Defence Research and Development Canada	Recherche et développement pour la défense Canada

CAN UNCLASSIFIED

DRDC | RDDC
technologysciencetechnologie

A practical guide for the development of a long-term monitoring program for water quality on canadian armed forces ranges and training areas

Richard Martel

Thomas Robert
André Saint-Hilaire
André-Guy Temgoua Tranquille
Clarisse Deschênes-Rancourt
Institut National de la Recherche Scientifique, Centre Eau Terre et Environnement

Prepared by:
Institut National de la Recherche Scientifique, Centre Eau Terre et Environnement,
490 Rue de la Couronne,
Québec, QC, Canada
G1K 9A9

PSPC Contract Number: W7701-082245/001/QCL, Task authorization 55
Technical Authority: Sylvie Brochu
Contractor's date of publication: November 2017

Defence Research and Development Canada

Contract Report
DRDC-RDDC-2018-C036
June 2018

CAN UNCLASSIFIED

Canada

IMPORTANT INFORMATIVE STATEMENTS

This document was reviewed for Controlled Goods by Defence Research and Development Canada (DRDC) using the Schedule to the *Defence Production Act*.

Research Contract W7701-082245/001/QCL
Reference W 7701-8-2245
File QCL-9-30318
Task -55

A PRACTICAL GUIDE FOR THE DEVELOPMENT OF A LONG-TERM MONITORING PROGRAM FOR WATER QUALITY ON CANADIAN ARMED FORCES RANGES AND TRAINING AREAS

Richard Martel, Thomas Robert, André Saint-Hilaire, André-Guy Temgoua Tranquille, Clarisse Deschênes-Rancourt

Institut National de la Recherche Scientifique

Centre Eau Terre et Environnement

November 2017

Glossary

CA	Canadian Army
CAF	Canadian Armed Forces
CAO	Canadian Army Order
DND	Department of National Defence
GW	Groundwater
MC	Munition constituents
RTA	Range and training areas
SW	Surface water
UXO	Unexploded ordnance

1. Introduction

The ability of the Canadian Armed Forces (CAF) to develop and maintain forces capable of fulfilling the Government of Canada's defence objectives relies on the completion of live-fire military training on land ranges and training areas (RTA). Although critical to the defence mission, live-fire military training inherently results in the deposition of metals, energetic materials and propellants (hereinafter referred to as munitions constituents (MC)) into RTA. Such deposition can adversely impact RTA users and/or the surrounding population; impact flora and fauna; and/or result in non-compliance with applicable legislation and policy.

In 2016, owing to a lack of departmental direction regarding the management of the environmental risks and impacts associated with live-fire training, the Commander of the Canadian Army (CA) endorsed Canadian Army Order (CAO) 23-15 "Environmental Risk Management of the Introduction and Presence of Munitions Constituents". The intent of CAO 23-15 was to ensure that CA Installations demonstrate a consistent level of due-diligence with regards to risk managing the introduction and presence of MC by articulating pan-Army environmental management objectives and actions related to such contamination. CAO 23-15 is predicated upon the following management principles:

1) Primacy of military training – RTA are the only locations where mission critical live-fire training can be conducted; as such, monitoring and mitigation of the risks and impacts of MC must be compatible with operational requirements.

2) Avoidance of off-site impacts – Given that the deposition of MC into RTA is an inherent consequence of live-fire training, the primary management objective related to the introduction and presence of MC is to minimize the likelihood that MC will have adverse impacts beyond a RTA boundary. Given that water is the primary vector for off-site impacts, priority of monitoring effort will be on surface water (SW) and groundwater (GW) resources within the RTA.

3) Risk-based – It is acknowledged that the risks and impacts associated with the introduction and presence of MC varies between sites and is dependent on multiple factors. Priority of monitoring and corrective action effort will be on those sites having the greatest potential for off-site impacts.

Owing to the transfer of RTA custodianship from the CA to Assistant Deputy Minister (Infrastructure and Environment, ADM(IE)), CAO 23-15 is currently being adapted into a departmental policy instrument applicable to all CAF land RTA on which live-fire training occurs.

The purpose of the present document is to support RTA managers and Defence Establishment Environment Officers in developing a long-term RTA water quality monitoring plan which meets the requirements of CAO 23-15. To achieve this objective, five steps are proposed in this guide (Table 1):

Table 1. Development of a long-term RTA water quality monitoring plan in five steps

STEP 1	Selection of high interest SW and GW monitoring locations within land RTA
STEP 2	Selection of background sampling locations
STEP 3	Selection of applicable water quality reference values
STEP 4	Selection of appropriate water quality parameters to be measured during sampling events
STEP 5	Determining the frequency and appropriate timing of SW and GW sampling events

This document provides guidance on how each of these steps should be conducted. It is important to note that while this document provides guidance on developing a long-term RTA water quality monitoring plan conformant to CAO 23-15 (or equivalent ADM(IE) policy instrument), the intent of this document is not to preclude additional RTA water quality monitoring where resources are available to do so.

