Quantitative Ecological Risk Assessment – Trial Area of Defence Research and Development Canada, Valcartier Research Centre

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ABSTRACT

Defence Research and Development Canada (DRDC) Valcartier trial area has been used for many types of activities since its implementation in the early 1940s, focusing primarily on the use of explosives. The site is located within the premises of the Valcartier Military Base Range and Training Area. Jacques-Cartier river runs on the south border of the site and constitutes the primary receptor for the potential contaminants leaving the site. Following many years of characterization studies, a detailed quantitative ecological risk assessment (ERA) study was contracted out in 2017. Study results revealed that no risks affect the aquatic life in Jacques-Cartier river based on current and past activities. However, some risks were identified with respect to aquatic life in lakes and creeks present in the area. The study also revealed that some uncertainty resides within the contribution of energetic materials by-products and that more detailed analysis should be performed. Finally, a site management program was developed by a consultant in 2018-19, based on the results of the ERA. This program is intended to be in use for a period of 15 years or until the vocation of the site changes.

1.0 INTRODUCTION

Defence Research and Development Canada (DRDC) trial area, Valcartier Research Centre, is located northwest of the city of Quebec, on federal property (see Figure 1). Since the end of the Second World War, DRDC operates this area of the Valcartier military base for research and development purposes using ammunition and explosives. A former residual hazardous materials dumping site (hereby referred to as MDR site) is also located in the test area and is no longer in use today.

To ensure sound environmental management, DRDC has contracted out many environmental studies in the past (mostly characterization studies). These revealed the presence of soils, sediments, groundwater and surface water exceeding applicable recommendations or criteria for various chemical parameters. Based on this information, DRDC wishes to guide its decisions regarding the management of a portion of the testing area, including three sub-sectors: the Plateau, the B307 sector and the former MDR release site. The overall objective of the work is to ensure the long-term use of this portion of the testing area while at the same time maintaining environmental risks at an acceptable level, thereby meeting the requirements of the legal and regulatory requirements, where applicable. The rationale for this evaluation for DRDC is therefore to manage exceedances of recommendations and criteria highlighted during the previous studies while preserving the vocation of the site.

To achieve this objective an Ecological Risk Assessment (ERA) associated with various matrices (soil, groundwater, surface water, sediment) of the three sub-sectors was contracted out and performed by a specialized consultant.

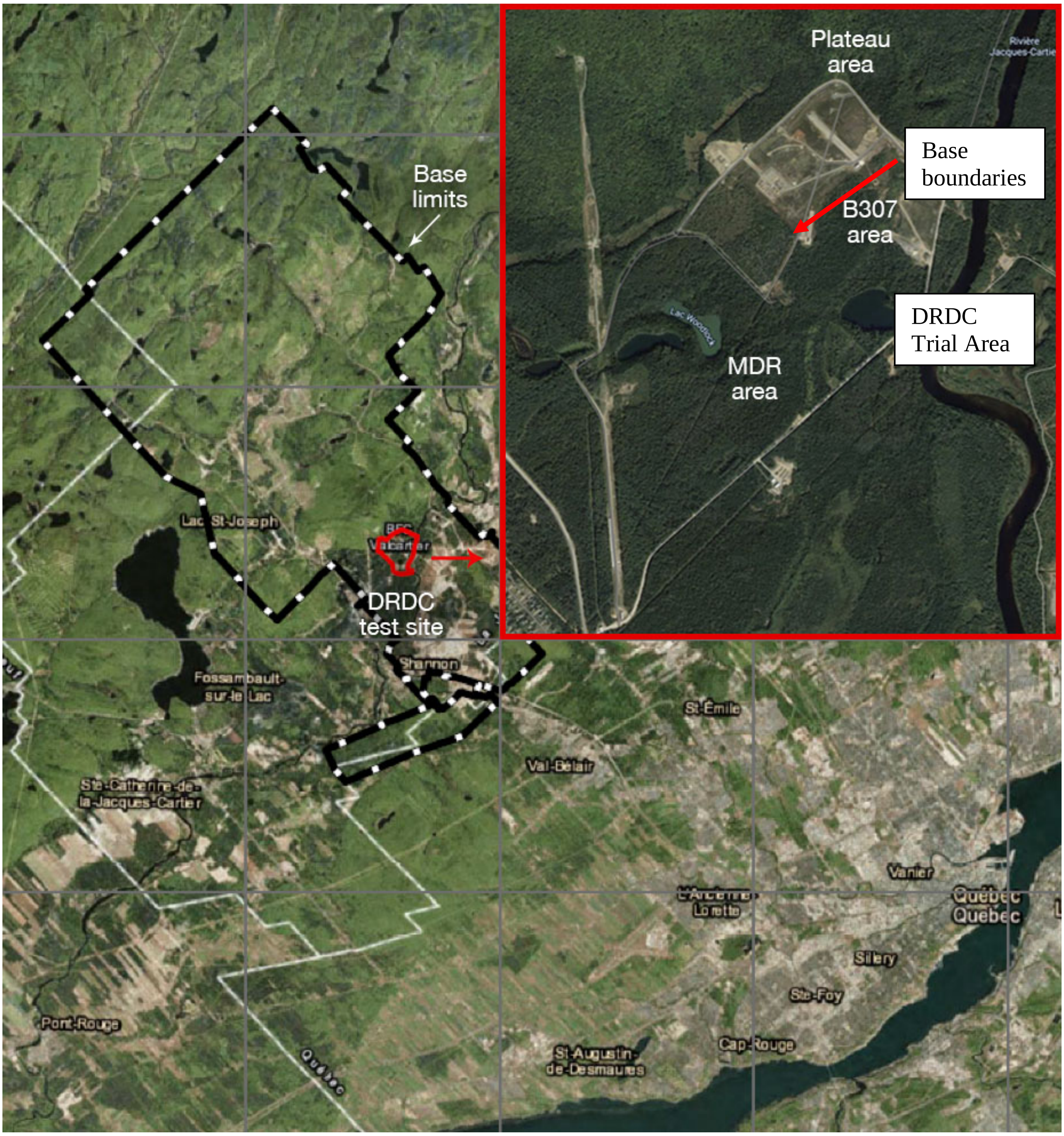

Figure 1: Site Localization.

1.1 Site Description

DRDC's Valcartier test area (later defined as the study area) is located approximately 35 kilometres northwest of Quebec city. The 172-hectare study area is located southeast of Mount Triquet and bordered by the Jacques-Cartier River and Perceval Creek. The Study Area is partially forested and contains Lake Laurie, a glacial lake with no outlet. Overall, the topography of the region is a typical Laurentian mountainous terrain to the north of the site and a more rugged terrain to the south. DRDC's Valcartier Test Area is located in a sparsely populated area with adjacent municipalities that are Shannon and Saint-Gabriel-de-Valcartier. The central geographical coordinates of the site are -71° 31' 03" W and 46° 55' 44" N (NAD 83).

Groundwater flow of the open water table in the area is from the northwest to the southwest towards the Jacques-Cartier River, which is the main outlet of the site. The level of groundwater located in the open water table (main aquifer formation), measured in the various piezometers throughout the site, varies between 3 and 25 m in depth.

The Jacques-Cartier River runs along the southeast side of the area. This river is the main outlet of the study site, receiving almost all of its runoff. From the study area, the river flows southwest through the Municipality of Shannon and the cities of Sainte-Catherine-de-la-Jacques-Cartier and Pont-Rouge before flowing into the St. Lawrence river in the town of Donnacona.

Perceval Creek is located at the northwestern boundary of the study site and flows southwestward. Since the study area slopes in a southeasterly direction, Perceval Creek does not receive any runoff from the site, except for a small strip along its shores. Perceval Creek flows to Lake Perceval to the west of the area and then joins the Rivière aux Pins, which flows into the Lake St. Joseph, used as a potable water intake for its residents.

