Methodology Associated with Risk Assessment of Outdoor Operating Small Arms Ranges: A Canadian Case Study

Efrosyni-Maria Skordaki¹ and Nicholas Vlachopoulos²*
¹Royal Military College of Canada, Kingston ON, Canada
²RMC Green Team, Department of Civil Engineering, Royal Military College of Canada, Canada

Abstract
Proactive risk management of operating small arms ranges (SAR) is necessary as spent ammunition at outdoor ranges can have a damaging effect on the environment. Heavy metals from projectiles or targets used at a range can potentially migrate in the environment. The Royal Military College of Canada (RMC) Green Team has conducted multiple environmental studies at 65 SAR sites across Canada. This paper presents the risk assessment methodology that was followed at these sites. The focus of this investigation was to assess the level of risk associated with the environmental impact of 65 active outdoor small arms ranges (SAR) with a view to determining the SAR site(s) that posed the highest risk to the environment. This methodology takes into account environmental and intrinsic (physical) parameters as well as usage and maintenance practices. The effective monitoring of firing ranges’ operations that is grounded in environmental stewardship principles can minimize the impact on human health and the environment in addition to supporting sustainable usage of SAR.

Keywords: Risk management; Firing ranges; Heavy metals

Introduction
Small Arms Ranges (SAR) are crucial to military training. Practical and pragmatic environmental management of operating small arm ranges is necessary as spent ammunition at outdoor small arms ranges can have a damaging effect on the environment. Heavy metals such as lead, copper and zinc from projectiles or targets used at a range can potentially migrate in the environment. Depending on groundwater depth, climate, soil chemistry, or proximity to surface water at a range, contaminants can reach groundwater or surface water bodies. Soil erosion and berm stability issues can also lead to heavy metals leaching off-site, affecting neighbouring sensitive land and water uses [1–3]. As well, insufficient operation and maintenance practices (O&M) at frequently used SAR can cause range users to be directly exposed to heavy metals (for example, by inhalation of contaminated dust and/or dermal exposure to lead (Pb) at the firing positions and during site clean-up). The authors have conducted multiple risk assessments on over 65 SAR sites. This paper presents a best-practices SAR management methodology that is based on our results obtained from several SAR case studies across Canada. These lessons learned are used to describe a proactive environmental management approach for operating small arm ranges. Our approach takes into account site-specific conditions, i.e. topography, geology, permeability of soils, annual precipitation averages as well as SAR design and remediation practices, i.e. berm condition and clean-up programs, known contaminants, disposal methods and environmental regulatory considerations.

This investigation included 65 active outdoor small arms ranges in 13 locations spanning six provinces of Canada. Each participating site had specific geographical and geological context. For example, certain ranges were located in regions where the groundwater table in the surrounding area was very shallow (2–3 m depth), and the training camp was partly sitting on bedrock; other ranges were in close proximity to sensitive surface water bodies with potential impact to species-at-risk.

Recently, there has been a growing public concern about the environmental and health effects of these ranges both nationally and internationally. Canada is expected to effectively address such concerns and comply with stringent environmental laws, such as the Fisheries Act (1985) and the Canadian Environmental Protection Act [1999] [4,5]. In addition, many compounds commonly found in training areas have been included in the Canadian Council of Ministers of the Environment (CCME) guidelines. In particular, there is concern about potential risks associated with the historical and continued use of lead shot and bullets and their associated impact. This concern is not unfounded. The intense training of federal organizations that has taken place in relatively small areas for over a century has potentially posed a risk for groundwater contamination.

Existing maintenance and construction practices at outdoor small arm ranges require of responsible organizations to clean each lane after a certain usage threshold has been reached; for example the recent practice of when 100,000 rounds have been fired at SAR locations. These practices are not based on solid scientific information and have been proven ineffective in the protection of the environment. Further, SAR users often apply low-cost practices in order to postpone or reduce the need for site remediation, such as soil removal of the berm (approx. 10 m high by 5 m wide and 100 m long depending on location) and replacement as well as treatment methods. As such, physical separation is usually employed and involves soil screening that removes metal particulates. This maintenance practice, however, allows for the removal of only large fragments of bullets from the berms [6]. The fine metal particles remain in the soil, thus migrating in the environment and potentially reaching the groundwater table and/or surface water bodies. Continual spent ammunition at the firing ranges can significantly impact the environment as it will result in accumulation of lead (Pb) and other metals above acceptable levels [7]. Figure 1 a,b&c shows the location of metal concentrations at the impact area and how it can disperse in the environment.