2. Development of a long-term RTA water quality monitoring plan

STEP 1. Selection of high interest SW and GW monitoring locations within land RTA

Identification of high interest SW and GW monitoring locations

Environmental monitoring within active RTA is challenging due to the large size of RTA, the presence of unexploded ordnance and the requirement to de-conflict monitoring with military training and other land use activities. When such challenges are coupled with the costs of water quality monitoring, it is imperative that priority of monitoring effort be placed on monitoring sites that will allow Defence Establishments to determine if they are meeting departmental environmental management objectives. As described previously, the primary environmental management objective described in CAO 23-15 is to prevent the introduction and presence of MC in land RTA from having adverse environmental impacts beyond the boundaries of a Defence Establishment. To support this, CAO 23-15 indicates that long-term munition constituents (MC) water quality monitoring plans need to focus on sampling locations of "high interest" which are described as follows:

a. **GW Monitoring Wells of high Interest:** At a minimum, Groundwater Monitoring Wells of high Interest are land RTA GW monitoring wells that have the potential to be impacted by MC and are located within 500 m of either a known potable water uptake or RTA boundary; that sample aquifers having a groundwater flow towards the exterior of the land RTA[1]

b. **SW Sampling Points of high Interest**: At a minimum, Surface Water Sampling Points of high Interest are any SW sampling points within a land RTA area that have the potential to be affected by MC and are located 500 m or less upstream of either a known potable water uptake or the point at which the sampled surface water body flows beyond the boundary of the RTA[2]

To that effect, the first step in establishing a long-term RTA water quality monitoring program is to identify within existing wells and surface water sampling locations which are considered as high-interest sampling sites. To perform this task in conformity the CAO-23-15 requirements, the following supporting information needs to be considered in order to properly identified upstream/upgradient vs. downstream/downgradient locations:

- The geological setting within the RTA boundary and its surroundings;

- The hydrogeological properties of local and/or regional aquifers present within the RTA boundaries and its surroundings;

---

[1] It is important to note that with respect to the boundary of the RTA, CAO 23-15 refers to the external boundary of the entire RTA and not the boundary of individual ranges (e.g. small arms ranges within the RTA).

[2] See footnote 1.

- The groundwater flow direction, especially in the areas corresponding to high interest locations as described above;

- The location of permanent and intermittent surface water bodies within and around the RTA boundaries: creeks, rivers, ponds, wetlands;

- The surface water drainage pattern: watersheds and sub-watersheds (outlets, stream network, headwaters);

- The location of groundwater uptake wells, within the RTA boundaries but also on the properties neighboring these boundaries, and the water use associated with these uptake wells (ex. potable water, livestock watering, etc.).

When studying the geological settings, hydrogeological properties of aquifers and the location of receptors such as surface water bodies or groundwater uptake wells, it is important to correctly identify the water bearing hydrogeological units associated with those receptors. This is best done by developing a RTA-specific conceptual site model such as the one presented in Figure 1. GW monitoring wells of high interest need to be screened over of the same hydrogeological units as those associated with the receptors. Also, when determining groundwater flow directions to establish upgradient or downgradient directions, only the groundwater levels representative of a same hydrogeological unit should be compared with one another.

The example illustrated on figure 1 is a simple conceptualized and fictive RTA. It is composed of 3 training areas where past and ongoing activities are potentially emitting MC in the environment. Past hydrogeological studies, including the drilling and installation of GW characterization wells, identified only one groundwater bearing unit, a water table aquifer. Also, surrounding properties are using groundwater from the same aquifer for potable water supply. Through rainwater runoff and infiltration processes, MC in the dissolved form has the potential to reach the creeks, ponds and the lake, as well as infiltrate into the water table aquifer. There are several existing GW wells, as well as SW sampling stations which have been used for the identification of potential MC impacts in surface water and groundwater. However, not all existing sampling point need to be part of the long-term monitoring plan. Following the guidelines presented above, the high interest GW and SW sampling sites to be included in the long-term monitoring program were selected as follows:

- GW-1, GW2 and GW-3 were selected as high interest GW sampling sites because they are:
  - Located within 500 m of the property limit;
  - Located downgradient of the training areas (which means that surface water and groundwater flow beyond the RTA boundaries at those locations);
  - Completed within the same hydrogeological unit as the one spanning across the RTA boundary and being used for potable water supply, or extending to the lake;

- SW-1, SW-2, SW-3 and SW-4 were selected as high interest SW sampling sites because they are:
    - Located within 500 m of the property limit;
    - Located downgradient of the training areas.

The other sampling points were not considered as high interest sampling sites because they are either located more than 500 from the RTA boundary (GW-5, SW-5 and SW-8), or within 500 from the boundary but at locations where surface water or groundwater flows inward with regard to the RTA boundary (SW-6, SW-7, GW-4, GW-5, SW-9 and GW-7).

The supporting information described above, as well as a description of the surface water drainage pattern and various hydrogeological units, is generally available in previous RTA-specific environmental characterisation reports. This information will also be useful for the determination of applicable water quality reference values required in STEP 3 of this guide.