Ruisseau du Plateau is a small stream found near the northeast limit of the study area. It drains the northwestern portion of the study area and flows southeastward to join the Jacques-Cartier River.

Lake Laurie has a surface area of 0.038 km², an average depth of 4.40 m and a maximum depth of 9.8 m. It is isolated from other surface water bodies on the site. According to Groupe Hémisphères, the hydrological estimate indicates a very fast turnover time (70 days) compared to the Quebec average of one and a half year. The imprecision of the basin boundary slope (0.982 km²) can explain this unusual value.

The stratigraphic sequence of unconsolidated deposits corresponds to:

- a till a few metres thick, with very low permeability and corresponding very high surface water flow;
- a layer of pro-glacial sediments mainly present to the west of the site and of which the thickness can be up to 30 m. This unit of sand and gravel has a high permeability and is a preferred path for groundwater flow;
- an esker passing under Lake Laurie and joining the Jacques-Cartier River could be a preferred route for groundwater flow. This hypothesis is not only based on stratigraphic observations but also on resurgence flow rate measurements and the values of water mineralization in the Jacques-Cartier River that show that the flow underground appears faster in a "corridor" from Lake Laurie to the Jacques-Cartier River;
- a deposit of continuous deltaic origin over most of the site (except on outcrops) of till and rock can be up to 50 m thick. This deposit consists of sand with variable proportions of silt and gravel. It is the main aquifer formation on the site;
- prodeltaic sediments form discontinuous lenses within the sediments. These sediments consist of silt. These lenses are responsible for the presence of a slick perched on the west side of the site;
- Alluvial deposits are located east of the site, along the Jacques-Cartier River, and their thickness

varies from 1 to 5 m.

1.2 Biological Features

The test area is located at the foot of the south slope of Mount Triquet. In general, the site is located in the bioclimatic domain of the linden sugar bush, which is divided into two sub-domains distinguished by their precipitation patterns since the study area is located in the sub-area from the east, where rainfall is heaviest. The flora is very diversified and many of species there reach the northern limit of their range. Approximately 65% of the site area is covered by shrub or tree vegetation and approximately 26% of the area is bare. Laurie Lake accounts for about 2% of the total area.

Mount Triquet, to the northeast and at the foot of which the study area is located, includes a yellow birch maple grove and a beech maple grove. As for Perceval Creek, which crosses the northwestern tip of the study site, its floodplain would consist of a mix of alder and wet meadow. The Plateau Creek is also located within the study area. It is a forest stream that crosses the fir stand and has a mainly coarse substrate of sand and pebbles.

Among the aquatic ecosystems found within the boundaries of the study site is the lake Laurie, a lake of glacial origin, mainly surrounded by a pine forest. A minerotrophic peat bog (fen) of 1,400 m² of tree-covered shoreline is also present on the northern edge of the Laurie Lake.

The ecological value of the identified ecosystems ranges from low to high. Within the boundaries of site under study, Perceval Creek and its banks (a mix of alder forest and wet meadow) have a high ecological value, as it is an unusual ecosystem in the region. Also considered to have ecological value the shoreline of lakes, including Laurie Lake, is important wildlife habitat for the birds, mammals and herpetofauna. The peat bog on the north side of Laurie Lake is also considered to be of high ecological value, since it is the only one in the sector and its integrity is high. It should be noted that these high-value habitats are all within sensitive areas and therefore benefit from the more stringent management objectives of the protectors established for these areas.

A large number of plant species were identified within the boundaries of the testing area and the surroundings. Among the most frequently encountered during the 2007 inventory these include Speckled Alder (Alnus rugosa) and Rattlesnake Mannagrass (*Glyceria canadensis*), identified in the alder grove in the Perceval Creek area. Still in this sector, but in the medium defined as a wet meadow, the most frequent species are the calamagrostids Bluejoint (*Calamagrostis canadensis*), Woolgrass (*Scirpus cyperinus*) and Knotweed (*Polygonaceae sp.*), all from the herbaceous stratum.

The most frequent species in the wasteland found on the site (Plateau, west of Laurie Lake) are the Broad-leaved Meadosweet (*Spirea latifolia*) in the low shrub stratum, Grey Birch (*Betula populifolia*) in the upper shrub stratum and Tamarack (*Larix laricina*) in the lower shrub stratum. Only two species have been recorded in the barren environment, either the Coast Jointweed (*Polygonella articulata*) and hair Moss (*Polytrichum sp*.), which covered either each, at the time of the inventory, less than 5% of the area of the environment. At the location of the pine forest located mainly west of Laurie Lake, the most frequent species are White Pine (*Pinus strobus*), Red Pine (*Pinus resinosa*), Balsam Fir (*Abies balsamea*) and Red Spruce (*Picea rubens*).

Several species of amphibians and reptiles are potentially present in the study site, particularly because of the different types of environments present on the study site and in the surrounding area. American Toads (*Anaxyrus americanus*), Wood Frogs (*Lithobates sylvaticus*), and Spring Peeper (*Pseudacris crucifer*) were observed in the birch maple grove area. A Redbacked Salamander (*Plethodon cinereus*) has been observed in the balsam fir/spruce area, one specimen of the Common Gartersnake (*Thamnophis sirtalis*) was observed in the area identified as wasteland (Plateau, Building B307 and west of Laurie Lake) in 2005 and 2006, a

Northern Leopard Frog (*Lithobates pipiens*) has been observed in the Lake Laurie shoreline area. Red-sided Garter Snakes (*Thamnophis sirtalis parietalis)* also were observed in the Lake Laurie subsector in 2005.

As mentioned previously, the presence of several types of environments and ecosystems within and around the test area will result in a large number of different mammals and small mammals that may be present on the site. Among those observed during the 2007 wildlife inventory include Moose (*Alces alces*) and Black Bear (*Ursus americanus*), including traces were observed in the B307 building sub-sector, as well as Mink (*Neovison vison*) in the area identified as a wet meadow along Perceval Creek.

Numerous beaver dams have also been observed along this creek. Finally, the Red Fox (*Vulpes vulpes*), American Porcupine (*Erethizon dorsatum*) and White-tailed Deer (*Odocoileus virginianus*) were observed in the various media of the test area and its surroundings.

As for small mammals, a few species have been observed and captured in the different backgrounds of the sector under study. These include the Red-backed Vole (*Myodes gapperi*), the Meadow Vole (*Microtus pennsylvanicus*), the Northern short-tailed Shrew (*Blarina brevicauda*), the Common Shrew (*Sorex cinereus*), the mouse of the genus *Peromyscus* and the Meadow Jumping Mouse (*Zapus hudsonius*).

Many avian species were seen or heard during the inventory conducted in 2007, including the yellow birch maple grove on Mont Triquet and the lakeshores. Among these species include the American Kestrel (*Falco sparverius*), the Red-tailed Hawk (*Buteo jamaicensis*), the Turkey Vulture (*Carthates aura*), the Black-throated Blue Warbler (*Setophaga caerulescens*), Ovenbird (*Seiurus aurocapilla*), Yellow-bellied Sapsucker (*Sphyrapicus varius*), the Red-eyed Vireo (*Vireo olivaceus*) and the Rose-breasted Grosbeak (*Pheucticus ludovicianus*). The Belted kingfisher (*Megaceryle alcyon*) was also seen in the Perceval Creek.

Among the species observed in 2005 were the Osprey (*Pandion haliaetus*), American Woodcock (*Scopolax minor*), several species of buntings and warblers, the Barred Owl (*Strix varia*), the Wild Turkey (*Meleagris gallopavo*), the Great Blue Heron (*Ardea herodias*), the Great Horned Owl (*Bubo virgianus*) and American Robin (*Turdus migratorius*).

