MILLENNIUM
EMS Solutions Ltd.

6111 91 Street
Edmonton, AB T6E 6V6
tel: 780.496.9048
fax: 780.496.9049

Suite 325, 1925 18 Avenue NE
Calgary, AB T2E 7T8
tel: 403.592.6180
fax: 403.283.2647

#106, 10920 84 Avenue
Grande Prairie, AB T8X 6H2
tel: 780.357.5500
fax: 780.357.5501

10208 Centennial Drive
Fort McMurray, AB T9H 1Y5
tel: 780.743.4290
fax: 780.715.1164

toll free: 888.722.2563
www.mems.ca

Evaluation of Background Metal Concentrations in Alberta Soils

Prepared for:
Petroleum Technology Alliance Canada (PTAC)

Prepared by:
Millennium EMS Solutions Ltd.
Suite 325, 1925 – 18th Avenue NE
Calgary, Alberta
T2E 7T8

August 2016
File #15-00403

Table of Contents

Page

List of Tables

List of Appendices

1.0 INTRODUCTION

Millennium EMS Solutions Ltd. (MEMS) was retained by Petroleum Technology Alliance Canada (PTAC) to develop a database of background concentrations for metals in Alberta soils. The database will aid industry and consultants to understand the typical ranges of background concentrations of metals in Alberta soils and provide context for situations when metal concentrations in soil samples exceed generic guideline values.

Metals occur naturally in Alberta soils but can also be present in soils as a result of contamination. In Alberta, the generic Tier 1 Soil Remediation Guidelines (AEP 2016) are a screening tool used in the evaluation of whether metal concentrations at a site are a result of contamination. Alberta Tier 1 soil remediation guidelines are available for the following twenty metals:

- Antimony;
- Arsenic (inorganic);
- Barium (barite and non-barite);
- Beryllium;
- Boron (saturated paste);
- Cadmium;
- Chromium (hexavalent and total);
- Cobalt;
- Copper;
- Lead;
- Mercury (inorganic);
- Molybdenum;
- Nickel;
- Selenium;
- Silver;
- Thallium;
- Tin;
- Uranium;
- Vanadium; and
- Zinc.

It is not uncommon for background metal concentrations in Alberta soils to exceed Tier 1 guideline values. In some instances, this situation can be reconciled by collecting site-specific background data; however, collecting sufficient data to get meaningful values for background levels can be challenging at some sites. The current work will provide a useful tool in evaluating such situations, and may facilitate a determination of whether a particular Tier 1 exceedance is likely to be related to background conditions.

2.0 OBJECTIVES AND SCOPE OF WORK

The overall objective of this project is to develop distributions for the concentrations of background metals in shallow Alberta soil. An additional objective is to determine if any of the metals are associated with produced water releases.

The scope of work for this project included the following:

- identify a population of analytical data for shallow soil and incorporate into a database;
- consult with analytical laboratories to determine current practices for sample preparation and analysis for metals in soil samples and identify whether varying practices between laboratories could affect data quality;
- develop and apply techniques for screening out non-background data points that are or may be affected by anthropogenic impacts;
- generate distributions and related statistics on background concentrations;
- develop correlations between trace metals and chloride concentrations for the full dataset; and
- generate a report summarizing the findings.

3.0 METHODOLOGY

3.1 Description of the Database

The initial dataset consisted of metal concentrations in soil samples from environmental impact assessments, environmental site assessments, remediation and reclamation activities in Alberta, BC and Saskatchewan. The dataset is stored in an SQL server ESdat database. At the time of analysis, the database contained data sampled between April 2008 and October 2015.

Metals data within the database was primarily received from five laboratories in Alberta, including Access Analytical Laboratories Inc., Agat Laboratories, ALS Environmental, Exova and Maxxam. Current practices for the preparation and analysis of metals in soil samples by the five laboratories were evaluated to determine whether different practices could significantly affect data quality.

The preparation and analytical methods used by all five laboratories for determining metal concentrations in soil, other than mercury, hot water boron and hexavalent chromium, involve the digestion of the sample using a combination of either nitric acid and hydrogen peroxide (EPA SW 846-3050) or nitric acid and hydrochloric acid (EPA 200.2), followed by analysis using inductively coupled plasma-mass spectrometry (ICP-MS). The two methods used for the digestion of these metals are expected to be equally effective since they both use strong acids and large variations in the analytical results are not expected due to the different methods of acid digestion used for these metals.

The preparation of samples for mercury analysis by the 5 different laboratories also involves sample digestion using either the EPA SW 846-3050 or EPA 200.2 methods; however, these laboratories perform mercury analysis by either ICP-MS or cold vapour atomic absorption spectrometry (CVAAS). Trace level analysis of mercury by ICP-MS may be problematic due to its low sensitivity compared to CVAAS (Pfeil 2011); however, mercury concentrations in the range of an order of magnitude below the Tier 1 guideline of 6.6 mg/kg can be readily measured using ICP-MS and, therefore, the lower sensitivity of ICP-MS is not likely to be a significant issue for comparison of mercury concentrations to the Tier 1 guideline.