Purpose and Scope
The focus of this investigation was to assess the level of risk associated with the environmental impact of 65 active outdoor Small Arms Ranges (SAR) with a view to determining the SAR site(s) that posed the highest risk to the environment. Specifically, the task undertaken by the RMC Green Team included a background investigation into soil and groundwater contamination from activities on SAR. This study encompassed the provision of a risk...
Lead is the primary soil contaminant of concern at these sites. Other metals that are present in an outdoor operating SAR environment may include: Copper (Cu), zinc (Zn) and antimony (Sb).

Lead Contamination - Impact on Human Health and Environment

Average concentration of lead (Pb) in the earth’s crust is estimated to be 14.8 mg/kg [8]. Lead is a chalcophile element, meaning that it tends to concentrate in sulfide minerals and ores. The most common Pb-bearing mineral is galena (PbS), but Pb is also found in the form of cerussite (PbCO₃) and angleite (PbSO₄). Lead is the most common of the heavy elements and has been extensively used since the Roman times. Thus, it has been widely spread throughout the environment. Everyone is exposed to lead (even in trace amounts) particularly through air, soil, dust, food and drinking water. Lead can accumulate in human, animal, and plant tissue and can cause chronic health effects.

Lead can be absorbed by inhalation of dusts or by eating foods containing lead and in case of plants by way of soluble lead salts in soils. Inhalation is the major source of intake in workplace. Approximately 30–50% of the lead inhaled persists in the lungs; the rest is absorbed by the body and usually is deposited in the bones. The biological half-life of lead in blood is between 20–40 days, in bones up several years [9,10].

Even low concentrations of lead can be harmful, especially to sensitive groups of people such as infants or young children who absorb lead more easily than adults. Low level exposure can result in detrimental effects (i.e. abnormal intellectual development, behavioural irregularities, impaired hearing ability etc.). Short-term exposure to high-levels of lead can be lethal. Continues exposure, as in an industrial setting can affect the kidneys [11,17].

Lead has been found to bond to small dust particles in the air. It can be transported over long distances depending on the air currents, as well as precipitation and humidity. Most of the lead in the atmosphere is removed by precipitation. Lead is toxic to freshwater fish and invertebrates; 0.3 mg/l is the threshold for fish toxicity [12]. Surface water basins form accumulation sinks for lead compounds. Insoluble lead compounds sink and are adsorbed in the sediment or accumulate on the clay fraction. Aquatic plants accumulate lead, while fauna is depleted at levels above 0.2 mg/l. A key factor in the solubility of lead is the pH of the fluid. The adsorption rate of lead depends on the soil properties. Lead has a significant affinity for humic substances. The pH range also affects the mobility of lead in soil. However, as lead is quite immobile as an element, it remains on topsoil (not readily absorbed by plants). Therefore, soils are an important sink for lead compounds. Very high levels of lead can affect the

Figure 1: Depiction of a sample small arms range and the potential issues associated with its use (a) Components of a SAR, (b) Potential contamination zones and influences, and (c) Activities and factors of consideration.
quality of groundwater depending on the pH, salt content of the groundwater; etc. [7,13–17].

Lead Contamination – Impact on Small Arms Ranges

SAR is crucial to military and police training. However, continual usage of these outdoor facilities has resulted in considerable heavy metal contamination of soil from spent bullets that are usually made of lead and copper alloys. The presence of metals on SAR can cause environmental and occupational health problems as long as these facilities are being used without proper management and remediation strategies.

At both rifle and pistol shooting ranges, bullets are shot towards fixed targets located just in front of a berm that serves to prevent bullets from going farther. Bullets are often fragmented and even crushed upon impact with the berms at a SAR, thus resulting into the distribution of small metal particles (particularly Pb) into the environment. Elevated heavy metal concentrations can be found behind the berm. These areas, which are commonly natural ecosystems (e.g. forests), have often been neglected in terms of environmental impact [7].