The results of the experimental fishing carried out by Groupe Hémisphères on Lake Laurie revealed only one species sampled in the nets (7 sampling stations, 19 hours of fishing time) or White Sucker (*Catostomus commersoni*). No fish were caught in the cans. A total of 35 white suckers were caught with an average weight of 470.29 g and an average maximum-minimum length of 502-137 millimetres. Considering the lake Laurie has neither tributary nor emissary, Groupe Hémisphères concludes that the population of fish was introduced and assumed that the lake was pristine. The study shows that the fish population appears to be holding steady, which seems to demonstrate that there are reproduction and that the lake has acceptable conditions for survival.

A total of 18 species of fish were found during the inventory conducted in 2006 in the Jacques-Cartier River. These include the Brook Stickleback (*Culaea inconstans*), Three-spined Stickleback (*Gasterosteus aculeatus*), Blackchin Shiner (*Notropis heterodon*), Creek Chub (*Semotilus atromaculatus*), Pearl Dace (*Margariscus margarita*), the Longnose Dace (*Rhinichthys cataractae*), the White Sucker (*Catostomus commersoni*), Brook Trout (*Salvenilus fontinalis*), Finescale Dace (*Phoxinus neogaeus*), Northern red-belly Dace (*Phoxinus eos*) and the Bluntnose Minnow (*Pimephales notatus*). Atlantic Salmon (*Salmo salar*) was also caught there during the inventory. Due to sport fishing, this species is of particular importance, especially since it would pose problems of conservation in Quebec. The salmon population of the Jacques-Cartier River is identified as being in decline and could be considered threatened in the short to medium term. One example is also that rearing areas for this species are present in the Jacques-Cartier River, and that an area of interest for this species has been identified immediately downstream of the study area.

2.0- METHODOLOGY

2.1 Contaminants of Concern

In order to identify the contaminants of concern, the whole series of analytical results for various matrices (soil, groundwater, surface water, sediments) was reviewed and compared to one of the following sources of environmental quality guidelines/criteria:

SOIL:

- The primary screening criteria used are the soil quality guidelines (SQG) in the agricultural and industrial sectors issued by the Canadian Council of the Ministers of Environment (CCME). Agricultural guidelines are used for sensitive media in the site, while industrial recommendations are used in the remaining areas. The recommendations in the agricultural and industrial sectors selected correspond respectively to those for the most to those for ingestion and soil contact. Where more than one value is available according to soil type (coarse/fine and surface/deep soil), the most restrictive value was used..

- The second screening criteria used are values from the Centre of Expertise in Environmental Analysis of Quebec (CEAEQ, 2012). The values correspond to criteria B (use residential/park) and C (industrial use) that have been validated to protect the ecosystem. Criteria B criteria are used for sensitive areas of the site, while criteria C are used in the remaining from the site.

- For several energetic materials, screening criteria were derived from Berthelot et al. (2011). The values used for sensitive media and other parts of the site respectively are those emitted for terrestrial plants and soil invertebrates. The screening criteria then selected are the Ministry of the Environment of Ontario (MOE, 2011) recommendations for agricultural and commercial/industrial. Values for mammals and plants and organisms in the soil have been retained. When several values are available according to soil type (coarse/fine), the most restrictive value has been retained.

- Subsequently, the screening criteria selected were values from the United States Environment Protection Agency (EPA). They correspond to Ecological Screening Levels (Eco-SSL) and Soil Screening Benchmark (SSB).

- The relational database (RDB) created by Environment Canada (2012) to facilitate the site review process that may be contaminated was also consulted.

- Finally, other sources such as U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM), Swartjes (1999) and U.S. National Oceanic and Atmospheric Administration (NOAA) were consulted.

SEDIMENT:

- The primary screening criteria used are those for assessing the quality of the Freshwater Sediments from Environment Canada (EC). The values selected are those developed on the benthic organisms.

- Screening criteria for several ammunition-related contaminants are derived from of Pascoe et al. (2010). The values corresponding to a Total Organic Carbon (TOC) concentration of 0.5% in sediments were selected, given the low TOC values in some sediments in the study site (minimum of 0.025%).

- The subsequent screening criteria were derived from the RDB created by EC (2012) to facilitate the review process for potentially contaminated sites. Where possible, the criteria from Canadian jurisdictions were used first, followed by those from the U.S. EPA. Last In the case of appeals, values from other jurisdictions have been used.

SURFACE WATER AND GROUNDWATER:

- To test for contaminants in groundwater more than 10 m from a water body, the federal groundwater interim quality guidelines for the protection of freshwater life have been retained. For metals, where the value is variable according to pH and hardness, the value for a pH below 6.5 was used, since the pH of the Jacques-Cartier River is often less than 6, and a hardness of 6 mg/L was used, since it corresponds to values measured in the Jacques-Cartier River. In addition, the guidelines used are the same for total extractable metals and for dissolved metals, unless a conversion factor is available.

- The screening criteria then used are the CCME aquatic life protection guidelines. The values for freshwater have been retained. The values used are the same for total extractable metals as for dissolved metals, unless a conversion factor is available.

- The third screening criterion is provincial surface water quality guidelines promoted by *Ministère du Développement Durable, Environnement, faune et Parcs du Québec* (MDDEFP, 2013).

- Subsequently, the aquatic life toxicity values presented by Pascoe et al. (2010) were retained for certain substances associated with ammunition.

- The RDB created by EC (2012) to facilitate the review process for sites was also consulted.

- To screen for contaminants in groundwater within 10 metres of a water body and in surface waters, surface water guidelines are used. They are therefore consistent with the surface water quality criteria for the protection of piscivorous wildlife or agricultural activities (livestock watering) of the *Ministère du Développement Durable, Environnement et Lutte contre les Changements climatiques du Québec* (MDDELCC), to the RDB values and the values of Pascoe et al. (2010). Where no recommendations for surface water are available, the federal groundwater interim quality guidelines are used.

- For pentaerythritol tetranitrate (PETN) and tetryl, the crtiteria used were calculated from the lowest lethal concentration (LC50) found in the literature (Krahl et al., 1936 and Drzyzga et al, 1995)

2.2 Challenging Substances

Certain substances not analysed, but for which sources have been identified have still not been analysed. It should be noted that several of these substances are degradation products of substances that have been analysed in the soil. Indeed 2,6-Diaminonitrotoluene (2,6-DANT), 2,4-Diaminonitrotoluene (2,4-DANT), Triaminotoluene (TAT) and Trinitrobenzoic Acid (TNBA) are by-products of Trinitrotoluene (TNT), while hexahydro-1-nitroso-3,5-dinitro-1,3,5-triazine (MNX), hexahydro-1,3-dinitroso-3,5-dinitro-1,3,5-triazine (DNX), hexahydro-1,3,5-trinitroso-3,5-dinitro-1,3,5-triazine (TNX), N,N'-Dinitromethanedianmine (MEDINA) and 4-nitro-2,4-diazabutanal (NDAB) are by-products of 1,3,5-trinitro-1,3,5-triazine (RDX). In addition, these substances, as well as 2,4,6,8,10,12-hexanitro-2,4,6,8,10,12- hexaazaisowurtzitane (CL-20), 2,4-dinitroanisole (DNAN), 3-Nitro-1,2,4-triazol-5-one (NTO), white phosphorus, ethyl centralite and nitroguanidine are not currently analyzed by Canadian commercial laboratories. By their cost and complexity, it is currently not possible to determine whether these substances should be retained as contaminants of concern.

2.3 Assessment of Transport Mechanisms

Some of the contamination is transported by water infiltrating the soil until it reaches the groundwater. Contamination then migrates with the groundwater flow until it reaches the Jacques-Cartier River, Laurie Lake and Perceval and Plateau creeks. The groundwater resurgence in the Jacques-Cartier River is present throughout the year, depending on the flow rates according to the seasons and rainfall.

Each contaminant has different characteristics that control its behaviour, when transported in groundwater. The main characteristics are sorption and degradation. Two parameters used in numerical mass transport simulations are used to reproduce its characteristics: the delay coefficient (sorption and desorption of the contaminant on the solid phase) and the rate of degradation (both physical degradation, biological). The paragraphs below present characteristics of the main contaminants related to site activities.

