPA-extractable fraction, rather than using total soil concentrations in the uptake models. Since the avian food chain exposure utilizes measured plant concentrations rather than modeled values, these estimates of potential risk are more realistic than only soil screening using the EcoSSLs.

4.5.1.3 Mammal Food Chain Evaluations

As for birds, since there were exceedances of EcoSSLs identified for mammals (see Section 4.5.1), additional food chain uptake evaluations were modeled for mammal species representing three feeding guilds that could be present at the site: herbivore (small, large, and livestock), soil invertivore, and carnivore. The potential for risk from these food chain pathway exposures was based on the estimated dietary concentrations discussed in Section 4.3.3 and the food chain model discussed in Section 4.3.4. The results from a comparison of TRVs to predicted uptake considering only the maximum soil concentration of Se are summarized in the following table.

Summary Table: Comparison of Maximum Current Measured and Future Predicted Concentrations of Se in the Soil in Irrigator 1A and Irrigator 2 Areas Compared to EcoSSLs

Current Measured Maximum Soil Se Concentration Exceed the Mammalian TRV					Future Predicted Maximum Soil Se Concentration Exceed the Mammalian TRV				
Mouse	Shrew	Deer	Cow	Coyote	Mouse	Shrew	Deer	Cow	Coyote
Irrigation Area 1A									
Yes	No	Yes	No	No	No	No	No	No	No
Irrigation Area 2									
Yes	No	No	No	No	No	No	No	No	No

Note: Green shading denotes soil concentrations from all depths and climate scenarios less than EcoSSL. Red shading denotes at least one soil concentration from all depths and climate scenarios considered was greater than the EcoSSL.

As for birds, the current vegetation concentrations of Se suggest a potential for risk to small herbivores, such as deer mice, in both the Irrigator 1A and Irrigator 2 areas (see Table 13). Current plant Se concentrations in Irrigator Area 1A may also pose a potential for risk to large herbivores as represented by a mule deer. Domestic cattle were not identified to have risk potential from Se ingestion. There is no predicted risk, i.e., all SQs < 1.0, for either area for all of the future predicted soil concentrations at any depth up to 36 inches (Tables 14b and 15b). Figures 29b and 30b illustrate the screening quotients for each of the climate scenarios by soil depth and species for the Irrigator 1A and Irrigator. 2 areas, respectively. The predicted decrease in plant concentrations according to a predicted decrease in soil concentrations should continue to be monitored to ensure this decrease in potential risk to mammals.

Table 15b: Range of Screening Quotients for Comparison of Future Conditions in Irrigator 2 for Mammals for the Five Modeled Scenarios

Soil Depth	Soil Conc.	Small Herbivore (Mouse)	Soil Invertivore (Shrew)	Large Herbivore (Mule Deer	Large Herbivore (Cow)	Carnivore (Coyote)
0-6 inch	Average	0.22 – 0.37	0.17 – 0.23	0.05 – 0.07	<= 0.01	0.48 – 0.59
	Maximum	0.41 – 0.65	0.25 – 0.33	0.07 – 0.10	<= 0.01	0.61 – 0.73
6-12 inch	Average	0.21 – 0.26	0.17 – 0.19	0.04 – 0.05	<0.01	0.46 – 0.50
	Maximum	0.31 – 0.35	0.21 – 0.22	0.06 – 0.06	<= 0.01	0.55 – 0.56
12-18 inch	Average	0.23 – 0.30	0.17 – 0.20	0.05 – 0.06	<0.01	0.48 – 0.51
	Maximum	0.26 – 0.39	0.19 – 0.24	0.05 – 0.07	<= 0.01	0.50 – 0.60
18-24 inch	Average	0.26 – 0.36	0.19 – 0.23	0.05 – 0.06	<0.01	0.50 – 0.58
	Maximum	0.30 – 0.42	0.20 – 0.25	0.06 – 0.07	<= 0.01	0.54 – 0.61

Soil Depth	Soil Conc.	Small Herbivore (Mouse)	Soil Invertivore (Shrew)	Large Herbivore (Mule Deer	Large Herbivore (Cow)	Carnivore (Coyote)
24-36 inch	Average	0.26 – 0.32	0.19 – 0.21	0.05 – 0.06	<= 0.01	0.50 – 0.55
	Maximum	0.32 – 0.39	0.22 – 0.24	0.06 – 0.07	<= 0.01	0.55 – 0.59

Notes: Values greater than 1.0 are noted with red font

4.6 Calculated Protective Soil Concentration for Wildlife

A risk-based Se soil concentration that would be equivalent to an allowable screening quotient of 1.0 for each of the representative bird and mammal receptors was calculated using the same dose parameters to estimate potential for risk. The maximum protective soil concentration of Se calculated for all potential wildlife receptors was 1.45 mg/kg dry weight, based on earthworm uptake and subsequent ingestion by birds like the robin (Table 16). It is worth noting that this soil concentration is based on general biota uptake factors, since site-specific uptake data were not available.