Pistols have a relatively low muzzle velocity. The projectiles tend to stay in their original configuration; less fracturing means less corrosion. Rifles ranges, however, pose a greater problem. As munitions split up, the jacket is in contact with lead and more surface area is exposed; this increases the potential for corrosion. Further, soil samples from rifle ranges show very small lead particles. Once bullets are deposited onto the soil, the surface of the metallic Pb core is slowly oxidized to Pb(II). Although Pb binds tightly to soil particles, some studies have shown that preferential flow can lead to Pb transport into the subsoil, bypassing the soil matrix [18,19]. This could result in potential Pb (II) contamination of shallow groundwater or surface water sources used for human consumption. The presence of Pb (II) in drinking water, even at low concentrations, may cause serious human diseases [20,21].

Lead Contamination in Soils at Small Arms Ranges Can Be Transported Via the Following Mechanisms

Airborne Particulate Lead: Lead can bond to small dust particles and be transported over long distances. If contaminated soil is disturbed by wind, foot traffic, or maintenance activities, then small lead particles can become airborne. Airborne particles smaller than 10 microns can be inhaled [22]. Fine particles smaller than 250 microns in diameter can be incidentally ingested [23]. With respect to SAR users and their potential risk of exposure to Pb, soil particles smaller than 100 to 200 microns are likely to be ingested because fine particles adhere to skin while larger particles are easily brushed off [23].

Storm water runoff and erosion: Contaminated soil and lead particles can be readily eroded and transported away from the firing range via storm water runoff. Several parameters can possibly affect the transport of Pb away from the SAR such as the regional precipitation rate and intensity of the rainfall, topography, soil type, vegetation or support structures surrounding the berm of the facility [6,24].

Dissolved lead in groundwater/surface water: pH is a key factor in the solubility of lead in groundwater/surface water. At a neutral pH, lead is relatively insoluble. With pH decreasing, lead solubility increases. When storm water, which is usually slightly acidic, mixes with lead contaminated soil, the metal can be dissolved into the water and transported to nearby groundwater or surface water. In cases where high concentrations of lead are introduced to nearby surface water bodies or even groundwater sources used for consumption purposes, the risk to the environment and especially to human health can increase significantly. While lead contaminated sites can have an effect on the quality of shallow aquifers, if groundwater is more than 4m below ground surface, it is usually not affected by leaching of lead from soil [7,14,15,25].

Sand-rich and clay-rich soils: The sand-rich surficial soil layer at a SAR can result in amplified mobility of lead particles within the environment as sand is normally a high-permeability soil type. Sandy soils can easily erode by wind and precipitation, thus releasing lead particles in the environment. On the other hand, lead has a tendency to adsorb and accumulate on clay-rich soils, which are usually of low permeability. The thickness of the clay-rich layer can also assist in reducing the mobility of lead; as rainwater is retained by clay horizons, soluble lead ions transported by storm water can deposit in clay and adsorb to its particles. Ranges with sandy surficial soils and frequent usage usually pose a higher risk to the environment and human health, compared to firing ranges with clay-rich top soil and similar rate of usage. Lead as well as antimony, copper, and zinc tend to adhere to soil grains and humic substances (organic material) and become “fixed” in shallow soils [17,26].

Methodology

The two-phase approach employed by the RMC Green Team involved: 1) A site characterization for each SAR, and 2) a risk assessment and subsequent ranking of the sites of concern. Specifically, the methodology that was followed included:

Phase I

Step 1: Literature Review

Step 2: Amassing of database information from user organizations related to:

• Initial site contact and/or review of supplied information on SAR (average annual usage between 2011-2015, maintenance etc.);
• Creation and preparation of relevant survey tool(s) for data collection;
• Ongoing communication with user organization representatives;
• Pertinent information were sought from other sources (i.e. GIS databases, airphotos etc.) when not provided by responsible organizations;
• Hydrogeological parameters that were considered included the characteristics of the native soil formations in and around the SAR, the depth to groundwater in vicinity of the berm (‘stop butt’), and the topography.
• The contaminants of concern (CoCs), in addition to Pb, on SAR and adjacent areas between the berms and responsible organizations;
• Stop butt design and associated distances to federal boundary;
• Characterization of adjacent or potentially affected surface areas.

water bodies (including known species at-risk and/or species of concern) and identification of metal concentration exceedances in water; and,

- Regional precipitation levels/climatic conditions.

**Phase II**

Step 3: Analysis and synthesis of a massed information with a view to characterizing and classifying each site (risk scoring and ranking).