The analytical methods used for hexavalent chromium by the five different laboratories involve alkaline digestion followed by colorimetric detection or ion chromatography with colorimetric detection. Since similar methods are used, large differences in data quality are not expected between laboratories. However, high concentrations of molybdenum, mercury or vanadium may interfere with colorimetric detection of hexavalent chromium (BC MOE 2015).

Boron concentrations in the database were measured by the hot water soluble method. The hot water soluble boron method is no longer recommended by AEP; instead, AEP has recently adopted the use of the saturated paste method for boron analysis (AEP 2016).

3.2 Data Screening Methods

Two groups of data screening processes were used to remove data points not related to background conditions. The first group of processes involved steps that could be applied to the dataset as a whole, removing unsuitable data points based on metadata contained in the database, such as location, depth, and concentrations of other chemicals. This group of processes is referred to herein as global screening. A second group of processes, referred to herein as site-specific screening, involved looking at the site setting of selected key data points to ensure that they were genuine background values. These two groups of processes are described in more detail below.

3.2.1 Global Screening Methods

Global screening of the full dataset was performed using the steps described below. Data meeting any of the following conditions were screened out of the database:

- soil analytical results from sites outside Alberta;
- soil analytical results from depths greater than 10 metres below ground surface, primarily to remove data associated with samples obtained from bedrock;
- anomalous data (*e.g.*, data entered as a concentration range, data with negative depths).
- soil analytical results with no metals data;
- soil analytical results associated with a chloride concentration greater than 100 mg/kg (assumed to indicate anthropogenic impact);
- soil analytical results associated with detectable benzene, ethylbenzene, xylenes, F1 or F2 hydrocarbon fractions (assumed to indicate anthropogenic impact). Toluene and F3 hydrocarbon fractions were not used for screening out data since these may also be elevated due to naturally occurring organic matter; and
- soil analytical results associated with detectable process chemicals (including alcohols and amines; assumed to indicate anthropogenic impact).

In addition, soil analytical results with barium concentrations greater than 500 mg/kg (by strong acid digest method) were screened out of the database. Barium is a common component of drilling muds and, thus, a common contaminant at oil and gas sites. The screening value of 500 mg/kg was derived based on background soil values reported by the Canadian Council of Ministers of the Environment (CCME 2013) and by the BC Ministry of Environment (BC MOE 2010).

The following data were retained in the database for screened-in samples:

- analytical data for metals;
- analytical data for all other available parameters;
- sample identification;
- sample location;
- sample depth; and,
- sample date.

3.2.2 Site Specific Screening Methods

Site specific screening of soil analytical data was completed on the database following the global screening steps (Section 3.2.1). The site specific screening was performed as follows:

- the data remaining after the global screening steps were used to generate an interim histogram for each metal using the data analysis tool in Excel and automatic bin size generation;
- the histograms were used to identify high outliers, with any data separated by more than two empty bins being flagged as potential outliers;
- soil data for each metal were sorted from lowest to highest concentration;
- a detailed review was performed for each metal starting at the highest concentration (including flagged outliers) and was continued until a maximum background concentration could be identified with high confidence. Once a maximum background concentration was identified with high confidence, a detailed review was not performed on the remaining (lower) background data. The following sources were used to perform the detailed review:
  - borehole logs;
  - site diagrams;
  - summary tables; and
  - report text.

Data points considered in the site-specific screening step are summarized for each metal in Appendix B, where the rationale for including or rejecting each value is provided.

Any metals data not consistent with a background location were screened out of the database. Data obtained from samples taken within bedrock, leaf litter, non-native fill material and samples taken within the footprint of known or remediated impacts were also screened out of the database.

The site-specific screening step ensured that the maximum value in the background distribution for each metal could be identified as a genuine background concentration with a high degree of confidence.

3.3 Statistical Methods

Statistical parameters (including mean, median, 25th percentile, 75th percentile, 95th percentile, minimum and maximum concentrations) were calculated after substitution of non-detect data (below reported detection limit [RDL]) with ½ RDL.

4.0 RESULTS

The full dataset, before screening, consisted of 5677 unique samples. Once potentially impacted samples had been removed via the global and site specific screening steps, 793 unique samples remained. Summary statistics for 19 of the 20 Tier 1 metals, following the global and site specific screening steps, are presented in Appendix C; and selected key values for these metals are summarized in Table 1. Summary statistics are not presented for barium since a barium concentration of 500 mg/kg was used as a screen to remove soil samples assumed to include drilling mud (Section 3.2.1). The maximum background metal concentration identified for each metal after global and site specific screening of the database is discussed below for each of the 19 metals.