Table 16: Maximum Risk-based Protective Soil Se Concentrations (mg/kg soil)

Receptor	Se Soil (mg/kg dry weight)
Robin	1.45
Mouse	1.52
Coyote	2.24
Shrew	5.27
Owl	7.44
Mule Deer	9.63
Grouse	9.74
Cow	76.91

4.7 Data Gaps and Uncertainties

Given the screening nature of this SLERA, several uncertainties should be identified so that the reviewer has a clear understanding of the limitations of the assessment. Additionally, certain data gaps are identified which could serve to strengthen the SLERA if this is desired by Cameco.

Uncertainties identified for each of the key steps in the SLERA process are as follows:

- **Exposure Assessment**
  - **Current Soil Concentrations**. The current and historic soil samples are assumed to be representative of site conditions. This may not be true if there is a high degree of spatial heterogeneity in the irrigation areas. Also, the current soil concentrations for the Site do not represent total concentrations of Se in the soil but rather AB-DTPA extractable concentrations as discussed in Section 4.3.2. This extractable fraction more closely represents the amount of Se that is available for plant uptake but may under- or over-estimate soil exposure conditions for other receptors such as invertebrates, birds and mammals. Accordingly, the comparisons of current soil concentrations with Se EcoSSLs may or may not be accurate since the EcoSSLs are intended for comparison with total soil concentrations.
  - **Future Predicted Soil Concentrations**. It is assumed that the hydrogeochemical model, as described previously in Section 3.0, accurately predicts soil concentrations in the irrigation areas over time and the concentration of Se in the irrigation water does not deviate significantly from 0.05 mg/L.
  - **Modeling Biological (Plants, Invertebrates, Small Mammals) Se Concentrations from Soil.** Uptake of Se into plants, earthworms, and small mammals was estimated using regression equations based on the results of published literature studies. However, the soil conditions of those studies may not be representative of Site soil conditions (e.g., organic carbon, metal oxide content, pH, etc.). The use of these equations could lead to an under- or over-estimation of the amount of Se taken up by biota, given variances in soil properties that govern metal uptake, and hence an under- or over-estimation of wildlife doses of Se.
  - **Wildlife Food Chain Exposure Modeling.** The birds and mammals were assumed to spend 100% of their time feeding and drinking in either the Irrigator 1A or 2 areas. This may not be realistic given the site conditions, and incorporates uncertainty into the estimation of risk potential for wildlife. However, this is a worst-case scenario that is typical of SLERAs. For example, the home range of a mule deer averages 2,780 acres (EPA 1999) and both irrigation areas combined are about 174 acres, which is about 6% of the mule deer's home range. Given the current maximum measured concentration of Se in the vegetation, deer would ingest a non-toxic dose of Se if they foraged less than 23% of their time in the irrigation area.

    Surrogate or modeled data for food or incidental soil ingestion were used in several instances (see Section 4.4) when not available for representative species. This leads to additional uncertainty in the calculations of wildlife exposures.

    It was expected that the exposures of reptiles in the irrigation areas would include ingestion of soil, soil invertebrates, aerial invertebrates, and some plants. In this assessment, avian and mammalian herbivores and invertivores are assumed to be exposed to higher concentrations of Se given the assumption that they eat 100% of one type of food. Thus birds and mammals are expected to represent more conservative indicators of potential risk to wildlife.
- **Effects Assessment**
  - The risk potential to ecological receptors from any other soil or irrigation water constituents (e.g., other metals) were not a part of the scope of this SLERA. Accordingly, risk potential from ecological exposure to mixtures of other soil and irrigation water constituents may not be fully represented by the results presented for Se.

4.8 Conclusions

4.8.1 SLERA Conclusions

Currently in the Irrigator 1A area, there is the potential for risk to herbivorous birds, small herbivorous mammals, and larger herbivorous mammals. There is no current risk potential for plants, soil invertebrates, insectivorous birds and mammals, carnivorous birds and mammals, and cattle. Currently in the Irrigator 2 area, there is the potential for risk to plants and small herbivorous mammals. There is no current risk potential for soil invertebrates, herbivorous birds, insectivorous birds and mammals, carnivorous birds and mammals, and large herbivorous mammals, including cattle.

For both of the irrigation areas, there is only the potential for future risk to plants. There is no future risk potential for any of the wildlife groups that could feed at the Site. This is because the hydrogeochemical modeling indicates that future soil concentrations, and hence risk potential, decreases with a predicted decrease in soil Se concentration in both irrigation areas.

For the potential new irrigator area, 1B, there is no future potential risk via any of the identified pathways.