**Site Characterization**

According to Benson, et al. [27], a site characterization is “the process of developing an understanding of the geologic, hydrologic and engineering properties at the site including the soil, rock, along with groundwater and in many cases, man-modified conditions in the subsurface (e.g. utilities, structures, mines and tunnels) that can impact site conditions”. A site characterization may also include the spatial and temporal assessment of contaminants when they are present. The site characterization process in this study took into consideration two types of factors that could potentially affect the quality of the SAR environment and pose a risk to human health (Figure 1): i) The parameters associated with the environmental and intrinsic conditions of the site, and ii) the parameters related to the frequency of SAR usage and maintenance practices. These two types of factors are further described below:

I. The environmental and intrinsic conditions of the SAR sites. This group of factors consisted of: a) The geological information with respect to the soil type, thickness of top soil layers and stratigraphy, b) the precipitation and pH data available, c) the flood potential on SAR, d) the depth to water table/aquifer, e) the type of groundwater use if applicable, f) the type of surface water bodies and distance of SAR to these water reservoirs, g) the distance of SAR from property boundaries, and h) the nature of vegetation cover of the berms and the near-by areas;

II. The frequency of usage and maintenance practices of the SAR sites. This list of factors was comprised of: a) The type of military training and ammunitions fired on-site, b) the frequency of use of respective SAR, c) the maintenance practices, including frequency and type of clean-up events of the berms, d) the type of known contaminants of the berm, e) the contaminated soil disposal methods and locations if within Base, and f) any SAR users’ activities causing disturbance to the berm on-site and potential migration of contaminants.

Other considerations included applicable local laws on the protection of endangered species or natural reserves, neighbouring sensitive land and water uses.

**Implementation of Methodology, Observations and Selected Results**

The following sections describe the results from the risk ranking process of the SAR sites based on: i) The environmental and intrinsic factors only, and b) the environmental and intrinsic factors coupled with SAR usage data.

**Risk Assessment Ranking with Respect to Intrinsic Factors**

A risk assessment, in general, provides an evaluation of the potential threat to the environment and potentially to human health from contaminants in environmental media and can provide a basis for determining the necessity for, and extent of, remedial action [28]. This risk assessment provided an evaluation of the potential for metals (particularly Pb) to migrate from SAR to neighbouring sites, surface water and groundwater. The site characterization process for each SAR (Phase I in our Methodology) allowed the identification of the major parameters (among all of the parameters that were considered initially) that could affect the environmental conditions at each site. The quality and availability of the data that were provided by the user organizations for all sites of concern functioned as a filter in the final screening of the collected information. As such, the final environmental and intrinsic factors that were included in this risk assessment (Phase II in our Methodology) were:

I. Native soil type;
II. Depth to ground water;
III. Distance from stop butt to property boundary;
IV. Distance between stop butt and nearest surface water (SW) body;
V. Importance of nearest SW body (i.e. habitat of species of concern or species at-risk); and,
VI. Regional precipitation levels and relevant climatic information.

Although data related (Table 1) to verify metal exceedances in soil, surface water and groundwater in the vicinity of the berm at each SAR were collected initially, this dataset was ultimately removed from the risk ranking process as there was not enough consistency with respect to how such data were collected across Canada. The feedback that was provided by the user organizations in this regard included the following: i) Some metal concentrations which exceeded guidelines could not be easily attributed to munitions used on SAR, ii) exceedances which were attributable to munitions used on SAR could also have elevated natural or regional background concentrations, and iii) exceedances could be due to poor stop butt conditions (for example, lack of vegetation and improper stop butt slope).

| SAR ID | Native soil type | Depth to groundwater | Distance from stop butt to property boundary | Distance between stop butt and nearest surface water body | Importance of nearest SW body (i.e. habitat of species of concern or species at-risk) | Regional precipitation levels | Usage | Total Point Score |
|--------|------------------|----------------------|---------------------------------------------|----------------------------------------------------------|--------------------------------------------------------------------------------|
|        | High Risk        | High Risk            | Low Risk                                    | High Risk                                                | High Risk                                                                       | High Risk                   | High  | =4 (> 3.5) High Risk × High Usage |

**RATIONALE (SAR Example from the study)**

"SAR A: High Usage site, with sand-rich surficial soil, shallow water table (2 to 3 m depth respectively), high precipitation. A drainage ditch runs right next to the site, which eventually drains into a salmon-bearing river. Cleaning practices have included screening for bullets and bullet fragments as well as some removal of soil. However, the removed soil has been piled behind the berms and the "new" filler soil may originate from these piles."