4.1 Antimony

A maximum background antimony concentration of 1.3 mg/kg was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is below the Tier 1 guideline value of 20 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was located at an active gas wellsite in Wheatland County. This sample was obtained from a location identified as background near the western boundary of the wellsite and approximately 50 m from the nearest identified area with anthropogenic impacts exceeding Tier 1 guidelines. The sample was collected from 2.25 m bgs in silty clay soil, outside the original lease boundary. Antimony concentrations in the same borehole were below the reported detection limit and below the Tier 1 guideline of 20 mg/kg at depths of 0.75 and 1.5 m bgs. Lower antimony concentrations in overlying samples precludes the possibility of downwards migration of any possible surface impacts, and provides additional support to this being a true background concentration. Former infrastructure at the site included a compressor building, above ground storage tanks, underground storage tank/flare pit area and land treatment areas (used to treat hydrocarbon and salt contaminated soil associated with remedial activities for the underground storage tank/flare pit area). Active infrastructure included a wellhead, aboveground flow lines, a separator, a solar panel and SCADA unit, a pipeline riser/valve system and a pig trap. All of the former and active infrastructure and identified Tier 1 exceedances at the site were contained within the original lease boundary. Chloride concentrations at the location where the maximum antimony concentration was identified were 3 mg/kg at 0.75 m bgs, 2 mg/kg at 1.5 m bgs and 4 mg/kg at 2.25 m bgs. Based on this information, there is a high level of confidence that the antimony concentration of 1.3 mg/kg represents background conditions.

A histogram and statistics illustrating the distribution of antimony concentrations in background shallow soils in Alberta are provided in Appendix C.

4.2 Arsenic

A maximum background arsenic concentration of 34.7 mg/kg was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is above the Tier 1 guideline value of 17 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was located at an abandoned wellsite in Kneehill County. This sample was obtained from a location identified as background near the southern boundary of the wellsite and approximately 40 m from the nearest identified area with anthropogenic impacts exceeding Tier 1 guidelines. The sample was collected from 2.2 meters below ground surface (m bgs) in clay soil. There is no record of spills having occurred at the site. Historical infrastructure at the site included a well head and sump. Hydrocarbon and salt impacts were present in the well centre and sump areas. Arsenic concentrations measured in the well centre and sump areas were all below Tier 1 guideline levels. The chloride concentrations at the location where the maximum arsenic concentration was identified was 7 mg/kg at 2.2 m bgs and 7 mg/kg at 0.75 m bgs. Based on this information, there is a high level of confidence that the arsenic concentration of 34.7 mg/kg represents background conditions.

A histogram and statistics illustrating the distribution of arsenic concentrations in background shallow soils in Alberta are provided in Appendix C.

4.3 Beryllium

A maximum background beryllium concentration of 1.3 mg/kg was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is below the Tier 1 guideline value of 5 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was located at an abandoned wellsite in Westlock County. This sample was obtained from a location identified as background near the eastern boundary of the wellsite and approximately 50 m from the nearest identified area with anthropogenic impacts exceeding Tier 1 guidelines. The sample was collected from 1.4 m bgs in sandy clay till. There is no record of spills having occurred near the sample location. Historical infrastructure at the site included a well head and a sump. Hydrocarbon and metal impacts were present in the sump area; however, beryllium concentrations measured in the sump area were all below the Tier 1 guideline of 5 mg/kg. Chloride concentrations at the location where the maximum beryllium concentration was identified were 45 mg/kg at 1.4 m bgs and 57 mg/kg at 3.7 m bgs. Based on this information, there is a high level of confidence that the beryllium concentration of 1.3 mg/kg represents background conditions.

A histogram and statistics illustrating the distribution of beryllium concentrations in background shallow soils in Alberta are provided in Appendix C.

4.4 Boron

A maximum background boron concentration of 2.08 mg/kg (evaluated as hot water soluble boron) was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is above the Tier 1 guideline value of 2 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was located at an abandoned wellsite in Birch Hills County. This sample was obtained from a location identified as background near the western boundary of the wellsite. The sample was collected from 1.8 to 2.0 m bgs in clay soil. There is no record of spills having occurred near the sample location. Historical infrastructure at the site included a well head and a sump. No impacts were noted at the site and a review of the drilling waste disposal notification for the site did not indicate elevated metal concentrations. Chloride concentrations at the location where the maximum boron concentration was identified were 13 mg/kg at 0 to 0.2 m bgs and 18 mg/kg at 1.8 to 2.0 m bgs. Based on this information, there is a high level of confidence that the boron concentration of 2.08 mg/kg represents background conditions.

A histogram and statistics illustrating the distribution of boron concentrations in background shallow soils in Alberta are provided in Appendix C.

4.5 Cadmium

A maximum background cadmium concentration of 3.22 mg/kg was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is above the Tier 1 guideline value of 1.4 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was located near an abandoned coal mine in Yellowhead County. This sample was obtained from a location identified as background approximately 780 m east of the mine permit area. The soil sample was collected from 0 to 0.3 m bgs. The maximum cadmium concentration measured in on-site soils was 0.85 mg/kg, well below the Tier 1 guideline value of 1.4 mg/kg. Cadmium was not identified as a contaminant of potential environmental concern for the site. Based on this information, there is a high level of confidence that the cadmium concentration of 3.22 mg/kg represents background conditions.

A histogram and statistics illustrating the distribution of cadmium concentrations in background shallow soils in Alberta are provided in Appendix C.