In the event where no monitoring well exists at a given high interest locations or with screened intervals located at depths representative of an aquifer used for GW uptake, then the option of drilling and installing a new groundwater monitoring well should be planned at those high interest locations. Similarly, in the event where no surface water sampling stations exist at high interest locations, then new sampling stations should be added for long-term monitoring purposes.

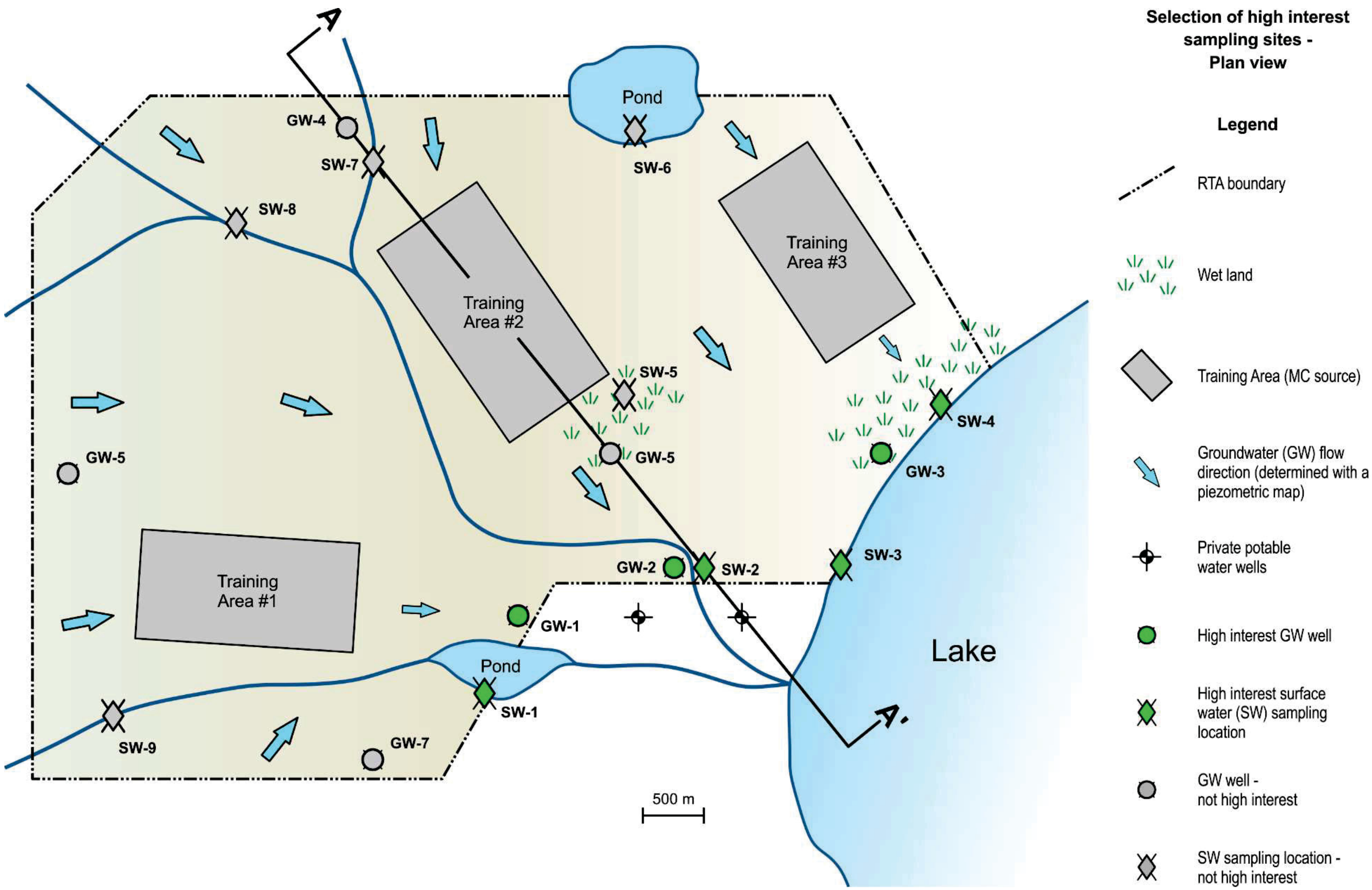


Figure 1 (a). Selection of high interest sampling sites – Plan view

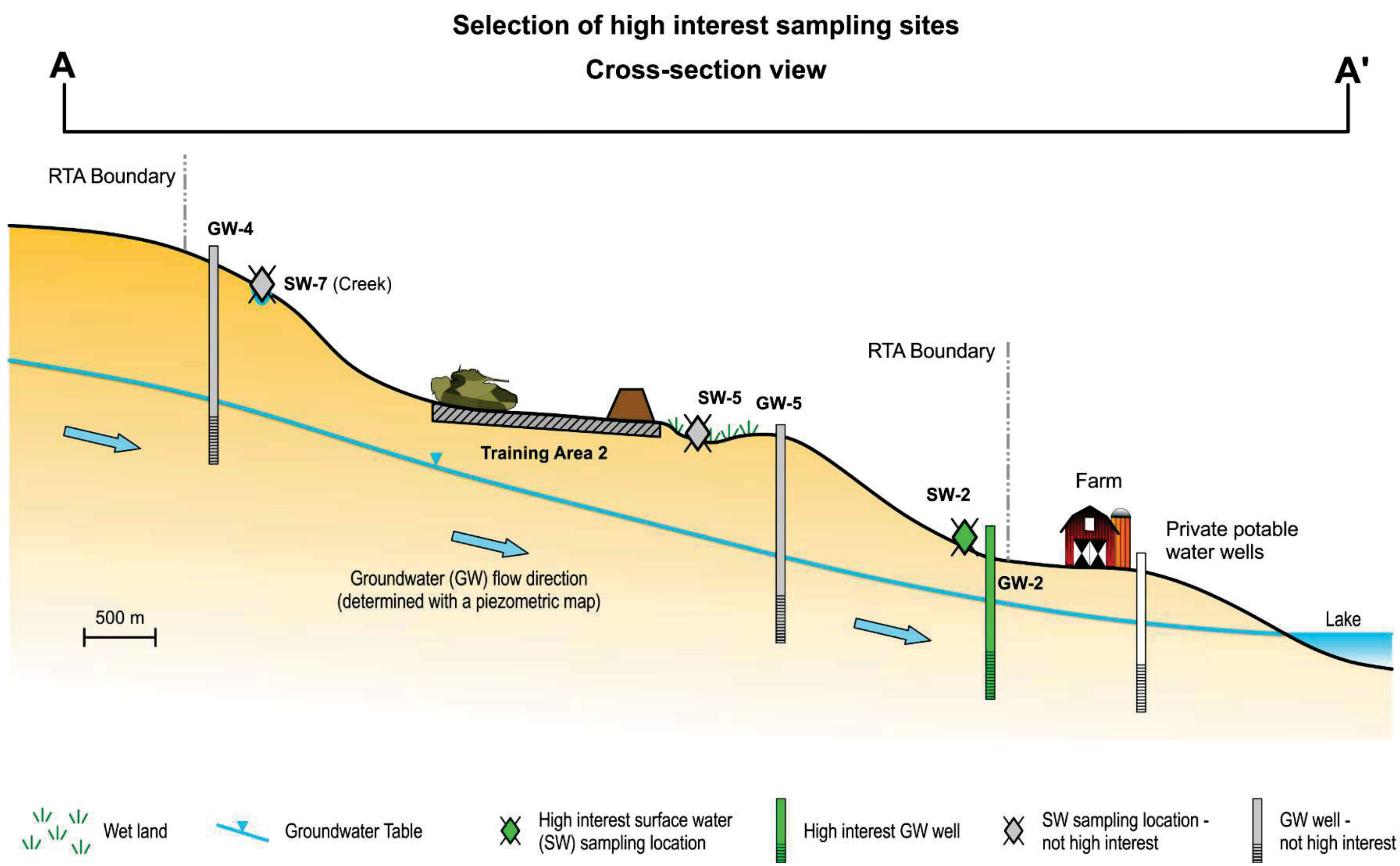


Figure 1 (b). Selection of high interest sampling sites – Plan view

High Interest Sampling Sites – Additional Considerations:

It is important to note that although spatial proximity to the RTA boundary or a potable water uptake is the primary consideration for identifying high-interest sampling points, CAO 23-15 allows Establishment Environment Officers to use their discretion in identifying sampling points of high interest outside of this spatial buffer. When considering additional sampling sites to include in a long-term RTA water quality monitoring program, Establishment Environment Officers should consider:

- The presence of SW bodies within the RTA which support a fishery of commercial, recreational or aboriginal importance;
- The presence of any waters that have the potential to impact an environmentally sensitive area within the RTA e.g. the Suffield National Wildlife Area, formally identified species at risk critical habitat, etc;
- Results from previous monitoring efforts which suggest that there are areas of concern within the RTA that warrant further monitoring; and