For plants, there is current and future risk based on comparison of soil Se concentrations to EcoSSLs. However, there has been no documentation of effects to plants during recent vegetation sampling events (see Section 2.0). All soil concentrations are less than 2.0 times the EcoSSL, meaning there is very slight potential for adverse effects for plants. Any SQ > 1.0 should be evaluated further in subsequent risk assessments with more site-specific data. However, given the absence of observed effects at the site, the low SQs based on the maximum predicted soil Se concentration over the next ten years, and the conservative nature of the EcoSSL value for plants, it is likely that there is minimal potential for risk to plants in the irrigation areas from Se.

The maximum calculated soil Se concentration protective of all potentially present wildlife receptors was 1.45 mg/kg dry weight.

4.8.2 Recommendations

1. This SLERA was focused on evaluating the potential for risk to plants, soil invertebrates, and wildlife given existing and future predicted concentrations of Se in the irrigation water and soil. Since the soil concentrations, and hence modeled plant, earthworm, and small mammal concentrations of Se are based on a future predicted concentration of 0.05 mg/L Se in the irrigation water, continued monitoring of the water, soil, and biota will be necessary to confirm that these predictions are accurate.
2. Since the maximum future predicted soil concentration (at any depth and climate scenario) is 0.75 mg/kg dry weight in the area of Irrigator 1A and 1.01 mg/kg at Irrigator 2 (both well below the 1.45 mg/kg threshold), the soil Se concentrations are predicted to attenuate, without additional soil remediation, to concentrations that are not expected to accumulate in plants or earthworms to potential risk levels.
3. Soil analysis should include the total fraction of metals.

4. If concentrations in any media are found to be greater than those predicted in the SLERA, additional exposure calculations could be performed to refine these estimates for potential toxicity. For example, collection of co-located earthworms and soil and vegetation would allow the calculation of a site-specific earthworm Se concentration and plant uptake factor for Se, given the soil properties in the irrigation area. This would provide a more realistic estimation of future concentrations of Se in soil invertebrates and vegetation than the use of general uptake models.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the conclusions presented in the previous sections, it is recommended that:

1. Monitoring of the water, soil, and biota continue in order to confirm that the predictions in this report are accurate. Soil analysis should include the total fraction of metals. WDEQ standards for irrigation water quality and soil concentrations of Se are conservatively protective compared to the risk-based goals developed in this report. However, they provide a guide for the Se concentration levels at which alternate management practices, analyses, or monitoring could be considered.
2. If concentrations in any media are found to be greater than those predicted in the SLERA, additional exposure calculations could be performed to refine these estimates for potential toxicity.
3. Alternate management practices, to be considered in the event that risk-based levels are exceeded, be conceptually evaluated. These could include: Rotation of irrigator locations to allow natural attenuation to reduce loadings at any individual location, and adjustments to brine fraction in effluent to irrigators resulting in a higher volume/lower concentration irrigator water.
4. Vegetation harvesting and disposal be re-assessed because the highest current potential ecological risk is from current vegetation samples. The modeling of future soil concentrations of Se yielded soil values that are not expected to accumulate to toxic plant concentrations. Until this 'drop' occurs, vegetation harvesting and disposal continues to be a viable mitigation strategy.
5. Soil remediation is not required. The maximum predicted future soil concentration (at any depth and climate scenario and irrigator location) are low enough that concentrations are not expected to accumulate in plants or earthworms to 'toxic' levels, so soil remediation is not required on the basis of ecological risk analyses.

6.0 CLOSING

Golder is pleased to have the opportunity to present this report to Cameco. Golder welcomes any questions that Cameco may have about this report which can be directed to Joanna Moreno or Mark McClain at 303-980-0540 or at joanna_moreno@golder.com.

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7.0 REFERENCES

Allen, R. G., Pereira, L. S., Raes, D., Smith, M. 1998. Crop Evapotranspiration – Guidelines for computing crop water requirements, Food and Agriculture Organization of the United Nations Rome (FAO) Irrigation and Drainage Paper, No 56, FAO, 300 p.

Barceloux, D.G. 1999. Selenium. Clinical Toxicology, 37:145-172.

Bechtel Jacobs Company LLC. 1998. Empirical Models for the Uptake of Inorganic Chemicals from Soil by Plants. Bechtel Jacobs Company LLC, Oak Ridge, Tennessee. BJC/OR-133.

Beyer, W.N., E.E. Connor, and S. Gerould. Estimates of Soil Ingestion by Wildlife. Journal of Wildlife Management. 58(2):375-382.

Cameco. 2012. Internal communication.

Carter, J.G. 2008. Updating the animal unit month. Western Watersheds Project, Inc. March 17.

Carter, M.R., and E.G. Gregorich. Soil sampling and methods of analysis, second edition. CRC Press, Florida.

Cornell. 2012. Greater Sage-Grouse. accessed in August 2012: http://www.allaboutbirds.org/guide/Greater_Sage-Grouse/lifehistory

EPA. 1993. Wildlife Exposure Factors Handbook. EPA/600/R-93/187.