4.6 Chromium

A maximum background total chromium concentration of 32 mg/kg was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is below the Tier 1 guideline value of 64 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was located at an abandoned wellsite in Birch Hills County. This sample was obtained from a location identified as background near the eastern boundary of the wellsite and approximately 35 m from the nearest identified area with anthropogenic impacts exceeding Tier 1 guidelines. The sample was collected from 2.8 to 3.0 m bgs in clay soil. There is no record of spills having occurred near the sample location. Historical infrastructure at the site included a well head, a sump and a potential flare pit on the northwest side of the site. Hydrocarbon and salt impacts were present in the sump area. Total chromium concentrations measured in the sump area were all below Tier 1 guideline levels. The chloride concentrations at the location where the maximum background total chromium concentration was identified were 4 mg/kg at 0.6 to 0.8 m bgs and 12 mg/kg at 2.8 to 3.0 m bgs. Based on this information, there is a high level of confidence that the total chromium concentration of 32 mg/kg represents background conditions.

Background hexavalent chromium concentrations were all below the RDLs reported for hexavalent chromium (see Appendix B). Hence, all of the background soil locations within Alberta had hexavalent chromium concentrations below the maximum reported RDL of 0.3 mg/kg in this dataset.

A histogram and statistics illustrating the distribution of total chromium concentrations in background shallow soils in Alberta are provided in Appendix C.

4.7 Cobalt

A maximum background cobalt concentration of 27 mg/kg was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is above the Tier 1 guideline value of 20 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was collected from a gas plant in the M.D. of Greenview No. 16 in Alberta. This sample was obtained from an off-site location identified as background to the north of the gas plant boundary and approximately 40 m from the nearest identified area with anthropogenic impacts exceeding Tier 1 guidelines. The sample was collected from 0 to 0.15 m in silty clay soil. There is no record of spills having occurred near the sample location. Hydrocarbon, salt, boron, nickel, copper and selenium impacts were present at other locations at the site; however, cobalt concentrations measured in impacted areas were all below the Tier 1 guideline value of 20 mg/kg. The maximum chloride concentration within the borehole where the maximum cobalt concentration was identified

was 14 mg/kg (for depths from 0.15 to 6.0 m bgs). Based on this information, there is a high level of confidence that this cobalt concentration of 27 mg/kg represents background conditions.

A histogram and statistics illustrating the distribution of cobalt concentrations in background shallow soils in Alberta are provided in Appendix C.

4.8 Copper

A maximum background copper concentration of 39.3 mg/kg was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is below the Tier 1 guideline value of 63 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was located at an abandoned wellsite in Birch Hills County. This sample was obtained from a location identified as background near the eastern boundary of the wellsite and approximately 35 m from the nearest identified area with anthropogenic impacts exceeding Tier 1 guidelines. The sample was collected from 0.6 to 0.8 m bgs in clay soil. There is no record of spills having occurred near the sample location. Historical infrastructure at the site included a well head, a sump and a potential flare pit on the northwest side of the site. Hydrocarbon and salt impacts were present in the sump area. Copper concentrations measured in the sump area were all below the Tier 1 guideline of 63 mg/kg. The chloride concentrations at the location where the maximum background copper concentration was identified were 4 mg/kg at 0.6 to 0.8 m bgs and 12 mg/kg at 2.8 to 3.0 m bgs. Based on this information, there is a high level of confidence that the total copper concentration of 39.3 mg/kg represents background conditions.

A histogram and statistics illustrating the distribution of copper concentrations in background shallow soils in Alberta are provided in Appendix C.

4.9 Lead

A maximum background lead concentration of 20.7 mg/kg was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is below the Tier 1 guideline value of 70 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was located at a gas plant in the M.D. of Greenview No. 16. This sample was obtained from a location identified as background near the western boundary of the gas plant and approximately 90 m west of the nearest identified area with anthropogenic impacts exceeding Tier 1 guidelines. The sample was collected from 0.7 m bgs in clay loam. There is no record of spills having occurred near the sample location. Lead concentrations measured at the site were all below the Tier 1 guideline level of 70 mg/kg. Chloride concentration at the location where the maximum lead

concentration was identified was 7 mg/kg at 0.7 m bgs. Based on this information, there is a high level of confidence that the lead concentration of 20.7 mg/kg represents background conditions.

A histogram and statistics illustrating the distribution of lead concentrations in background shallow soils in Alberta are provided in Appendix C.

4.10 Mercury

A maximum background mercury concentration of 0.1 mg/kg was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is below the Tier 1 guideline value of 6.6 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was located at an abandoned wellsite in Birch Hills County. This sample was obtained from a location identified as background near the eastern boundary of the wellsite and approximately 35 m from the nearest identified area with anthropogenic impacts exceeding Tier 1 guidelines. The sample was collected from 0.6 to 0.8 m bgs in clay soil. Mercury concentration in the same borehole at 2.8 to 3.0 m bgs was 0.05 mg/kg. There is no record of spills having occurred near the sample location. Historical infrastructure at the site included a well head, a sump and a potential flare pit on the northwest side of the site. Hydrocarbon and salt impacts were present in the sump area. Mercury concentrations measured in the sump were all below the reported detection limit (0.05) and below the Tier 1 guideline of 6.6 mg/kg. The chloride concentrations at the location where the maximum background mercury concentration was identified were 4 mg/kg at 0.6 to 0.8 m bgs and 12 mg/kg at 2.8 to 3.0 m bgs. Based on this information, there is a high level of confidence that the mercury concentration of 0.1 mg/kg represents background conditions.