- Metals have generally high retardation coefficients and do not degrade. These contaminants migrate slowly and their concentrations can increase in the time. The concentration of metals in soil pore water is dependent on the complexation with organic and inorganic substances, oxidation-reduction reactions, precipitation/dissolution and adsorption/desorption. The mobility of metals is dependent on their oxidation state. In addition, metal adsorption is dependent on soil pH, the redox potential, the presence of clay, organic matter, iron oxides and manganese and calcium carbonate. Metals and other inorganic substances do not tend to volatilize, with the exception of mercury in elemental form (McLean and Bledsoe, 1992).

- Perchlorate is highly soluble and has a zero delay coefficient, i.e., it travels at the same rate as groundwater and its degradation is considered negligible. This contaminant is the one most at risk of migrating off site.

- Dissolution in water is the primary transport mechanism for energetic materials in the water (Pichtel, 2012). TNT is more soluble than RDX or HMX, but it is highly degradable, which means its arrival at the river in its original form is unlikely. In addition, it adsorbs more to soil particles than RDX and HMX. TNT contamination is therefore more problematic close to the sources. 2,4-DNT and 2,6-DNT dissolve rapidly in water, but like TNT, water mobility is reduced by adsorption and degradation (Clausen, 2014). RDX has a low retardation coefficient and degrades very slowly. Because it dissolves relatively slowly, this contaminant has the potential to migrate into the environment off-site. The solubility of HMX is intermediate between RDX and TNT. HMX interacts little with soil and can migrate rapidly into groundwater (Pichtel, 2012). Nitroglycerine dissolves rapidly in water but is strongly adsorbed to the soil (Clausen, 2014). White phosphorus is poorly soluble and oxidizes rapidly in air. It can be persistent under anoxic conditions, but has very little mobility in the environment (Clausen, 2014).

- Dioxins and furans have high delay coefficients, which makes their transport very slow-moving in groundwater. Transport by surface water runoff or by atmospheric transport is more likely. These contaminants are more likely to accumulate near the sources.

- Several volatile organic compounds (VOCs) can be found in groundwater. Their solubility and adsorption to soil varies significantly from one substance to another. Among the VOCs found in groundwater in the study area, it should be noted that: 1,2-Dichlorobenzene is relatively insoluble in water and has an affinity for relatively high organic matter in soils (Lawrence, 2006). Perchloroethylene, carbon tetrachloride, and trichloroethylene (TCE) have solubilities and affinities for organic matter in average soils. In order with increasing solubility, these substances are classified as follows: perchloroethylene < carbon tetrachloride < TCE. In descending order of affinity for organic matter, these substances are classified as follows: perchloroethylene > TCE >

tetrachloroethylene tetrachloride > perchloroethylene tetrachloride carbon.

In addition to transport in water, contaminants can move through the atmosphere. All substances found in soils can be displaced by the suspension of dust. However, gas-phase transport is only important for volatile substances.

2.4 Assessment of Toxicity

Toxicologial reference values (TRVs) were found for a variety of receptors in order to compare the concentrations of contaminants of concern. Among the available sources for TRVs:

- CEAEQ (2012);
- Eco-SSL from EPA (2010);
- Oak Ridge National Laboratory (ORNL) (Efroymson et coll., 1997b);
- Screening level ecological risk assessment protocol for hazardous waste combustion facilities (EPA, 1999).
- Toxicological Benchmarks for Wildlife US Department of Agriculture (DOA) (Sample et coll., 1996).
- Environmental Quality Guidelines (EQG) from CCME (2015);
- Chronic Aquatic Life Criteria (CALC) from MDDELCC (2013).

However, for a more specific approach, toxicity tests were also realized on many samples collected on the site for the various matrices:

<u>SOIL TOXICITY FOR PLANTS:</u>

- *Hordeum vulgare* (barley). Inhibition of germination and growth in seeds of plants. Chronic test (7 days), EC25 and EC50 germination, IC25 and IC50 length of the stems, Method # MA. 500 - GCR. 1.0.
- Biological test method: Test for measuring emergence and growth of plants exposed to contaminants in the soil. Method # SPE1/RM/45
- Biological Test Method: Growth Test of Native Terrestrial Plants in the Region exposed to contaminated soil. Method # SPE1/RM/56

<u>SOIL TOXICITY FOR INVERTEBRATES:</u>

- Earthworms. Biological Test Method: Tests for Soil Toxicity for earthworms (*Eisenia andrei, Eisenia fetida or Lumbricus terrestris*). Test acute survival (LC50-14 days). Method # SPE1/RM/43
- *Folsomia candida* (Collembolus). Biological Test Method: Survival Test and the growth of springtails exposed to contaminants in the soil. Reproduction test and survival (28 days). Method # SPE/RM/47.
- *Eisenia an*drei (earthworm). Avoidance test. The test consists of exposing the organisms to a single

concentration of the sample in a hexagonal enclosure, where compartments of contaminated and control media alternate and communicate between them, allowing organisms to move from one compartment to another. The worms can therefore "avoid" and "choose" the control medium or sample. This test is very sensitive. In addition, it is fast and inexpensive. Its application is particularly indicated in screening contexts (CEAEQ, 2015).

- Determination of lethal toxicity in earthworms (*Eisenia andrei/Eisenia fetida*). Method # MA. 500 - VTL 1.0.

WATER TOXICITY FOR REPTILES AND AMPHIBIANS

- Frog. Standard Guide for Conducting the Frog Embryo Teratogenesis Assay-Xenopus (FETAX). Acute test on survival, development and growth (96 h). Method # ASTM-E1439-98.

- Frog. OECD Guideline for the Testing of Chemicals - Test of amphibian metamorphosis. Trial No. 231.

- Amphibians (*Rana pipiens, Rana clamitans, Rana sylvatica, Bufo americanus*). Standard Guide for Conducting Whole Sediment Toxicity Tests with Amphibians. Chronic Survival Test and growth (10 d). Method # ASTM-E2591-07.

WATER TOXICITY FOR REPTILES AND AMPHIBIANS

- Alga *Pseudokirchneriella subcapitata*. Chronic growth test (IC25, 96 h). Method # MA.500-P.sub

- Alga *Pseudokirchneriella subcapitata*. Chronic growth test (IC25, 72 h). Method # SPE1/RM/25

- *Ceriodaphnia dubia* (aquatic invertebrate). Chronic and acute tests 6 to 8 days on the reproduction and survival. Biological Test Method: Test for Reproduction and Survival of the cladoceran *Ceriodaphnia dubia*. Method # SPE1/RM/21

- *Ceriodaphnia dubia* (aquatic invertebrate). Acute mortality test (48 hours). Method # EPA-821-R-02-012

- *Daphnia magna* (aquatic invertebrate). Acute survival test (LC-50, 48 h). Method # SPE1/RM/11 and 14, and MA.500-D.mag

- *Lemna minor* (aquatic plant). Chronic growth test (IC25, 7 days). Method # SPE1/RM/37

- Fathead minnow (fish). Acute survival test (LC50, 96 h). Method # EPA 821/R-02-012

- Fathead minnow (fish). Chronic growth and survival test (LC50/IC25-7d). Biological test method: growth and survival test on fathead minnow larvae. Method # SPE1/RM/22

- Rainbow trout (fish). Acute survival test (LC50, 96 h). Method # SPE1/RM/09 and 13

- *Vibrio fischeri* (luminescent bacteria). Chronic bioluminescence inhibition test (IC50,15 minutes). Method # SPE1/RM/24

SEDIMENT TOXICITY FOR BENTHOS

- *Lumbriculus variegatus* (invertebrate, oligochaete). Survival (96 h) and growth and survival (10 days). Method # EPA 600/R-99/064

- *Hyalella azteca* (invertebrate, amphipod). Growth and survival test (14 days). Method # SPE1/RM/33

- *Hyalella azteca* (invertebrate, amphipod). Growth and survival test (10 or 28 days), or growth, survival and reproduction test (42 days). Method # EPA 600/R-99/064

- *Chironomus tentans* (invertebrate, insect). Growth and survival test (10 days). Method # SPE1/RM/32 or EPA 600/R-99/064

- *Vibrio fischeri* (luminescent bacteria). Chronic bioluminescence inhibition test (IC50, 25 minutes). Method # SPE1/RM/42

- *Hexagenia limbata* (invertebrate, insect). Growth and survival test (21 days). Bedard et al. 1992.