- Particular hydrogeological setting where local, surficial aquifers are directly connected to a deeper regional aquifer or a main surface water body.

Rationalizing high interest sampling locations

In some instances, simply applying a spatial proximity of 500 m to the RTA boundary may result in too many sampling points within the long-term monitoring plan to be manageable. To prioritize amongst high Interest sampling points, Establishment Environment Officers should consider:

- Land-use activities upstream of the sampling point e.g. a sampling point immediately downstream from and impact area should be sampled in priority over a sampling point downstream of an area utilised for “dry” training;
- Receptors downstream of the sampling point e.g. sampling points upstream of an inhabited area should be considered in priority over sampling points upstream of an undeveloped area;
- The spatial distribution of GW and SW sampling locations, with the possibility of selecting one representative GW well or SW location in an area with similar properties and conditions;
- Ease of access e.g. all things being equal prioritize sampling points that are easily accessed by roads; and
- Have minimal UXO considerations, wherever possible.

Documentation

For all high interest sampling sites identified in a long-term monitoring plan it is important for Defence Establishment Environment Officers to document in their program why the sampling site is considered to be of high interest. Such documentation provides context as to why exceedances of a MC reference value should be of concern to land managers, and should be included in every environmental monitoring report. Moreover, environmental officers should elaborate a standard numerical spreadsheet template that could be easily used by others for different aims and scopes (as well as reduce the cost of data treatment).