A histogram and statistics illustrating the distribution of mercury concentrations in background shallow soils in Alberta are provided in Appendix C.

4.11 Molybdenum

A maximum background molybdenum concentration of 3.8 mg/kg was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is below the Tier 1 guideline value of 4 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was located at a gas plant in the M.D. of Greenview No. 16. This sample was obtained from an off-site location identified as background approximately 235 m west of the nearest identified area with anthropogenic impacts exceeding Tier 1 guidelines. The sample was collected from 2.2 meters below ground surface (m bgs) in clay soil. There is no record of spills having occurred near this location. Molybdenum concentrations measured at the site were all

below the Tier 1 guideline of 4 mg/kg. Based on this information, there is a high level of confidence that the molybdenum concentration of 3.8 mg/kg represents background conditions.

A histogram and statistics illustrating the distribution of molybdenum concentrations in background shallow soils in Alberta are provided in Appendix C.

4.12 Nickel

A maximum background nickel concentration of 49.9 mg/kg was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is above the Tier 1 guideline value of 45 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was located at an abandoned wellsite in Birch Hills County. This sample was obtained from a location identified as background near the eastern boundary of the wellsite and approximately 35 m from the nearest identified area with anthropogenic impact. The sample was collected from 0.6 to 0.8 m bgs in clay soil. There is no record of spills having occurred near the sample location. Historical infrastructure at the site included a well head, a sump and a potential flare pit on the northwest side of the site. Hydrocarbon and salt impacts were present in the sump area. Nickel concentrations measured in the sump area were all below Tier 1 guideline levels. The chloride concentrations at the location where the maximum background nickel concentration was identified were 4 mg/kg at 0.6 to 0.8 m bgs and 12 mg/kg at 2.8 to 3.0 m bgs. Based on this information, there is a high level of confidence that the nickel concentration of 49.9 mg/kg represents background conditions.

A histogram and statistics illustrating the distribution of nickel concentrations in background shallow soils in Alberta are provided in Appendix C.

4.13 Selenium

A maximum background selenium concentration of 1.3 mg/kg was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is above the Tier 1 guideline value of 1 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was located at an abandoned wellsite in the M.D. of Spirit River No. 133. This sample was obtained from a location identified as background near the south western boundary of the wellsite. The sample was collected from 0.7 m bgs in clay soil. There is no record of spills having occurred near the sample location. Historical infrastructure at the site included a well head, a sump, a former tank storage area, flare pit and flare stack. No impacts were noted at the site and a review of the drilling waste disposal notification for the site did not indicate elevated metal concentrations. Chloride concentration at the location where the maximum selenium

concentration was identified was 3 mg/kg at 0.2 m bgs, 3 mg/kg at 0.7 m bgs and 4 mg/kg at 1.4 m bgs. Based on this information, there is a high level of confidence that the selenium concentration of 1.3 mg/kg represents background conditions.

A histogram and statistics illustrating the distribution of selenium concentrations in background shallow soils in Alberta are provided in Appendix C.

4.14 Silver

A maximum background silver concentration of 0.32 mg/kg was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is below the Tier 1 guideline value of 20 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was located near an abandoned coal mine in Yellowhead County. This sample was obtained from a location identified as background approximately 780 m east of the mine permit area. The soil sample was collected from 0.3 to 0.5 m bgs. Silver was not identified as a contaminant of potential environmental concern for the site. Based on this information, there is a high level of confidence that the silver concentration of 0.32 mg/kg represents background conditions.

A histogram and statistics illustrating the distribution of silver concentrations in background shallow soils in Alberta are provided in Appendix C.

4.15 Thallium

A maximum background thallium concentration of 0.6 mg/kg was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is below the Tier 1 guideline value of 1 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was located at an active gas wellsite in Wheatland County. This sample was obtained from a location identified as background near the western boundary of the wellsite and approximately 50 m from the nearest identified area with anthropogenic impacts exceeding Tier 1 guidelines. The sample was collected from 2.25 m bgs in silty clay soil and outside a fenced area (outside the original lease boundary). Thallium concentrations in the same borehole were below the reported detection limit and below the Tier 1 guideline of 1.0 mg/kg at depths of 0.75 and 1.5 m bgs. Former infrastructure at the site included a compressor building, above ground storage tanks, underground storage tank/flare pit area and land treatment areas (used to treat hydrocarbon and salt contaminated soil associated with remedial activities for the underground storage tank/flare pit area). Active infrastructure included a wellhead, aboveground flow lines, a separator, a solar panel and SCADA unit, a pipeline riser/valve system and a pig trap. All of the former and active infrastructure was contained within a fenced area and within the original lease boundary. Thallium

concentrations measured in the active biocell were below the reported detection limit and well below the Tier 1 guideline. Chloride concentrations at the location where the maximum thallium concentration was identified were 3 mg/kg at 0.75 m bgs, 2 mg/kg at 1.5 m bgs and 4 mg/kg at 2.25 m bgs. Based on this information, there is a high level of confidence that the thallium concentration of 0.6 mg/kg represents background conditions.