EPA (U.S. Environmental Protection Agency). 1998. Guidelines for ecological risk assessment. EPA/630/R-95/002F. April.

EPA. 1999. Data Collection for the Hazardous Waste Identification Rule; Section 12: Ecological Exposure Factors.

EPA. 2005. Guidance for developing ecological soil screening levels. OSWER Directive 9285.7-55. February.

EPA. 2007. Ecological soil screening levels for selenium; Interim Final. OSWER Directive 9285.7-72. Office of Solid Waste and Emergency Response. July.

EPA. 2007b. Attachment 4-1: Guidance for developing ecological soil screening levels (Eco-SSLs), Exposure factors and bioaccumulation models for derivation of wildlife Eco-SSLs. OSWER Directive 9285.7-55. April.

EPA (US Environmental Protection Agency). 2011. Level III Ecoregions of the Continental United States. National Health and Environmental Effects Research Laboratory. December.

Freeze, R. A. and Cherry, J. A. (1979). Groundwater. Englewood Cliffs, N.J.: Prentice-Hall, Inc.

Fredlund, M. 2004. SoilVision, A Knowledge-Based Soils Database User's Manual. ED-4A, December 2, 2004. SoilVision Systems Ltd. Saskatoon, Saskatchewan, Canada.

Golder Associates Inc. 2009. Smith Ranch-Highlands Irrigation Operations Soil and Vegetation Survey, Letter submitted to Cameco, February 6, 2009.

Golder. 2010. Smith Ranch-Highland operations vegetation harvest and disposal plan; Specific guidelines for SAT1 and SAT2 locations. Prepared for Cameco Resources. July 8.

Golder. 2011. Review of Soils Data Collected for Resolution of Wyoming Department of Environmental Quality Regarding Selenium at Cameco Resources Smith Ranch-Highlands Facility. Prepared for Cameco Resources. March 30.

Hargreaves, G.L., Hargreaves, G.H., and Riley, J.P. 1985. Agricultural benefits for Senegal River Basin, Journal of Irrigation and Drainage Engineering, ASCE 111:113-124.

Nagy, K.A. 1987. Field metabolic rate and food requirement scaling in mammals and birds. Ecological Monographs. 57:111-128.

Orabona, A., S. Patla, L. Van Fleet, M. Grenier, B. Oakleaf, and Z. Walker. 2009. Atlas of birds, mammals, amphibians, and reptiles in Wyoming. Wyoming Game and Fish Department, Wildlife Division. Nongame Program. April. 227 pp.

Pasch, R.N. and Vance, G.F. 1995. Soil Selenium: Laboratory Comparisons and Soil/Backfill Variability. http://www.asmr.us/Publications/Conference%20Proceedings/1995/Pasch%20258-269.pdf accesed 10/30/2012.

Power Resources, Inc. 1993. Application for satellite No. 2 wastewater land application facility. Highland Uranium Project. September 30.

Power Resources, Inc. 1995. Application for satellite No. 1 Irrigation area 1B.. Highland Uranium Project. April 20.

Ramirez, R., and B. Rogers. 2000. Selenium in a Wyoming grassland community receiving wastewater from an in situ uranium mine. US Fish and Wildlife Service, Contaminants Program. Project #: 98-6-6F37-FC. September.

Ritchie, J. T. and Burnett, E. 1971. Dryland evaporative flux in a subhumid climate, 2, plant influences., Water Resources Research, 12(3), p 513-522.

Sample, B.E., M.S. Aplin, R.A. Efroymson, G.W. Suter, C.J.E. Welsh. 1997. Methods and tools for estimation of the exposure of terrestrial wildlife to contaminants. ORNL/TM-13391.

Sample, B.E., J.J. Beauchamp, R.A Efroymson, G.W. Suter, and T.L. Ashwood. 1998a. Development and validation of bioaccumulation models for earthworms. Prepared for the US Department of Energy. ES/ER/TM-220.

Sample, B.E., J.J. Beauchamp, R.A Efroymson, and G.W. Suter. 1998b. Development and validation of bioaccumulation models for small mammals. Prepared for the US Department of Energy. ES/ER/TM-219.

Sharmasarkar, S. and Vance, G. F. (2002). Soil and Plant Se at a Reclaimed Uranium Mine. Journal of Environmental Quality, 31, 5, 1516-1521.

Shepherd Miller, Inc. 1996. Analysis of the effects of irrigation on soils and plants at the Satellite No. 1 irrigation area. Prepared for Power Resources, Inc., Highland Uranium Project, Casper, Wyoming. August 22.

Simunek J., Sejna, M., Saito, H., Sakai, M., and van Genuchten M. 2009. The HYDRUS-1D Software package for Simulating the One-Dimensional Movement of Water, Heat, and Multiple Solutes in

Variably-Saturated Media. Version 4.08. HYDRUS Software Series 3. Department of Env. Sciences, University of California Riverside, Riverside, CA. USA PP 330.