Medium interest sampling locations

The selection of high interest GW and SW sampling points as part of a long-term monitoring program should not prevent GW and SW sampling at locations not identified as such. If not identified as high interest, a GW or SW sampling location within a RTA may still be pertinent to sample occasionally in order to identify or quantify sources of MC constituents, and to determine temporal trends of MC concentrations. This information becomes valuable in order to determine the fate of MC constituents in GW and SW, and to determine if MC concentrations has the potential to reach high interest sites or receptors. These medium interest sampling locations can be identified using historical data and current land use. Those showing previously identified impacts with regards to applicable criteria, or those located in areas where active military training is being conducted, should be included in a sampling plan.

STEP 2. Selection of Background Sampling Locations

In addition to high interest GW and SW sampling locations identified through STEP 1, it is also important for Establishment Environment Officers to consider GW and SW background sampling sites. Certain MC are naturally occurring in the environment and others can be elevated regionally due to non-DND anthropogenic activities (e.g. leaded gasoline use, use of certain agricultural products in the region, etc.). Understanding regional background concentrations is important as DND is not accountable for exceedances that aren't related to its land-use activities.

For GW, background samples are taken from background wells installed in the same hydrogeological units that is evaluated for its water quality in the RTA. At least one background well must exist for each hydrogeological unit sampled in the RTA.

For SW, background samples are taken from surface water bodies having the same hydrogeological context as SW bodies located in the RTA, and be located within the same watershed. This hydrogeological context includes a similar geological environment, and similar water quality such as dissolved oxygen and pH. At least one background SW location must exist for each type of SW sampled in the RTA.

In addition, a suitable GW and SW background location should have the following properties:

- It must be located in an area where land-use activites (previous, present and future) are not related to military training or other activities potentially resulting in MC being emitted in one form or another. If possible, such a location should be located outside of the RTA limits, and at least 100 m from any locations where military activities are suspected;

- It must be located hydraulically upgradient of the RTA;

- If possible, knowing the directions of prevailing winds over the RTA area, it should also be located upwind from the RTA.

Using the example shown in figure 1, GW-4 and GW-5 would constitute interesting candidates for the determination of background GW concentrations, and SW-6, SW-7, SW-8 and SW-9 for background SW concentrations.

STEP 3. Selection of applicable water quality reference values

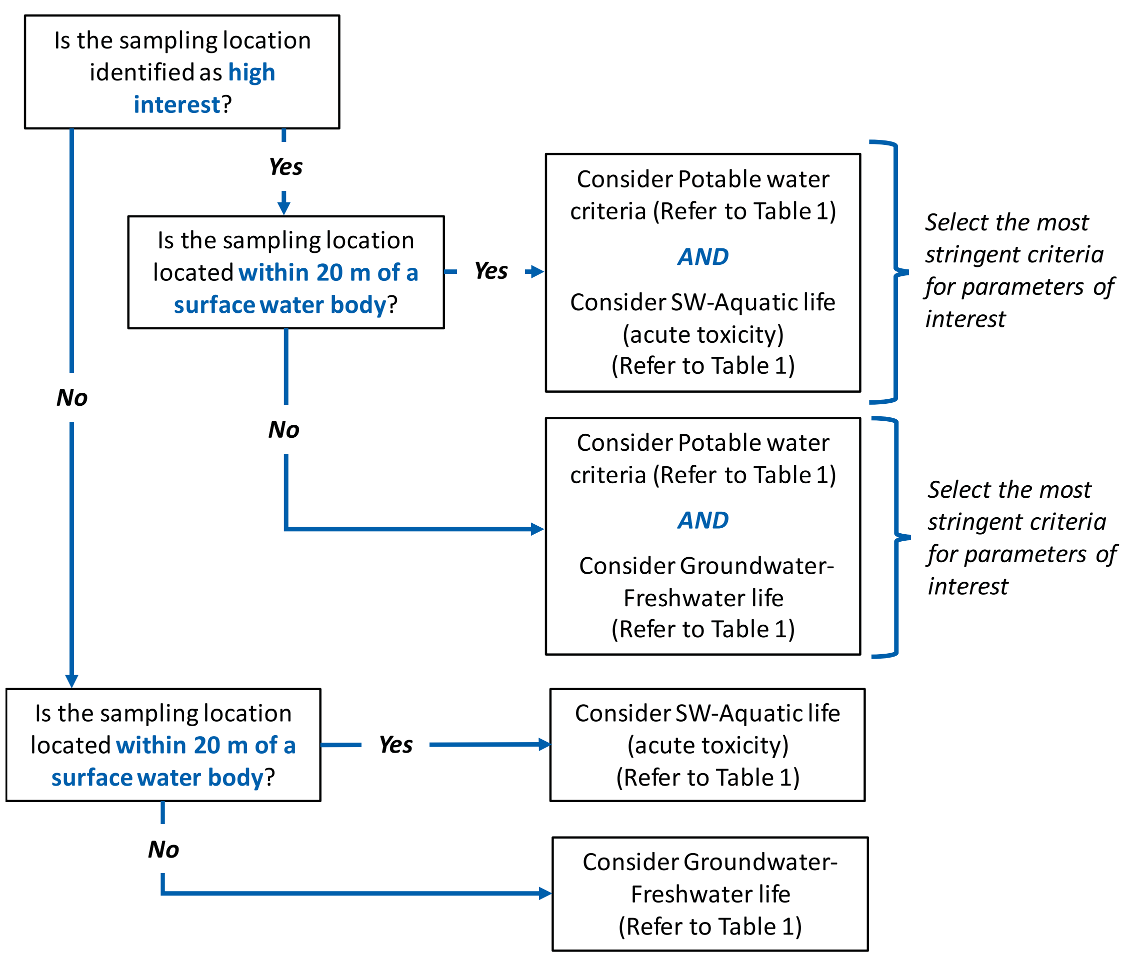
MC reference values include screening values, criteria, guidelines, guidance values, etc. used for the comparison of RTA water samples results in order to determine whether MC concentrations are acceptable or not. However, from the perspective of MC monitoring, the selection of the appropriate MC reference value can be challenging for the following reasons:

- In certain instances, and primarily for metals, different reference values from multiple jurisdictions exist for the same substance and it can be difficult to determine which value is the appropriate one to use in the context of an active RTA;

- Conversely, for energetics and propellants, there are often no Canadian guidance values (federal or provincial), so such values need to be sought from other jurisdictions.

In an effort to ensure that a consistent level of due-diligence is being applied across the CAF with regards to the introduction and presence of MC in active RTA, CAO 23-15 identifies how MC reference are to be applied to SW and GW samples taken from land RTA as illustrated below (Figure 2):

GW Sampling



SW Sampling

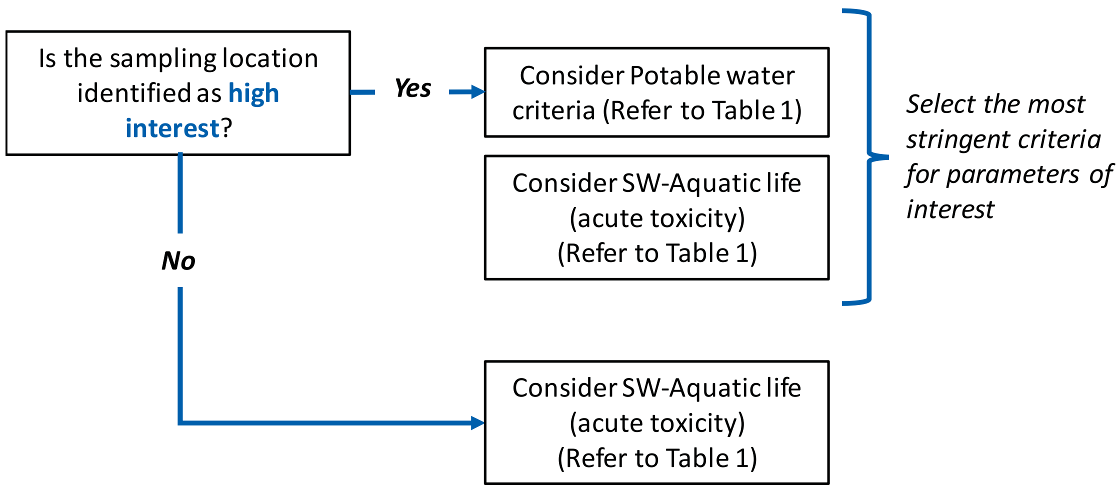


Figure 2 : Determination of applicable groundwater (GW) and surface water (SW) quality reference values as per CAO 23-15

Additionally, existing provincial reference values for SW and GW from the province within which the RTA is located will apply when there is an imminent threat of off-site MC migration. Provincial reference values shall be applied in the same spirit as outlined above. Finally, other jurisdiction guidelines from other source may be selected if needed (e.g. USEPA).

In the event where more than one reference value is applicable for a parameter, the most stringent criteria among all those identified as applicable (federal and provincial) is selected and used to assess the conformity of the analytical results. This task shall be conducted for each parameter for which this situation occurs.

Table 1 of this Guide summarizes the federal aquatic life and potable water criteria to be used to verify if RTA water samples results are within acceptable limits, according to the information provided above.

It is important to note that the intent of this document is to support the development of a long-term water quality monitoring plan for MC in *active* RTA. In the event that Defence Establishment lands currently have a primary purpose other than supporting military training (e.g. the Suffield National Wildlife Area) or where such lands will be divested or repurposed to another primary land use, Defence Establishment environment officers may have to consider alternative MC reference values. Moreover, in saline/marine environments, other federal aquatic life criteria from CCME (1999) would need to be applied.