A histogram and statistics illustrating the distribution of thallium concentrations in background shallow soils in Alberta are provided in Appendix C.

4.16 Tin

A maximum background tin concentration of 2.6 mg/kg was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is below the Tier 1 guideline value of 5 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was located at an abandoned wellsite in the M.D. of Smoky River No. 130. This sample was obtained from a location identified as background near the western boundary of the wellsite and approximately 60 m from the nearest identified area with anthropogenic impacts exceeding Tier 1 guidelines. The sample was collected from 2.8 to 3.0 m bgs in clay soil. There is no record of spills having occurred in the vicinity of the sample location. Historical infrastructure at the site included a well head and sump. Hydrocarbon and salt impacts were present in the sump area. Tin concentrations measured in the sump area were all below the reported detection limit (<5 mg/kg) and below the Tier 1 guideline of 5 mg/kg. Chloride concentrations at the location where the maximum tin concentration was identified was 7 mg/kg at 1.2 to 1.4 m bgs, 8 mg/kg at 1.8 to 2.0 m bgs and 11 mg/kg at 2.8 to 3.0 m bgs. Based on this information, there is a high level of confidence that the tin concentration of 2.6 mg/kg represents background conditions.

A histogram and statistics illustrating the distribution of tin concentrations in background shallow soils in Alberta are provided in Appendix C.

4.17 Uranium

A maximum background uranium concentration of 10.6 mg/kg was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is below the Tier 1 guideline value of 23 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was located at an abandoned wellsite in the M.D. of Opportunity No. 17. This sample was obtained from a location identified as background near the western boundary of the wellsite. The sample was collected from 0.5 to 1.0 m bgs in silty clay soil. Historical infrastructure at the site included two non-producing wells. No spills or contamination was

reported for the site. The chloride concentration at the location where the maximum uranium concentration was identified was 5 mg/kg at 0.5 to 1.0 m bgs. Based on this information, there is a high level of confidence that the uranium concentration of 10.6 mg/kg represents background conditions.

A histogram and statistics illustrating the distribution of uranium concentrations in background shallow soils in Alberta are provided in Appendix C.

4.18 Vanadium

A maximum background vanadium concentration of 52 mg/kg was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is below the Tier 1 guideline value of 130 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was located at an abandoned wellsite in Birch Hills County. This sample was obtained from a location identified as background near the eastern boundary of the wellsite and approximately 35 m from the nearest identified area with anthropogenic impacts exceeding Tier 1 guidelines. The sample was collected from 2.8 to 3.0 m bgs in clay soil. Vanadium concentration in the same borehole at 0.6 to 0.8 m bgs was 46.8 mg/kg. There is no record of spills having occurred near the sample location. Historical infrastructure at the site included a well head, a sump and a potential flare pit on the northwest side of the site. Hydrocarbon and salt impacts were present in the sump area. Vanadium concentrations measured in the sump were all below the Tier 1 guideline of 130 mg/kg. The chloride concentrations at the location where the maximum background vanadium concentration was identified were 4 mg/kg at 0.6 to 0.8 m bgs and 12 mg/kg at 2.8 to 3.0 m bgs. Based on this information, there is a high level of confidence that the vanadium concentration of 52 mg/kg represents background conditions.

A histogram and statistics illustrating the distribution of vanadium concentrations in background shallow soils in Alberta are provided in Appendix C.

4.19 Zinc

A maximum background zinc concentration of 122 mg/kg was identified from the database, once the global and site-specific screening processes had excluded samples impacted, or potentially impacted by anthropogenic impacts (see Appendix B). This maximum value is below the Tier 1 guideline value of 200 mg/kg for agricultural and other sensitive land uses. The sample with the maximum confirmed background value was located at an abandoned wellsite in the M.D. of Spirit River No. 133. This sample was obtained from a location identified as background near the south western boundary of the wellsite. Previous investigations have not identified any contaminants exceeding Tier 1 guidelines at the site and there is no record of spills having occurred at the site. The sample was collected from

0.7 m bgs in silty clay soil. Historical infrastructure at the site included a well head, a sump (northwest quadrant), a produced water storage tank and a flare pit/flare stack area (north east corner). A chloride concentration of 3 mg/kg was available from 0.2 m bgs at the location where the maximum zinc concentration was identified. Based on this information, there is a high level of confidence that the zinc concentration of 122 mg/kg represents background conditions.

A histogram and statistics illustrating the distribution of zinc concentrations in background shallow soils in Alberta are provided in Appendix C.

5.0 DISCUSSION

5.1 Provincial Coverage for Verified Background Data

The distribution of sample locations available for consideration in the current project is indicated in Figure 1. As can be seen, most areas of the province are represented in the dataset.

5.2 Results

The starting point for this project was a database of soil samples from environmental site investigational and other activities across the province. Global screening steps focused the dataset on soil samples from the top 10 m from sites within Alberta and removed any samples associated with other contaminants. Site specific screening steps then examined the highest concentrations in the remaining database, rejecting samples that could not unequivocally be associated with background conditions until a maximum background value could be identified.