- Fathead minnow (fish). Survival and bioaccumulation test on sediment (21 days). Bedard et al, 1992.

2.5 Exposure Pathways

- Suspension of soil particles is considered to be a transport mechanism for the contaminants found in soils to the air. This mechanism is selected for the study site, being given the presence of bare soil and contamination in surface soils

- Volatilization of volatile substances is a possible transport mechanism to the air. These substances may come from soil, water, sediment or during testing of explosives. The inorganic substances considered in this study are not volatile, with the exception of ammoniacal nitrogen and mercury. Mercury is volatile in its elemental form only. Volatilization is an important transport mechanism for VOCs.

  For other organic substances, volatiles have been defined as those boiling below 180 °C or having a Henry's Law Constant above 180 °C, or at 6.58E-07 atm-m^3/g (MEF, 1998). Acrylonitrile, hexachlorobutadiene, nitroglycerin, the chlorpyrifos, dioxins and furans, dichlorobiphenyls and monochlorobiphenyls are considered volatile.

- The heavy fractions of the HP (F3 and F4) are not volatile, but the light fractions (F1 and F2) are volatile. Volatilization of HP(C10-C50) and mineral oils and fats can take place as these parameters contain light fractions.

- Volatilization is a potential transport mechanism for some polycyclic aromatic hydrocarbons (PAHs). Indeed, the light PAHs are found mainly in gaseous form in the air. (ATSDR, 1995 and INSPQ, 2005). Conversely, heavy PAHs are mainly present in particulate form and volatilization contributes little to the loss of these substances from the soils. According to Health Canada, acenaphthene, benzo(a)anthracene and naphthalene are volatile, while benzo(a)pyrene, benzo(b+j+k)fluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, pyrene and indeno(1,2,3-cd)pyrene are not volatile. Acenaphthylene, benzo(g,h,i)perylene, chloro-1+2naphthalenes, 1,3-dimethylnaphthalene, 3-methylcholanthrene and phenanthrene have been assessed for their potential to volatilize by Health Canada. PAHs with MOE recommendations for inhalation of vapours (S-OA and S-IA) were considered as volatile. Acenaphthylene is one such substance and is therefore considered volatile.

The potential for volatilization of the other PAHs was then assessed under the soil and contaminated land remediation (MEF, 1998). Volatile substances are defined as those that boil below 180°C or have a Law of Henry is greater than 6.58E-07 atm-m³/g. Since benzo(g,h,i)perylene, dibenzo(a,h)pyrene,the 3-methycholanthrene and phenanthrene do not meet these conditions, they are not considered volatile. However, 1,3-dimethylnaphthalene, 1-methylnaphthalene, chloro-1+2 naphthalenes and 2-methylnaphthalene meet these criteria.

- Surface runoff at the site is towards the Jacques-Cartier River, Ruisseau du Plateau and the Lake Laurie. Perceval Creek does not receive any runoff from the site, with the following exceptions of a small strip along its shores. As a result, contaminants present in the soils of surface water may be transported to these surface waters by runoff during precipitation and contaminate water and sediment. Contaminants have been found in all these bodies of water. This transport mechanism has therefore been retained.

- Rainwater can infiltrate through the soil and run down to the water table, allowing it to contaminate it. Contaminants have also been found in the groundwater.

- Contaminants present in the air as a result of the suspension of soil particles or created by explosions may settle in the waters of surface or on the ground. Contaminants have been found in all water bodies on the site.

- Contaminants in soils reaching water bodies by runoff, by groundwater or by deposition in surface water can accumulate and thus contaminate the sediment. In sediments, contaminants can be buried or released into the water column.

- To the extent that contaminants are present on a site, all organisms in contact with the site will be affected with soils and surface water is likely to support and bioaccumulate these contaminants. Terrestrial and aquatic organisms therefore represent a pathway for the transport of contaminants to higher trophic level organisms. Bioaccumulation is therefore a retained transport mechanism for terrestrial and aquatic organisms.

3.0 RESULTS AND CONCLUSION

The problem statement completed for the test site in the DRDC Valcartier test area has concluded that several substances were found at levels higher than their screening criteria in soil, sediment and water at the site, and that all pathways are operating at the site, but the level and extent of risk is not known.

The main conclusions of this risk assessment are as follows:

- There do not appear to be any unacceptable risks to vegetation from site contamination.

- The only potential index of risk to terrestrial invertebrates that could be associated with a contamination is the exceedance of the adverse effect level (AEL) of 40 % effect level with respect to reproduction. of the springtails in the 2 samples from the MDR sub-sector and the B307. However, this effect could not be linked to a specific contamination since no contamination was found in these samples for the substances analysed. Additional testing conducted in 2018 proved that this risk can be scratched.

- No risk is identified for birds and mammals based on the site contamination.

- No risk is identified for amphibians in water bodies in the study area.

- No risk to benthic organisms is identified for sediments in Perceval Creek, Plateau Creek and the Jacques-Cartier River.

- The few toxic effects observed in the sediments collected in Laurie Lake, which showed exceedances of TRVs for some parameters (ammonia nitrogen, lead, and benzo(b+j+k)fluoranthenes) make it impossible to conclude in the absence of actual risk to benthic wildlife with respect to Laurie Lake sediments. A monitoring program will be implemented and followed over the next 15 years.

- Identified risks to aquatic life vary for different water bodies in the study area :

    - Actual risks to aquatic organisms in Laurie Lake are identified based on the toxic effects observed on fathead minnows and *Ceriodaphnia dubia*. This could be related to confounding parameters unrelated to DRDC activities. Since the samples from this lake had the highest nitrogen content ammonia and the lowest pH. It is also important to note that this lake already supports a fish population and is isolated from other water bodies. A monitoring program will be implemented and followed over the next 15 years.

    - It is not possible to conclude on the influences of the sources of contamination of the Plateau Creek aquatic life risk study area, but the observed effects that may be related to the contamination of the site are relatively minor.

    - It is considered that the reproductive inhibition effect of *Ceriodaphnia dubia* observed at Perceval Creek is not related to contamination from the site. No real unacceptable risks are apprehended in this watercourse.

    - In the case of the Jacques-Cartier River, there have been very few toxic effects observed and no effect on the survival of test organisms. Groundwater of the site are likely a source of various contaminants to the river and some toxic effects have been observed in these waters between sources of contamination and the river. However, based on the results of the toxicity and chemical analyses of the river water, the study site does not appear to have a large enough effect on surface water quality to pose a risk to aquatic life in the river.

There is no clear relationship between the observed toxic effects and the measured parameters. There is a possibility that unmeasured parameters are in question. Recommendations on actions to be taken to manage the identified risks will be developed in a monitoring program that will be used over the next 15 years or until the site vocation changes.

REFERENCES

Akifer. (2017) *Caractérisation environnementale – Secteur d'essai RDDC Valcartier (Québec)*. Rapport préliminaire présenté à Travaux publics et Services gouvernementaux Canada. 15 février 2017. 18 p. + annexes.

ASTM RBCA Task Group. (1995). *RBCA State Risk Policy / Strategy Issues Workbook*.