STEP 4. Selection of appropriate water quality parameters to be measured during sampling events

Metals, energetic materials, perchlorate and general chemistry parameters should be analysed on samples collected at high interest sites. Table 1 lists more specifically the parameters to be evaluated within a long-term RTA water quality monitoring program for MC. Establishment environment officers should be aware that other substances may need to be evaluated depending on local training that occurs at the site. If not previously done, it is strongly recommended that a phase 1 RTA characterization study be undertaken to identify other potential contaminants not listed in the tables (e.g. polycyclic aromatic hydrocarbons, dioxins and furans).

Moreover, historical results obtained during previous sampling campaigns, when compared with the referenced values contained in Table 1, allows the identification of parameters of concern. In the event where chemical analysis needs to be restricted or more focused, the long-term RTA water quality monitoring should account minimally for these previously identified parameters.

The laboratory method used for sample analysis must have detection limits below the reference values indicated for each parameters.

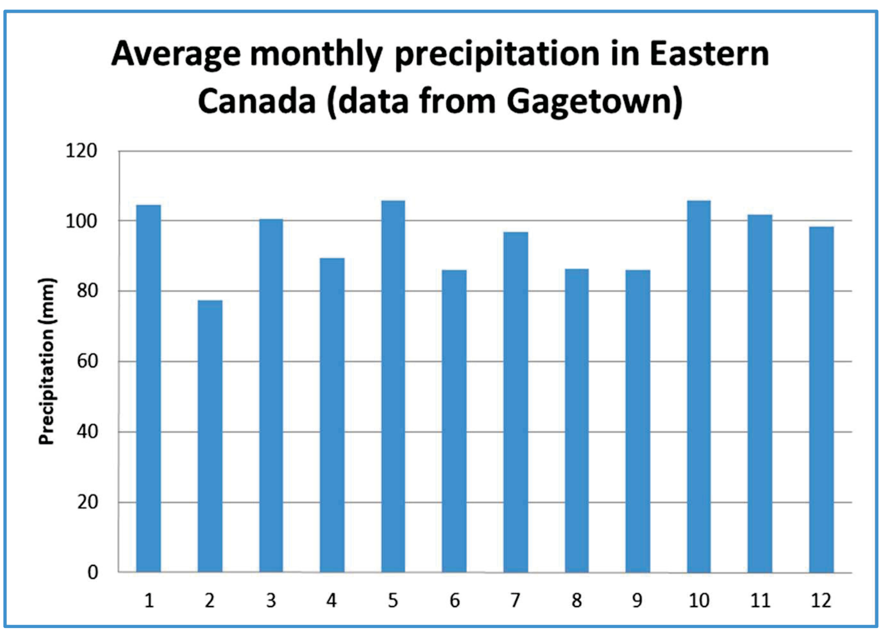
STEP 5. Frequency and timing of sampling

Sampling frequency and timing of the sampling events should be determined on a site specific basis. These need to be fixed by the Defence Establishment Environment Officers, based on the sum of information and field observations available for a given RTA. It should be noted that sampling of high interest sites should be planned as long as active military training is taking place on a RTA.

Surface water

Surface water sampling frequency and timing should be primarily based on site-specific or regional precipitation data. Since precipitation regimes vary greatly across Canada, SW sampling will not be required at a same frequency in all regions of Canada in order to provide an adequate portrait of MC concentration temporal trends.

For example, sampling frequency in the Prairies should be lower than in eastern Canada because of lower precipitation and lower flow rate over the years. Figures 3 highlights the contrast in the precipitation regime of the Prairies vs Eastern Canada regions. In Eastern Canada (Gagetown) average monthly total precipitation always exceeds 70 mm, while this value is only exceeded during the months of June and July in the Prairies (Edmonton).



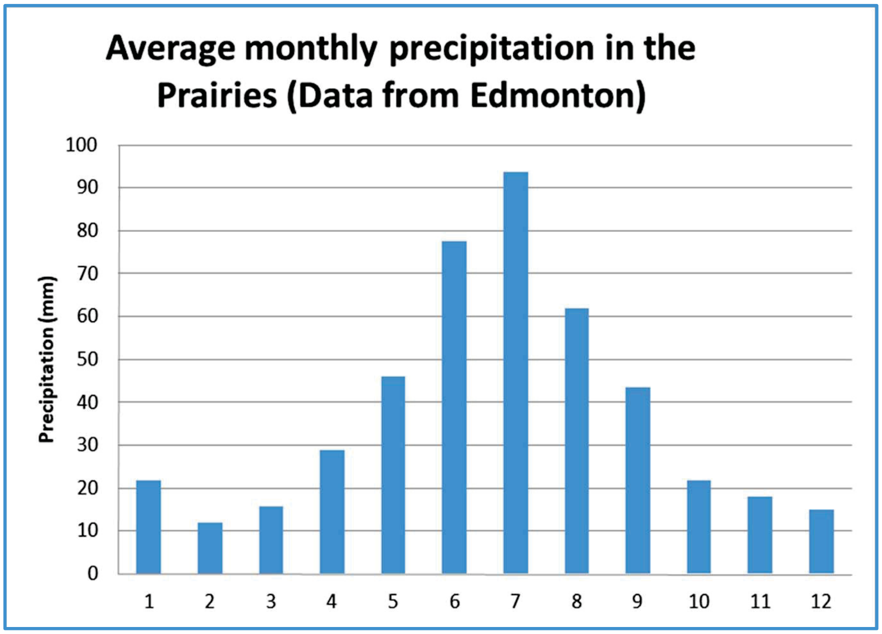


Figure 3 : Average monthly precipitation regime in the Prairies and in Eastern Canada (1 being January and 12 December)