Statistical data for background metal distributions in Alberta soil are summarized in Table 1, along with the most stringent Tier 1 guideline value for each metal. Statistical analyses were based on the number of background samples identified in Table 1 for each metal, ranging from 259 to 793 samples. All maximum background metal concentrations identified from the database were associated with locations identified as background in their respective investigations. Maximum background metal concentrations were well below their respective Tier 1 guideline value for antimony, beryllium, total chromium, hexavalent chromium, copper, lead, mercury, silver, thallium, tin, uranium, vanadium and zinc. Maximum background concentrations for arsenic, cadmium, cobalt, nickel and selenium exceeded their respective Tier 1 guideline value; and maximum background concentration for molybdenum was just below its Tier 1 guideline value. The maximum background hexavalent chromium concentration was below the reported RDL of 0.3 mg/kg.

Table 1 Statistical Summary for Background Metal Distributions in Alberta Soil (mg/kg)

Metal	Tier 1 Guideline	Background Metal Concentration			
		Maximum	95th Percentile	Mean	Number of samples
Antimony	20	1.3	0.7	0.3	738
Arsenic (inorganic)	17	**34.7**	12.4	6.9	766
Beryllium	5	1.3	1.0	0.5	774
Boron (hot water soluble)	Tier 1 Guideline uses saturated paste method	2.08	1.74	0.55	342
Cadmium	1.4	**3.22**	1.10	0.37	779
Total Chromium	64	32	28	17	739
Hexavalent Chromium	0.4	<0.3	-	-	259
Cobalt	20	**27**	13	8	779
Copper	63	39.3	29.2	16.0	780
Lead	70	20.7	15.1	9.0	793
Mercury (inorganic)	6.6	0.10	0.08	0.05	302
Molybdenum	4	3.8	1.9	0.9	752
Nickel	45	**49.9**	38.0	22.0	773
Selenium	1	**1.3**	0.9	0.4	715
Silver	20	0.32	0.25	0.21	674
Thallium	1	0.6	0.3	0.2	760
Tin	5	2.6	2.5	0.8	757
Uranium	23	10.6	2.9	1.3	741
Vanadium	130	52	44	27	746
Zinc	200	122	97	56	773

Bolded and underlined values indicate concentrations above the Tier 1 guideline value

Histograms and associated statistics for background metal concentrations in Alberta are shown in Appendix C. Several metals including antimony, beryllium, boron, cadmium, mercury, molybdenum, selenium, silver, thallium, tin and uranium show artificially elevated frequencies in the histograms for their lowest metal concentrations due to substitution of data below the RDL with ½ RDL. As is evident from the histograms, the Tier 1 guideline is distinctly higher than distributions of background antimony, beryllium, chromium, copper, lead, mercury, silver, thallium, tin, uranium, vanadium and zinc. The highest background concentrations of arsenic, cadmium, cobalt, nickel and selenium exceeded the Tier 1 guideline value , with less than 5th percentile of data showing a distribution above the respective Tier 1 guideline value.

5.3 Comparison to Other Studies in Alberta

Previous unpublished work by AECOM (2008) evaluated background metal concentrations at Alberta industrial sites. This work evaluated data reported under the Alberta Soils Monitoring Directive and consisted of:

- data collected between 1986 and 1998 (71 reports; 4,095 soil samples collected from 54 industrial sites), and
- data collected from 1997 to 2006 (517 reports; 15,649 samples collected from 251 industrial sites).

The procedure used by AECOM (2008) to identify background data included identification and removal of outliers through graphical methods. The resulting background soil concentrations, following the removal of outliers, were not validated due to the limited amount of information available. Maximum background metal concentrations reported by AECOM (2008) are summarized in Table 2. Both the AECOM and present studies reported maximum background nickel and selenium concentrations above Tier 1 guideline values and maximum background cobalt and molybdenum concentrations that were either just below their Tier 1 guideline value or above their Tier 1 guideline value. The most notable differences between the two studies were the maximum background concentrations for hexavalent chromium and tin. The current study did not identify any hexavalent chromium concentrations above the reported RDL of <0.3 mg/kg, whereas the AECOM study reported a maximum background concentration of 0.85 mg/kg for hexavalent chromium. The current study identified a maximum background concentration of 2.6 mg/kg for tin, whereas the AECOM study reported a maximum background concentration of 5 mg/kg. The maximum background value reported for tin by AECOM would be identified as an outlier based on the present study (Appendix B). It is noteworthy that AECOM (2008) was unable to validate their data due to a lack of site specific information.