ATSDR (Agency for Toxic Substances and Disease Registry). (1995). *Toxicological Profile for Polycyclic Aromatic Hydrocarbons (PAHs)*. August 1995. [Online] http://www.atsdr.cdc.gov/toxprofiles/tp71.html

ATSDR (Agency for Toxic Substances and Disease Registry). (1997). *Toxicological Profile for chlorpyrifos*. September 1997. [Online] https://www.atsdr.cdc.gov/toxprofiles/tp84.pdf

ATSDR (Agency for Toxic Substances and Disease Registry). (2005). *Toxicological Profile for tin*. August (2005). [Online] https://www.atsdr.cdc.gov/ToxProfiles/tp55.pdf

ATSDR (Agency for Toxic Substances and Disease Registry). (2008). *Toxicological Profile for aluminium*. September 2008. [Online] https://www.atsdr.cdc.gov/toxprofiles/tp22.pdf

ATSDR (Agency for Toxic Substances and Disease Registry). (2016). *Agency for Toxic Substances and Disease* Registry. [Online] http://www.atsdr.cdc.gov/

Baes, C. F., Sharp, R. D., Sjoreen, A. L., and Shor, R. W. (1984). *A review and analysis of parameters for assessing transport of environmentally released radionuclides through agriculture - ORNL-5786*.

Oak Ridge National Laboratory, Oak Ridge, TN. [Online] http://www.nrc.gov/docs/ML1015/ML101590306.pdf

Bhattacharyya, S., Klerks, P. L., and Nyman, J. A. (2003). *Toxicity to freshwater organisms from oils and oil spill chemical treatments in laboratory microcosms*. Environmental Pollution, 122(2), 205 215. [Online] https://doi.org/10.1016/S0269-7491(02)00294-4

Beaulieu, M. (2016). *Guide d'intervention - Protection des sols et réhabilitation des terrains contaminés*. Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, ISBN 978-2-550-76171-6. 210 p.

Bechtel Jacobs Company LLC. (1998). *Biota sediment of accumulation factors for invertebrates: review and recommendations for the Oak Ridge Reservation*. Rapport préparé pour U.S. Department of Energy. [Online] https://rais.ornl.gov/documents/bjcor-112a1.pdf

Bédard, D., A. Hayton and D. Persaud. (1992). *Ontario Ministry of the Environment Laboratory Sediment Biological Testing Protocol*. Water Resources Branch, Ontario Ministry of Environment.
Berthelot, Y., G.I. Sunahara and P.Y. Robidoux. (2011). *Explosives Soil Concentrations for Military Training Sustainability (SCMTS): An update*.

Beyer, W. N., Connor, E. E., and Gerould, S. (1994). Estimates of Soil Ingestion by Wildlife. *The Journal of Wildlife Management*, *58*(2), 375-382. [Online] https://doi.org/10.2307/3809405

Casellatio, S., Del Piero, S., Masiero, L., and Covre, V. (2015). *Fluoride toxicity and its effects on gametogenesis in the aquatic oligochaete Branchiura sowerbyi*.

CCME (Conseil canadien des ministres de l'environnement). (1999). Recommandations canadiennes pour la qualité des sols : Environnement et santé humaine - vanadium (1997). Dans *Recommandations canadiennes pour la qualité de l'environnement*. le Conseil, Winnipeg, MN. [Online] http://ceqg-rcqe.ccme.ca/download/fr/198

CCME (Conseil canadien des ministres de l'environnement). (2004). *Canadian water quality guidelines for the protection of aquatic life: Phosphorus: Canadian Guidance Framework for the Management of Freshwater Systems.* In: Canadian environmental quality guidelines, 2004, Canadian Council of Ministers of the Environment, Winnipeg.

CCME (Conseil canadien des ministres de l'environnement). (2015a). *Recommandations canadiennes pour la qualité de l'environnement.* [Online] http://documents.ccme.ca/?lang=fr

CCME (Conseil canadien des ministres de l'environnement). (2008). *Standard pancanadien relatif aux hydrocarbures pétroliers (HCP) dans le sol*. Tableau 1 mise à jour en janvier 2008. [Online] http://www.ccme.ca/fr/resources/contaminated_site_management/phc_cws_in_soil.html

CEAEQ (Centre d'expertise en analyse environnementale du Québec). (2005a). *Paramètres d'exposition chez le Martin-pêcheur d'Amérique - Fiche descriptive*. Ministère du Développement durable, de l'Environnement et des Parcs du Québec. [Online] http://www.ceaeq.gouv.qc.ca/ecotoxicologie/oiseaux/MartinPecheur.pdf

CEAEQ (Centre d'expertise en analyse environnementale du Québec). (2005b). *Paramètres d'exposition chez les oiseaux – Bernache du Canada – Fiche descriptive*. Ministère du Développement durable, de l'Environnement et des Parcs du Québec, Sainte-Foy, QC. [Online] http://www.ceaeq.gouv.qc.ca/ecotoxicologie/oiseaux/Bernache.pdf

CEAEQ (Centre d'expertise en analyse environnementale du Québec). (2005c). *Paramètres d'exposition chez les oiseaux – Crécerelle d'Amérique – Fiche descriptive*. Ministère du Développement durable, de l'Environnement et des Parcs du Québec, Sainte-Foy, QC. [Online] http://www.ceaeq.gouv.qc.ca/ecotoxicologie/oiseaux/Crecerelle

CEAEQ (Centre d'expertise en analyse environnementale du Québec). (2005d). *Paramètres d'exposition chez les oiseaux – Merle d'Amérique – Fiche descriptive*. (Ministère du Développement durable, de l'Environnement et des Parcs du Québec). [Online] http://www.ceaeq.gouv.qc.ca/ecotoxicologie/oiseaux/Merle.pdf

CEAEQ (Centre d'expertise en analyse environnementale du Québec). (2006a). *Paramètres d'exposition chez les mammifères – Campagnol des champs – Fiche descriptive*. Ministère du Développement durable, de l'Environnement et des Parcs du Québec, Québec, QC. [Online] http://www.ceaeq.gouv.qc.ca/ecotoxicologie/mammifere/Campagnol.pdf

CEAEQ (Centre d'expertise en analyse environnementale du Québec). (2006b). *Paramètres d'exposition chez les mammifères – Hermine – Fiche descriptive.* Ministère du Développement durable, de l'Environnement et des Parcs du Québec. [Online] http://www.ceaeq.gouv.qc.ca/ecotoxicologie/mammifere/Hermine.pdf

CEAEQ (Centre d'expertise en analyse environnementale du Québec). (2006c). *Paramètres* *d'exposition chez les mammifères – Musaraigne cendrée – Fiche descriptive*. Ministère du Développement durable, de l'Environnement et des Parcs du Québec, Québec, QC. [Online] http://www.ceaeq.gouv.qc.ca/ecotoxicologie/mammifere/MusaraigneCendree.pdf

CEAEQ (Centre d'expertise en analyse environnementale du Québec). (2006d). *Paramètres d'exposition chez les mammifères – Raton laveur – Fiche descriptive*. Ministère du Développement durable, de l'Environnement et des Parcs du Québec. [Online] http://www.ceaeq.gouv.qc.ca/ecotoxicologie/mammifere/Raton_laveur.pdf

CEAEQ (Centre d'expertise en analyse environnementale du Québec). (2012). *Valeurs de référence pour les récepteurs terrestres*. Québec, ministère du Développement durable, de l'Environnement et des Parcs, Centre d'expertise en analyse environnementale du Québec. 28 p.

CEAEQ (Centre d'expertise en analyse environnementale du Québec). (2014). *Toxicité chimique de l'uranium sur les organismes terrestres - Revue de littérature*. Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs. [Online] http://www.ceaeq.gouv.qc.ca/ecotoxicologie/revue_uranium.pdf

CJB Environnement. (2016). *Rapport d'échantillonnage des tissus biologiques - Site d'étude dans le secteur d'essai de Recherche et développement pour la défense Canada*. Rapport préparé pour Services publics et Approvisionnement Canada. N/Réf : J0020188 (2).

CJB Environnement. (2014) *Approche méthodologique pour l'évaluation et le suivi de l'état de santé de la végétation.* Méthode 2.0. Présenté à Travaux publics et Services gouvernementaux Canada pour le compte de Pêches et Océans Canada. N/Réf. J020120-E2.