Table 1: Example of a high risk SAR ranking based on the risk assessment factors described in table 2.
The first three items from the list of factors above (i.e. native soil type, depth to groundwater and distance from berm (or ‘stop butt’) to property boundaries) were assigned with a higher weight within the risk calculation (weight = 1) due to their higher influence on the total risk, as it was determined by the analysis of the data. The last three factors (distance between stop butt and nearest surface water (SW) body, importance of nearest SW body (i.e. flowing vs. non-flowing, bog, etc.) and regional precipitation levels and relevant climatic information) were assigned with a lower weight (weight = 0.5) due to their lower influence on the total risk.

As well, the assessment of the data associated with each SAR site showed that all environmental and intrinsic factors had a wide range of variation. Therefore, in order to address all of the sites and to keep the consistency within the risk assessment, each factor was also categorized in three groups with a score of 0 or 0.5 or 1; The higher score was assigned to the category with a potential higher risk and the lower score was given to the category with a lower potential risk. A score of one was given to each category that the information was unavailable, assuming it had the highest potential risk.

A summary of categories within each environmental/intrinsic factor and the scores assigned to each category are summarized in Table 2. The total risk associated with the intrinsic factors at each SAR site is the summation of the intrinsic factor weight multiplied by its category score, as in the formula below (Equation 1):

$$\text{Total risk} = \sum_{i=1}^{6} w_i * s_i$$

Where, \(w\) is the weight for each factor, \(s\) is the score for each category of the intrinsic factor, and \(i\) is the intrinsic factor.

Considering the values of calculated risks using the above formula, a site with the total value of less than 2.5 was considered as low risk, whereas a site with a score between 2.5 and 3.4 as medium risk, and equal or higher than 3.5 as a high risk (Figure 2).

**High risk SAR with respect to intrinsic factors:** Two examples of High Risk SAR are included here, SAR A and SAR B. The main factors that contributed to the ranking of SAR A as High Risk were

<table>
<thead>
<tr>
<th>Average Annual Usage</th>
<th>Description</th>
<th>As per score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
<td>Score</td>
<td></td>
</tr>
<tr>
<td>&lt; 75 days</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>75–120 days</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>&gt; 120 days</td>
<td>High</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Native Soil Type</th>
<th>Category</th>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse, gravel, sand</td>
<td>1</td>
<td>Lower surface area and faster permeability of sand-rich soils lead to longer transport distance of dissolved lead, particularly if underlain by clay. Also, sand and gravel soils allow dissolved lead in groundwater in these type soils can move long distances relatively unchanged (ITRC, 2005).</td>
<td></td>
</tr>
<tr>
<td>Sand underlain by Clay, till</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>0</td>
<td></td>
<td></td>
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<table>
<thead>
<tr>
<th>Groundwater Table</th>
<th>Category</th>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 7.5 m</td>
<td>1</td>
<td>The risk that lead will migrate into the environment increases if groundwater depth is small. Shallow depth to groundwater is indicative of potentially higher risk for mobilized lead to reach the groundwater. The depths of 7.5 m and 15 m were selected as average thresholds after comparing the GW depths of all SAR sites.</td>
<td></td>
</tr>
<tr>
<td>7.5 m–15 m</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 m</td>
<td>0</td>
<td></td>
<td></td>
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<table>
<thead>
<tr>
<th>Precipitation</th>
<th>Category</th>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 500 mm</td>
<td>0</td>
<td>High annual precipitation results in extended contact between metallic lead and rain water, thus increasing the potential for corrosion and leaching of lead. Sand-rich soils will absorb more rainfall than clay-rich soils. Hence, for a given rainfall intensity, the volume of runoff will be greater from areas underlain by clays or other low-permeability soils than from permeable, sandy soil. As stratigraphy data regarding variations in the thickness of a clay layer or penetration resistance, water content, silt inclusions etc. between the stop butts and adjacent SW are not consistent or available for all 60 sites, an assumption that SAR with sandy soils underlain by clay pose a greater risk to SW due to run-off had to be made in this report.</td>
<td></td>
</tr>
<tr>
<td>500 mm–1000 mm</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000 mm</td>
<td>1</td>
<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Distance from Stop Butt to the Federal Boundaries</th>
<th>Category</th>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 100 m</td>
<td>1</td>
<td>Soil erosion from SAR may cause the transport of dissolved or particulate lead off-site, increasing the potential for environmental impacts. The shorter the distance between lead-contaminated soils and range boundaries, the higher the potential of lead fragments in suspension to be transported off range.</td>
<td></td>
</tr>
<tr>
<td>100 m–500 m</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 500 m</td>
<td>0</td>
<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Distance from Stop Butt to the Nearest Surface Water Body</th>
<th>Category</th>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 150 m</td>
<td>1</td>
<td>As per above, the shorter the distance between lead-contaminated soils and closest surface water body, the higher the potential of lead fragments in suspension to be transported off range.</td>
<td></td>
</tr>
<tr>
<td>150 m–500 m</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 500 m (up to 3 km)</td>
<td>0</td>
<td></td>
<td></td>
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<table>
<thead>
<tr>
<th>Importance of the Nearest Surface Water Body</th>
<th>Category</th>
<th>Score</th>
<th>Description</th>
<th>As per score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contains species at risk or protected area</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contains habitat</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Otherwise</td>
<td>0</td>
<td></td>
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</tbody>
</table>