Table 2 Comparison of Maximum Background Metal Concentrations to AECOM Results (mg/kg)

Metal	Tier 1 Guideline	AECOM 2008 (no outliers)	Current Study
Antimony	20	1.1	1.3
Arsenic	17	15.4	34.7
Beryllium	5	1.2	1.3
Cadmium	1.4	1.2	3.22
Chromium (hexavalent)	0.4	0.85	<0.30
Chromium (total)	64	49.8	32
Cobalt	20	19.6	27
Copper	63	45	39.3
Lead	70	25	20.7
Mercury	6.6	0.11	0.10
Molybdenum	4	10.4	3.8
Nickel	45	46.9	49.9
Selenium	1	2.7	1.3
Silver	20	1	0.32
Thallium	1	1	0.6
Tin	5	5	2.6
Uranium	23	-	10.6
Vanadium	130	77.6	52
Zinc	200	137	122

5.4 Correlations Between Chloride and Metal Concentrations

Produced water releases may occur at oil and gas facilities. Produced water can contain high concentrations of sodium, chloride, other major ions, and trace metals. Correlations between chloride and Tier 1 metal concentrations were examined in the full dataset prior to screening out impacted samples. Any positive correlations would suggest that either: i) the metal is a significant component in produced water, or ii) that high concentrations of sodium in produced water mobilized the metal via ion exchange. The results of this assessment are summarized in Appendix D. The results show a strong linear correlation between sodium and chloride concentrations ($R^2 = 0.96$), as would be expected for produced water impacts. A linear correlation was also observed between boron and chloride concentrations ($R^2 = 0.63$). High boron concentrations in produced water are well documented. No other significant correlations were observed between chloride and Tier 1 metals for the dataset.

6.0 DISCUSSION OF DATA GAPS AND UNCERTAINTY

Factors affecting the level of uncertainty associated with the data presented in this report are discussed below.

The dataset of background samples on which the distributions were based comprised of approximately 300 to 800 samples for the different metals. While a greater number of samples would improve the statistical results, the number of samples available is assumed to be sufficient to include the majority of variability in shallow soils across the province.

The spatial coverage of samples available in this project is provided in Figure 1. Most areas of the province are represented, however the potential exists for different distributions in areas that are not represented.

Global screening methods were used in this work to reject any samples which appeared to have elevated levels of anthropogenic contaminants typically associated with oil and gas activities (including chloride, petroleum hydrocarbons and process chemicals). This step is expected to remove the majority of instances of soil samples impacted with anthropogenic metals on the assumption that anthropogenic metals will typically be associated with other contaminants. However, this relatively broad brush screening step will likely have removed some samples that had background concentrations of metals since the presence of chloride, petroleum hydrocarbons or process chemicals will not always be associated with anthropogenic metals.

There is a high level of confidence that the concentration identified as the maximum background value for each metal is a true background value. However, since the site-specific screening process rejected many samples based on not being able to definitively exclude the possibility of anthropogenic impact, it is likely that some samples were rejected that did in fact represent background conditions.

It was not practical within the scope of this project to make a site-specific evaluation of each of the samples included in the background dataset. Site-specific evaluation efforts were focused on identifying a maximum value that represented background conditions for each metal with a high degree of confidence. It is therefore possible that the distribution of background concentrations for each metal contains some values that could include anthropogenic impacts. However, it is expected that the global screening steps will have eliminated the majority of these, and any impact on the distributions presented in Appendix C will be minor.

7.0 BEST PRACTICE RECOMMENDATIONS

Natural background metal concentrations in soil can vary substantially between sites, depending largely on the nature of the parent material from which the soil formed. Caution should therefore be exercised when extrapolating the results described in this report to other sites. Sound professional judgement is required when evaluating whether elevated metal concentrations are anthropogenic or natural in origin. Elevated background metal concentrations identified at other sites outside the magnitude of maximum background metal concentrations reported here may require additional site specific background data to support an argument for natural occurrence. Elevated background metal concentrations that occur at magnitudes similar to those of the outliers identified in this report (Appendix B) require greater scrutiny and may be a result of anthropogenic activities.

8.0 ACKNOWLEDGEMENTS

This work was made possible by funding from Petroleum Technology Alliance Canada (PTAC) under project number #15-SGRC-02.

9.0 CLOSURE

We trust that the information presented herein meets your requirements. Should you have any questions, please call either of the undersigned at (403) 592-6180.

Yours truly,

Millennium EMS Solutions Ltd.

Prepared by:

Nailish Samanani, Ph.D.
Risk Assessment Scientist

Reviewed by:

Miles Tindal, M.Sc.
Contaminated Sites Risk Assessment Specialist

10.0 REFERENCES

AECOM. 2008. Trends in Soil Quality at Alberta Industrial Sites: Analysis of the Alberta Industrial Soils Monitoring Database, unpublished.

Alberta Environment and Parks (AEP). 2016. Alberta Tier 1 Soil and Groundwater Remediation Guidelines.

British Columbia Ministry of Environment (BC MOE). 2010. Protocol 4 for Contaminated Sites, Determining Background Soil Quality.

British Columbia Ministry of Environment (BC MOE). 2015. BC Laboratory Manual. Accessed at: http://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/sampling-methods-quality-assurance/bc-environmental-labratory-manual

Canadian Council of Ministers of the Environment (CCME). 2013. Canadian Soil Quality Guidelines for Barium: Protection of Human Health Scientific Criteria Document.

Edwards I.K., Kalra Y. P. and Radford F.G. 1981. Chloride determination and levels in the soil-plant environment. Environmental Pollution (Series B). 2: 109-117.

Pfeil D. 2011. Measurement Techniques for Mercury. accessed at: https://www.envirotech-online.com/article_read/1051/