USACHPPM (US Army Center for Health Promotion and Preventative Medicine). 2004. Development of Terrestrial exposure and bioaccumulation information for the army risk assessment modeling system (ARAMS).

US FWS (Fish and Wildlife Service). 2012. Endangered, threatened, proposed, and candidate species and their designated and proposed critical habitat that occur in or may be affected by actions in Converse County, Wyoming. United States Department of the Interior. May.

van Genuchten, M.Th. (1980). A closed-form equation for predicting the hydraulic conductivity of unsaturated soils". Soil Science Society of America Journal 44 (5): 892–898.

WA DOE. 2007. Model toxics control act statute and regulation. Washington State Department of Ecology. Publication 94-06.

WDEQ (1987) Land Application Permit No. 86-217 issued 4/7/87. Highland Section 21 Land Application Facility.

WDEQ (2012a). Wyoming State Voluntary Remediation Program, (http://deq.state.wy.us/volremedi/index.asp accessed in 2012)

WDEQ (2012b). Water Quality Rules and Regulations, Chapter 11, (http://deq.state.wy.us/wqd/WQDrules/Chapter_11.pdf accessed in 2012)

WRCC (Western Regional Climate Center). 2008. Station: Douglas Converse County Airport, Climatological Summary, Period of Record July 1999 to December 2008. Accessed in October 2012 from: http://www.wrcc.dri.edu/.