CJB Environnement. (2015a). *Analyse des risques écotoxicologiques – Secteur d'essais, Valcartier (QC) – Rapport-lettre de validation de la base de données – Final*.

CJB Environnement. (2015b). *Analyse des risques écotoxicologiques – Secteur d'essais, Valcartier (QC) – Plan d'échantillonnage additionnel (PEA) – Préliminaire*.

Clausen, J. (2014). *The fate of munition constituents (MC) on military ranges*. Military Munitions Support Services-Munitions Constituents seminar, U.S. Environmental Protection agency, Technology Innovation and Field Services Division.

Connor, J. A., Newell, C. J. N., and Malander, M. W. (1996). Parameter estimation guidelines for riskbased
corrective action (RBCA) modelling. Dans *NGWA Petroleum Hydrocarbons Conference, Houston, Texas, November 1996*. Groundwater Services, Inc. [Online] <https://www.researchgate.net/profile/John_Connor9/publication/281005050_Parameter_Estimation_Guidelines_for_Risk-Based_Corrective_Action_RBCA_Modeling/links/55d0b68f08ae118c85c014a8.pdf?origin=publication_detail>

Drzyzga, O., T. Gorontzy, A. Schmidt and K. H. Blotevogel. (1995). *Toxicity of explosives and related compounds to the luminescent bacterium Vibrio fischeri NRRL-B-11177. Archives of Environmental Contamination and Toxicology* 28(2) : 229-235.

EC and MDDEP (Environnement Canada et ministère du Développement durable, de l'Environnement et des Parcs du Québec). (2007). *Critères pour l'évaluation de la qualité des sédiments au Québec et* *cadres d'application : prévention, dragage et restauration*, 39 pages.

ECHA (European Chemicals Agency). (2016). *Information on Chemicals*. [En ligne] https://echa.europa.eu/home (consulté le 11/07/2016).

Edwards, D.A., M.D. Andriot, M.A. Amoruso, A.C. Tummey, C.J. Bevana, A. Tveit, L.A. Hayes, S.H. Youngren and D.V. Nakles. (1997). *Development of fraction specific reference doses (RfDs) and references concentrations (RfCs) for total petroleum hydrocarbons (TPH).* Volume 4. Amherst, MA. 137 p. Préparé pour le Total Petroleum Hydrocarbon Criteria Working Group.

Efroymson, R.A., M.E. Will and G.W. Suter II. (1997a). *Toxicological Benchmarks for Contaminants of Potential Concern on Soil and Litter Invertebrates and Heterotrophic Processes: 1997 Revision*. Oak Ridge National Laboratory, Oak Ridge, TN. ES/ER/TM-126/R2.

Efroymson, R.A., M.E. Will, G.W. Suter II and A.C. Wooten. (1997b). *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants: 1997 Revision*. Oak Ridge National Laboratory, Oak Ridge, TN. 128 pp. ES/ER/TM-85/R3.

Environnement Canada. (2012) *Base de données de recommandations (BDR)*. 31 décembre 2012.

Environnement Canada. (1996). *La politique fédérale sur la conservation des terres humides – Guise de mise en oeuvre à l'intention des gestionnaires de terres fédérales*. Direction de la conservation de la faune, Service canadien de la faune, Environnement Canada. Ottawa, Ontario. 37 pages.

EPA (United States Environmental Protection Agency). (1993). *Wildlife Exposure Factors Handbook* (Vol. I of II). Office of Research and Development. EPA/600/R-93/187. [Online] https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=2799

EPA (Environmental Protection Agency). (1999). *Screening level ecological risk assessment protocol for hazardous waste combustion facilities*, Peer review draft, vol.III, app.D : Bioconcentration factors (BCFs) for Wildlife Measurement Receptors. [Online] http://www.epa.gov/osw/hazard/tsd/td/combust/ecorisk.html

EPA (Environmental Protection Agency). (2016a). *Ecological Soil Screening Level (Eco-SSL) - Guidance and Documents.* [Online] https://www.epa.gov/risk/ecological-soil-screening-level-ecossl-guidance-and-documents

EPA (Environmental Protection Agency). (2016b). *ECOTOX Knowledgebase*. [Online] https://cfpub.epa.gov/ecotox/quick_query.htm

ECCC (Environnement et Changement climatique Canada). (2016). *Moteur de recherche pour les résultats des substances sur la LIS*. Site Internet d'ECCC. [Online] http://www.ec.gc.ca/lcpecepa/default.asp?lang=Fr&n=5F213FA8-1&wsdoc=D031CB30-B31B-D54C-0E46-37E32D526A1F

Fichet, D., and Miramand, P. (1998). *Toxicity To Three Marine Invertebrates Larvae : Crassostrea gigas, Paracentrotus lividus* and *Artemia salina*. *Chemosphere*, 37(I), 1363 1368.

Garn, H. S., Scudder, B. C., Richards, K. D., and Sullivan, D. J. (2001). *Characteristics of Water, Sediment, and Benthic Communities of the Wolf River, Menominee Indian Reservation, Wisconsin, Water Years 1986–98*. U.S. Geological Survey. Water-Resources Investigations Report 01-4019, Middelton (WI). [Online] http://wi.water.usgs.gov/pubs/wrir-01-4019/wrir-01-4019.pdf

Gouvernement du Canada. (2012). *Plan d'action pour les sites contaminés fédéraux (PASCF) : Document d'orientation sur l'évaluation du risque écotoxicologique*. Sa Majesté la Reine du Chef du Canada, représentée par le ministre de l'Environnement.

Groupe Hémisphères. (2017). Caractérisation environnementale – Secteur d'essai RDDC Valcartier – Résultats des essais toxicologiques. Rapport technique préliminaire présenté à Akifer, 20 p.

Hamilton, S. J., and Buhl, K. J. (2001). *Selenium and other trace elements in water, sediment, aquatic plants, aquatic invertebrates, and fish from streams in southeastern Idaho near phosphate mining operations: May 2001*. Final Report as part of the USGS Western U.S. Phosphate Project. U.S. Department of the Interior. U.S. Geological Survey. [Online] https://www.cerc.usgs.gov/pubs/center/pdfdocs/91272.pdf

Hargreaves, J. and M. Brunson. (1996). *Carbon Dioxide in Fish Ponds*. SRAC Publication No. 468. Southern Regional Aquacultural Center.

INSPQ (Institut national de santé publique du Québec). (2005). *Validation des critères B et C de la Politique de protection des sols et de réhabilitation des terrains contaminés. Protection de la santé humaine.* Direction des risques biologiques, environnementaux et occupationnels. Mars 2005. [Online] http://www.inspq.qc.ca/pdf/publications/380-ValidationSols_Rapport.pdf

Integrated Risk Information System (IRIS). (2016). *Integrated Risk Information System*. US Environmental Protection Agency. □Online□ www.epa.gov/iris/

Krahl, M., G. Clowes and J. Taylor. (1936). *Action of metabolic stimulants and depressants on cell division at varying carbon dioxide tensions*. Biol. Bull. 71 : 400.

Lawrence, S. J. (2006). *Description, properties, and degradation of selected volatile organic compounds detected in ground water— A Review of Selected Literature*: Atlanta, Georgia, U. S. Geological Survey, Open-File Report 2006-1338, 62 p. [Online] http://pubs.usgs.gov/ofr/2006/1338/

McLean, J. E. and B. E. Bledsoe. (1992). *Behavior of metals in soil*. (EPA/540/S-92/018). U.S. Environmental Protection Agency, Washington, D.C.

MDDEFP (ministère du Développement durable, de l'Environnement de la Faune et des Parcs). (2013). *Critères de qualité de l'eau de surface*. 3e édition, Québec, Direction du suivi de l'état de l'environnement, ISBN 978-2-550-68533-3 (PDF), 510 p. et 16 annexes.