Table 2: Summary of weights and categories assigned to each factor in the SAR risk assessment.
the sand-rich surficial soil layers combined with small groundwater depth (less than 7.5 m), high average annual precipitation and in vicinity to environmentally sensitive areas (salmon-bearing river). For the High Risk SAR B, the native soil type (coarse grain) combined with high average annual precipitation and in proximity to an oceanic channel which was of high importance to marine species (e.g. shellfish industry in immediate area, distance from stop butt to nearest surface water body at 25 m) resulted in a high score ranking (although this site was not frequently used).

Risk Assessment Ranking with Respect to Intrinsic Factors and Usage

Range usage was divided in three groups: Low, medium, and high, depending on the number of days that the range was booked or rounds fired at that range for five consecutive years (Table 3). Table 3 illustrates the risk level using a colour code. The colours green, yellow and red shows: i) low, ii) medium, and iii) high risk level, respectively. For instance, if the calculated risk from the intrinsic factors is high, but the risk from the range usage is low, then the total risk considering both these parameters will be medium (yellow colour in the table).

High risk SAR with respect to intrinsic factors and usage:
The main factors that contributed to the ranking of these SAR included the frequent range usage (> 120 days per year), the permeability of the surficial soil (high permeable sandy soils) coupled with the shallow water table (< 7.5 m depth), average annual precipitation as well as the distance to surface water bodies that were environmentally sensitive, existing habitats of species-at-risk or threatened species (salmon-bearing rivers and wetlands that connected to fish-bearing rivers/creeks).

Certain sites among these high-risk SAR had several groundwater supply wells, in and around the ranges, that were used to collect potable water, as well as for industrial and agricultural use, at the time of the study. This could potentially result in human exposure to Pb as a result of the SAR activities [29,30].

Summary of Results, Recommendations and Conclusions

The methodology of the case study presented was employed in an area-wide study of a national scale, in a risk-based framework, and allowed for the delineation of the primary factors that affected the ranking process of the SAR. The SAR sites were classified with respect to seven major parameters, including environmental/intrinsic factors as well as usage data. The results indicated 13 high risk sites. Table 2 includes an example of the ranking process and methodology.

In terms of future activities or potential solutions to this environmental issue of a national scope and interest, there are recommendations that can be made and investigated. Selected options and/or solutions include:

**Figure 2: Idealized risk assessment summary table.**

**Table 3: Qualitative total risk according to intrinsic factors and usage.**
I. Develop New Range Design: This would call for the design of a closed system, preventing contaminants from affecting the surrounding environment.

II. Remediate/Clean-up Sites: Such activities would reduce liability and environmental/health issues. They should be implemented in a prioritized sequence, addressing the issues at higher priority bases first. This would need to proceed within the fiscal and operational realities of each user organization, i.e. sites may need to be temporarily closed.

III. Improve Monitoring, Operations and Maintenance Practices: This would involve well-trained staff on revised current standard operating procedures, based on best practices as well as solid field data collection, analyses and interpretation.

Effective management planning, implementation, and monitoring of small arms range operations that are grounded in environmental stewardship principles can minimize impacts on human health and the environment.

Acknowledgements

The authors would like to thank the federal and provincial agencies that contributed to this study by providing access to their datasets, valuable feedback and ongoing support.

Conflict of Interest

The authors declared that they have no conflict of interest to declare.

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