TABLE

Table 1. Summary of all Data Reviewed and Considered for Modeling Evaluation

Document Title	Author	Date	Meteorological Data	Permit Application Information	Irrigation Recharge Data (quantity, quality)	Irrigation Area	Irrigation-type	Project Production Timeframe	pH, Eh	Soil Concentration	Soil Water Concentration	Vegetation Concentration	Depth of Affected Soil Column	Co-located Soil and Plant or Soil and Invertebrate Data	Soil-type, Porosity, Particle-size Distribution	Saturated Hydraulic Conductivity	Organic Carbon Content, Cation Exchange Capacity	Vegetation-type, Root Depth	Background Concentrations (Soil or Water) in Nearby Areas	Sample Location Information and History	Derived for Modeling	Sampe Details	Notes
SRH Land App Inventory.xls	unknown																						Partial data inventory (type, title, author, date, e-file)
Status of Land Application Facilities	unknown	2010 date of last entry		X				X												X		Satelite Locations 1 and 2 and Purge Storage Locators and Irrigators 1 and 2, respectively	Document summarizes operational details and also provides a usable naming convention for irrigator locations.
Copy of SRH WeatherHawk Data 2010-2012.xlsx	unknown	2010 through 2012	X																				Temp, wind, solar, precip
Irrigator 1 Fluid (Rev Dec 2011).xls	unknown	Sept 1989 through July 2003			X				X													Irrigator 1A	Data collected consistent with permit requirements. Annual samples for 1989 and 1990 and monthly samples collected 1991 through 2004. Irrigator 1A stopped operating in 2004. Quantity and quality provided.
Irrigator 2 Fluid (Rev Jan 2012.xls	unknown	Sept 1995 through July 2011			X				X													Irrigator 2	Monthly sample analysis consistent with permit requirements. Quantity and quality provided.
1999 Irrigator soil data.xls	unknown	Aug-99								X			X									Irrigator 1A (14 locations) and 2 (16 locations) Irrigator 1A: SE 1-3, SW 4-7, NW 8-10, NE 11-14 Irrigator 2: SW 1-4, NW 5-8, NE 9-12, SE 13-16	Samples collected from 30 locations between the two irrigators from 0-6" and 6-12" depth intervals (60 total samples). Analytical profile is consistent with the '87 permit but the depth intervals are not. Not sure about the renewed permits.
2000 Irrigator soil data.xls	unknown	Aug-00								X			X									"	"
2001 Irrigator soil data.xls	unknown	Aug-01								X			X									"	"
2002 Irrigator soil data.xls	unknown	Aug-02								X			X									"	"
2003 Irrigator soil data.xls	unknown	Aug-03								X			X									"	"
2004 Annual Data.xls	unknown	2003			X					X		X	X									Irrigator 1A and 2	Compilation of all 2003 soil, water, vegetation data. This data should all be located elsewhere also.
2004 Irrigator 1 Soil.xls	unknown	1986 through 2004								X			X						X			Irrigator 1A	File contains background soil concentration data by depth (0-6" and 6-12") but doesn't provide any other location description except Irrigator 1.
2004 Irrigator 2 Soil.xls	unknown	1993 through 2004								X			X						X			Irrigator 2	1993 to 1995 data supposedly represents background soil concentration.
2006 Annual Data.xls	unknown	July 2004 through June 2005			X					X		X	X									Irrigator 1A and 2	Compilation of all 2004 soil, water, vegetation data.
2007 Annual Data.xls	unknown	June 2006 through August 2007			X					X		X	X									Irrigator 1A and 2	Compilation of all 2006/2007 soil, water, vegetation data.
2009 Annual Report data.xls	unknown	June 2008 through June 2009			X	X																Irrigator 1A and 2	Irrigation volumes and a list of 'affected areas' seem to be only relevant data. 2009 spills and reclamation options are discussed and well water data is also provided.
2010 Annual Report data.xls	unknown	June 2009 through June 2010			X	X				X		X	X									Irrigator 1A and 2	
2011 Annual Report data.xlsx	unknown	June 2010 through June 2011	X		X	X				X		X	X									Irrigator 1A and 2	Meteorological data from Nov 2010 through April 2011
Irrigator 1 Soil Summary.xls	unknown	1996 through 2006								X			X						X			Irrigator 1A	
Irrigator 2 Soil Summary.xls	unknown									X			X						X			Irrigator 2	
Irrigator 1 and 2 Soil Water.xls	unknown	1991 through 2003									X		X									Irrigator 1A and 2	
Irrigator 1 veg 2011.pdf	Energy Laboratories (report)	2011										X										Irrigator 1A	
Irrigator 1 Veg.xls	unknown	1999 through 2011										X										Irrigator 1A	
Irrigator 2 veg 2011.pdf	Energy Laboratories (report)	2011										X										Irrigator 2	
Irrigator 2 Veg.xls	unknown	1993 through 2011										X							X			Irrigator 2	
VegData1993_1998.PDF	Energy Laboratories (report)	1993 through 1998										X										Irrigator 2	
VegData1999.PDF	Energy Laboratories (report)	1999										X										?	
VegData2000.PDF	Energy Laboratories (report)	2000										X										?	
VegData2001.PDF	Energy Laboratories (report)	2001										X										?	
VegData2002.PDF	Energy Laboratories (report)	2002										X										?	
VegData2003.PDF	Energy Laboratories (report)	2003										X										?	
VegData2004.PDF	Energy Laboratories (report)	2004										X										?	
VegData2005.PDF	Energy Laboratories (report)	2005										X										?	
VegData2006.PDF	Energy Laboratories (report)	2006										X										?	
VegData2007.PDF	Energy Laboratories (report)	2007										X										?	
2003-06-30 Permit 603 2003 Annual Rpt Sec 7 Monitoring.pdf	unknown	2003 with comparison to historic data		X						X		X										Irrigator 1A and 2	Plates 1A and 1B from this report show the location of the soil samples - the maps are not included in the file. Also note: radium settling basins discontinued in August of 2002.
2011-06-30 Permit 603 2011 Annual Rpt Sec 7 Monitoring.pdf	unknown	2011	X	X						X		X						X				Irrigator 1A and 2	
FIGURE 7-3 new.pdf	unknown	1986 and 1990-2010			X																	Irrigator 1A	
FIGURE 7-3 new.xls	unknown	1986 and 1990-2010			X																	Irrigator 1A	
FIGURE 7-4 new.pdf	unknown	1993 and 1995-2010			X																	Irrigator 2	
FIGURE 7-4 new.xls	unknown	1993 and 1995-2010			X																	Irrigator 2	
FIGURES 7-1 AND 7-2veg at irrigators2010.pdf	unknown	1996-2010										X										Irrigator 1A and 2	
FIGURES 7-1 AND 7-2veg at irrigators2010.xlsm	unknown	1996-2010										X										Irrigator 1A and 2	