MEF (Ministère de l'Environnement et de la Faune du Québec). (1996). *Guide technique pour la réalisation des analyses préliminaires des risques toxicologiques. Version préliminaire pour consultation*. Direction des laboratoires. Document non publié.

MEF (ministère de l'Environnement et de la Faune). (1998). *Politique de protection des sols et de réhabilitation des terrains contaminés*. Ste-Foy, QC. 124 p. Envirodoq EN980478. Mises à jour consultées sur le site Internet. [Online] http://www.mddelcc.gouv.qc.ca/sol/terrains/politique/

MOE (Ministère de l'Environnement (Ontario)). (2008). *Guidelines for Identifying, Assessing and Managing Contaminated Sediments in Ontario: An Integrated Approach*. [Online] https://dr6j45jk9xcmk.cloudfront.net/documents/1170/93-contaminated-sediments-en.pdf

MEO (ministère de l'Environnement de l'Ontario). (2011). *Rationale for the development of soil and ground water standards for use at contaminated sites in Ontario*. Prepared by Standards

Development Branch, Ontario Ministry of the Environment. PIBS 7386e01.

MFFP (Ministère des Forêts, de la Faune et des Parcs). (2017). *Liste des espèces fauniques menacées ou vulnérables au Québec - Pipistrelle de l'Est*. [Online] http://www3.mffp.gouv.qc.ca/faune/especes/menacees/fiche.asp?noEsp=65

Michelsen, T. (2011). *Development of Benthic SQVs for Freshwater Sediments in Washington, Oregon, and Idaho*. Department of Ecology, Olympia, WA. [Online] https://fortress.wa.gov/ecy/publications/documents/1109054.pdf

Muscatello, J. R., and Liber, K. (2009). *Accumulation and chronic toxicity of uranium over different life stages of the aquatic invertebrate Chironomus tentans*. Archives of Environmental Contamination and Toxicology, 57(3), 531 539. [Online] https://doi.org/10.1007/s00244-009-9283-1

National Pesticide Information Center. (2017). *Glyphosate - Technical Fact Sheet*. [Online] http://npic.orst.edu/factsheets/archive/glyphotech.html

NYSDEC (New York State Department of Environmental Conservation). (2014). *Screening and Assessment of Contaminated Sediment*. Division of Fish, Wildlife and Marine Resources, Bureau of Habitat. Consulté à l'adresse [Online] http://www.dec.ny.gov/docs/fish_marine_pdf/screenasssedfin.pdf

Parametrix. (2001). *Ecological Screening-level Risk Assessment of the Lower Ottawa River*. Rapport préparé pour Limno-Tech, Inc. Numéro de projet 555-3763-001 (01/03).

Pascoe, G., K. Kroeger, D. Leisle and R. J. Feldpausch. (2010). *Munitions constituents: Preliminary sediment screening criteria for the protection of marine benthic invertebrates*. U.S. Navy Research. Paper 40.

Phillips, B. M., Nicely, P. A., Hunt, J. W., Anderson, B. S., Tjeerdema, R. S., and Palmer, F. H. (2005). Tolerance of five west coast marine toxicity test organisms to ammonia. *Bulletin of Environmental Contamination and Toxicology*, 75(1), 23-27. [Online] https://doi.org/10.1007/s00128-005-0713-0

Pichtel, J. (2012). *Distribution and Fate of Military Explosives and Propellants in Soil: A Review*. Applied and Environmental Soil Science, Volume 2012, Article ID 617236, 33 p., 2012. doi:10.1155/2012/617236

Pieterek, T., and Pietrock, M. (2012). *Comparative selenium toxicity to laboratory-reared and fieldcollected Hyalella azteca (Amphipoda, Hyalellidae)*. Water, Air, and Soil Pollution, 223(7), 4245 4252. [Online] https://doi.org/10.1007/s11270-012-1188-3

Provisional Peer Reviewed Toxicity Values for Superfund (PPRTV). (2016). *PPRTV Quickview*. US Environmental Protection Agency. [Online] https://hhpprtv.ornl.gov/quickview/pprtv.php

RAIS (Risk Assessment Information System). (2017) *RAIS Toxicity and Properties*. [Online] https://rais.ornl.gov/cgi-bin/tools/TOX_search?select=chem_spef

Rickwood, C. J., King, M., and Huntsman-Mapila, P. (2015). *Assessing the fate and toxicity of thallium I and thallium III to three aquatic organisms*. Ecotoxicology and Environmental Safety, 115, 300 308. [Online] https://doi.org/10.1016/j.ecoenv.2014.12.024

Riviera, F., and coll. (2009) *Fate and transport of explosives in the environment: a chemist's view*. In Ecotoxicology of Explosives. CRC Press, Boca Raton, FL, USA.

RSC (Royal Society of Chemistry). (2017). *ChemSpider*. [Online] http://www.chemspider.com/

Sample, B.E., D.M. Opresko and G.W. Suter II. (1996). *Toxicological Benchmarks for Wildlife: 1996 Revision.* Oak Ridge,TN: Oak Ridge National Laboratory. 43 pages + annexes. ES/ER/TM-86/R3.

Sample, B. E., Beauchamp, J. J., Efroymson, R. A., Suter II, G. W., and Ashwood, T. L. (1998a) *Development and Validation of Bioaccumulation Models for Earthworms*. ES/ER/TM-220. [Online] https://rais.ornl.gov/documents/tm220.pdf

Sample, B. E., Beauchamp, J. J., Efroymson, R. A., Suter II, G. W., and Ashwood, T. L. (1998b). *Development and Validation of Bioaccumulation Models for Small Mammals*. ES/ER/TM-219. [Online] https://rais.ornl.gov/documents/tm219.pdf

Santé Canada. (2008). *Federal contaminated site risk assessment in Canada. Part IV: Spreadsheet tool for human health preliminary quantitative risk assessment (PQRA).*

Santé Canada. (2010). *L'évaluation des risques pour les sites contaminés fédéraux au Canada – Partie VII : Guide d'orientation pour l'évaluation de l'intrusion de vapeurs du sol sur les sites contaminés.* Division des sites contaminés. Direction de la sécurité des milieux.

Schuette, J. (1998). *Environmental fate of glyphosate*. California Department of Pesticides Regulation. [Online] http://www.cdpr.ca.gov/docs/emon/pubs/fatememo/glyphos.pdf

Schulte-Hostedde, A. I., Millar, J. S., and Hickling, G. J. (2001). Evaluating body condition in small mammals. *Canadian Journal of Zoology*, *79*(6), 1021-1029. [Online] https://doi.org/10.1139/z01-073

Shuhaimi-Othman, M., Yakub, N., Umirah, N. S., and Abas, A. (2011). *Toxicity of eight metals to Malaysian freshwater midge larvae Chironomus javanus (Diptera, Chironomidae)*. Toxicology and Industrial Health, 27(10), 879 886. [Online] https://doi.org/10.1177/0748233711399318

Swartjes, F.A. (1999). *Risk-based Assessment of Soil and Groundwater Quality in the Netherlands: Standards and Remediation Urgency*. Risk Analysis 19(6): 1235-1249.

SYKE (Finnish Environment Institute). (2016). *Chemical information*. [Online] http://www.syke.fi/>

Verbruggen, E. M. J., Posthumus, R., and van Wezel, A. P. (2001). *Ecotoxicological Serious Risk Concentrations for soil, sediment and (ground)water: updated proposals for first series of compounds.*

National Institute of Public Health and the Environment. RIVM report 711701 020, Bilthoven, Pays-Bas. [Online] http://rivm.nl/bibliotheek/rapporten/711701020.pdf

Wang, N., Dorman, R. A., Ingersoll, C. G., Hardesty, D. K., Brumbaugh, W. G., Hammer, E. J., Mount, D. R. (2016.) *Acute and chronic toxicity of sodium sulfate to four freshwater organisms in wateronly exposures*. Environmental Toxicology and Chemistry, 35(1), 115-127. [Online] https://doi.org/10.1002/etc.3148