Golder Associates

Document Title	Author	Date	Meteorological Data	Permit Application Information	Irrigation Recharge Data (quantity, quality)	Irrigation Area	Irrigation-type	Project Production Timeframe	pH, Eh	Soil Concentration	Soil Water Concentration	Vegetation Concentration	Depth of Affected Soil Column	Co-located Soil and Plant or Soil and Invertebrate Data	Soil-type, Porosity, Particle-size Distribution	Saturated Hydraulic Conductivity	Organic Carbon Content, Cation Exchange Capacity	Vegetation-type, Root Depth	Background Concentrations (Soil or Water) in Nearby Areas	Sample Location Information and History	Derived for Modeling	Sampe Details	Notes
2010-03-12 Analysis of Soil and Veg.pdf	Golder, Advani	3/12/2010			X					X		X										SAT 1 and SAT 2	Treatment plant began operations on 9/23/09; concentrations in plant water <0.2 mg Se/L.
10381513 Rpt VegHarvestDisposal 08JUL10.pdf	Golder, Advani	7/8/2010										X						X				SAT 1 and SAT 2	
Scope Development Memo.pdf	Golder, Advani	1/12/2010																					
SoilCharacterizationPlan 20Aug10 FINAL.pdf	Golder	Aug-10																				SAT 1 and SAT 2	Sampling and characterization plan
TM-SoilsDataReview_29Mar11.pdf	Golder, Advani	3/30/2011								X												SAT 1 and SAT 2; 10 locations each; 0-2",2-12",2-4'	
NRC Ops Plan Sec 4.2.3 Sat 1 Irrigator and 4.2.4 Sat 2 Irrigator.pdf	unknown	2006				X										X						Satellite 1 and 2	Estimate of permeability at Sat 1: k=1.8E-08 cm/sec. Additional information on evaporation ponds incl. rates, wind consideration, capacity, etc.
NRC Ops Plan Sec 5.3.7 WW Land App Mon Program.pdf	unknown	2006																		X		Satelite 1 and 2	Information pertaining to water treatment and monitoring activities.
Vol 9 - 1) Land Application Permit.pdf	Wyoming Department of Environmental Quality (WY DEQ)	Issued 4/7/87, valid through 4/6/91		X																		Permit requires monthly grab sample of irrigation water, annual soil water sample at 2, 4, 6 ft depth, 1 annual composite soil sample per 4 acres irrigated, composite vegetation sample per soil sample.	Permit number 86-217. See 'Monitor program per '87permit' worksheet for more details pertaining to monitoring program and parameters.
Vol 9 - 2) Table of Contents.pdf	Everest Minerals Corporation	Jul-86		X																			Document title: Application for Wastewater Land Application Facility
Vol 9 - 3) Sec 1-General Introduction.pdf	Everest Minerals Corporation	Jul-86		X																			Contains site maps of the proposed site setup.
Vol 9 - 4) Sec 2-Facility Description.pdf	Everest Minerals Corporation	Jul-86	X	X		X	X	X	X	X				X (soil/ plant)	X		X		X			Satellite 1 (original permited area)	There is some information pertaining to plants that were intended to be vegetated at the time the permit application was submitted. It is not clear if these plans were implemented. Also provided is a vegetation and soil-type survey with map. Provides description of irrigation area, including proposed irrigation method: center pivot irrigation (r = ~866 ft) with rotation timing and flow rates
Vol 9 - 5) Sec 3-Anticipated Environ Impact.pdf	Everest Minerals Corporation	Jul-86		X				X									CEC					Satellite 1 (original permited area)	Describes predicted impacts and water balance. Provides good description and review of bioavailability of radium and references an Appendix B that describes selenium soil reactions and toxicity levels.
Vol 9 - 6) Sec 4-References.pdf	Everest Minerals Corporation	Jul-86		X																			Reference list
Vol 9 - 7) Appendix A.pdf (Soil Test Borings and Lab Testing)	Lab reports from Inberg-Miller Eng.	Jun-86		X						X			X		ST, GSD				X			Satellite 1 (original permited area)	Results presented from field test borings advanced to 15 feet depth.
Vol 9 - 8) Appendix B.pdf	K.W. Brown and Associates, Inc.	Jul-86		X				X	X	X		X	X					X				Satellite 1 (original permited area)	Includes soils map and information on selenium chemistry.
Vol 9 - 9) WDEQ Land Application Info.pdf	Power Resources to DEQ	Jul-90		X																		Satellite 1 (original permited area)	Transfer of ownership to PRI required submission of revised permit application. Irrigation season changed to annual with the condition that environmental conditions are favorable (i.e. no irrigating frozen land). Sampling points for irrigation water required at discharge of radium settling basins during non-irrigation and at discharge pump during irrigation (no change in frequency or analyses). Change in frequency and location of irrigated vegetation samples requested. Approval and initiation of sampling revisions are not provided.
Vol 12 - 1) TFN 3 6_22 Change No. 26.pdf	Power Resources	Jul-95		X																		Irrigator 1B and Satellite 2	Conditional approval of use for Irrigator 1B. Approval granted based on completion of soil and vegetation sampling being completed. Area map included.
Vol 12 - 2) Satellite No. 1 Irrigation Area 1B.pdf	Power Resources	Apr-95	X	X		X		X	X	X		X	X	X (soil/ plant)			X		X			Irrigator 1B	Center pivot irrigator appx. 850 feet long, 6 or 7 spans, low profile with appx. 5 low pressure, 360-deg spray nozzle per span. Will attach to irrigator 1.
Vol 13 - 2) Sat 2 Wastewater Land Appl Facility.pdf	Power Resources	Sep-93	X	X	X	X		X	X	X		X	X	X (soil/ plant)			X		X			Irrigator 2	Center pivot irrigator appx. 1250 feet long, 10 spans, 42 inch drop pipes at each nozzle location, appx. 5 low pressure 360-deg nozzles per span.
1996-08-22 Shepherd Miller Irrigator 1 Analysis.pdf	Shepherd Miller, Inc.	8/22/1996 (Evaluated data from 1989 to 1995)	X		X				X	X		X	X	X (soil/ plant)	X	?	X	X	X			Satellite 1	Useful review paper. Modeling work toward end goal of estimating the flow rate of water passing below the root zone and the rate of flow within the vadose zone.
1999-02-02 Journal Env Quality_Irrigation.pdf	Levy, D.B., Kearney, W.F.	1999												X								Most likely Sat 1 area.	Peer reviewed journal article studying the effect of irrigation water on soil, plant, and animal concentrations.
2000-09-01 USFWS Contaminant Rpt_Se in Wyo Grassland.pdf	US Fish and Wildlife Service	2000												X (Soil& Invertebrate)								Site-wide survey performed externally by the Fish and Wildlife. Not at all consistent with our current sample location naming convention.	Paper documenting results of a study that correlated soil concentrations with insect and bird tissue(?) concentrations.
Cameco Site Visit 2 23 12 Memo.pdf	Golder, Moreno	2/23/2012																		X			
Cameco Site Visit Memo (2).doc	Golder, Moreno	2/23/2012																		X			
Figure 1.pdf	Golder, Moreno	2/23/2012																		X			
SR Land Application Project Meeting 2 (Feb 23-12).pdf	Golder, Moreno	2/23/2012																		X			
Cameco_PSD graphs.xlsx		6/27/2012													X							Irrigator 1A	
IRR1A-1-1 @ 0-2.3 (AH).xlsx		6/22/2012													X							Irrigator 1A	
IRR-1A-1-3 @ 4.4-6.2 (AH).xlsx		6/22/2012													X							Irrigator 1A	
IRR1A-3-1 @ 0-2.9 (AH).xlsx		6/22/2012													X							Irrigator 1A	
IRR1A-3-2 @ 2.9-3.4 (AH).xlsx		6/22/2012													X							Irrigator 1A	
IRR-1B-3-1 @ 0-3.8 (AH).xlsx		6/22/2012													X							Irrigator 1A	
IRR1B-3-3 @ 5.25-6 (AH).xlsx		6/22/2012													X							Irrigator 1A	
IRR1B-4-1 @ 0-6.6 (AH).xlsx		6/22/2012													X							Irrigator 1A	
Soil Summary 2012.xlsx		6/22/2012													X							Irrigator 1A	
GATP 2-1 @ 0-0.5 (AH).xlsx		6/4/2012													X							Irrigator 2	

Document Title	Author	Date	Meteorological Data	Permit Application Information	Irrigation Recharge Data (quantity, quality)	Irrigation Area	Irrigation-type	Project Production Timeframe	pH, Eh	Soil Concentration	Soil Water Concentration	Vegetation Concentration	Depth of Affected Soil Column	Co-located Soil and Plant or Soil and Invertebrate Data	Soil-type, Porosity, Particle-size Distribution	Saturated Hydraulic Conductivity	Organic Carbon Content, Cation Exchange Capacity	Vegetation-type, Root Depth	Background Concentrations (Soil or Water) in Nearby Areas	Sample Location Information and History	Derived for Modeling	Sampe Details	Notes
GATP 2-2 @ 0-0.85 (AH).xlsx		6/4/2012													X							Irrigator 2	
GATP 2-4 @ 1.35 (AH).xlsx		6/4/2012													X							Irrigator 2	
GATP 2-4 @ 1.35 (AH)v2.xlsx		6/22/2012													X							Irrigator 2	
GATP 4-1 @ 0-1.5 (AH).xlsx		6/4/2012													X							Irrigator 2	
GATP-1-1 @ 0-1 (AH).xlsx		6/22/2012													X							Irrigator 2	
Soil Summary 2012 v1.xlsx		6/4/2012													X							Irrigator 2	
Soil Summary 2012 v2.xlsx		6/4/2012													X							Irrigator 2	
20081107_DataEntered.xlsm	Golder, Advani	2008			X					X										X		Satellite 2	File contains lots of data, but without references. Seems to be satellite 2 soil, irrigator water, and maybe groundwater data.
AgronomicTesting.xls and .pdf	IML	2008								X							X					Not sure where these sample locations are.	12 samples collected from 6 locations at 0-6 and 6-12 in. depths.
HighIndMine_Selen.pdf	US Fish and Wildlife Service (repeat of above file)	2000												X (Soil& Invertebrate)								Site-wide survey performed externally by the Fish and Wildlife. Not at all consistent with our current sample location naming convention.	Paper documenting results of a study that correlated soil concentrations with insect and bird tissue(?) concentrations.
Soil_Report.pdf	NRCS	2010													X								Good report on the soil-type and distribution around the Smith Ranch Highlands Operations.
Soil_Report_Sat2.pdf	NRCS	2010													X							Satellite 2	ditto
Speciation	unknown	unknown																				Satellite 1 and 2	Soil selenium speciation data. Could be very useful in determining the bioavailability of the selenium present in the soils (no date). There is an associated tech memo that was written in March of 2011 by Sanjay Advani.