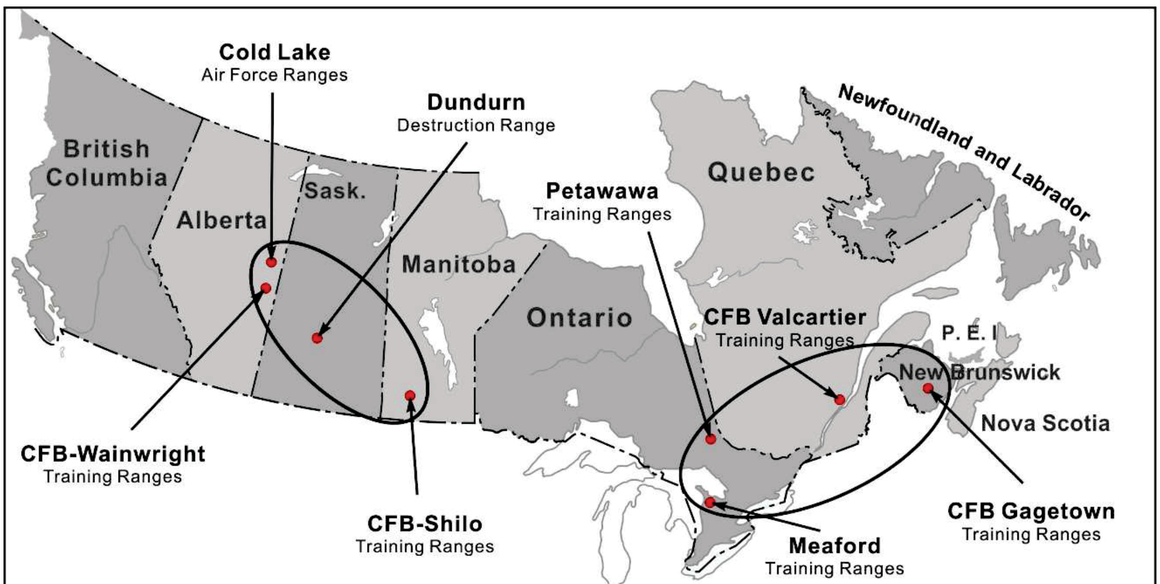
In any case, the different rain falls for each region can be used to modulate surface water quality sampling. In the Prairies, sampling should be intensified during wetter months (e.g. May to Sept), while during drier months sampling frequency can be decreased. For surface water, months where the majority of precipitation falls as snow require minimal sampling, as runoff is usually very low or non-existent. Minimally, for RTAs located under a typical prairie climate, surface water samples at high interest sites should be collected once a year, in July or August. However, this proposed minimal sampling can be refined based on historical result trends.

In Eastern Canada, precipitations are higher than in the Canadian Prairies throughout the year. Again, although precipitation is high during the winter months, the sampling effort should focus on warmer months. Minimally, for RTAs located in Eastern Canada (and coastal BC), surface water samples at high interest sites should be collected twice a year. The first sample should be collected in May or June following the snow melt, and the second one should be collected at the end of the summer (September). However, this proposed minimal sampling can be refined based on historical result trends.

If a particular context requires additional sampling (ex. a receptor at risk), or if available resources allow it, sampling frequency can be increased to provide better temporal MC concentration trends. The ratio of monthly average precipitation to total annual average precipitation can be used as a first crude method to allocate a site-specific sampling frequency. For instance, in the Prairies, total annual average precipitation is 455 mm (1981-2010). Total precipitation in July represents 20% of that amount (93 mm). In contrast precipitation in November in Edmonton only represents 4% of total annual precipitation (18 mm). It can therefore be argued that the likelihood of variable water quality is higher in July than November at this location, and a larger sampling effort should occur in July. In contrast, the figure shows that sampling in Eastern Canada should be spread much more evenly during the ice-free period.

Groundwater

GW sampling frequency and timing should also be determined considering the information provided above for SW sampling. However, the vulnerability of the receptors with regards to groundwater impacts also have to be accounted for. The vulnerability of receptors, which should be identified on the site-specific conceptual model (see Figure 1 above for an example), is mainly controlled by the dissolution rate of the MC source, the water infiltration velocity, the groundwater flow velocity and dilution. Other mechanisms also play a role, such as adsorption onto the porous media or degradation. In any case, water transit times in the saturated zone is a key factor determining receptor's vulnerability to MC contamination. Low transit times in the saturated zone, as observed in Eastern Canada (Figure 4), mean that groundwater travels at a high velocity, thus it has a greater potential of reaching the receptors located in or around RTA.



Prairies - low rain fall	Processes	Eastern Canada - high rain fall
low	Dissolution rate of source	high
low	Infiltration velocity	high
low	Groundwater flow velocity	high
low	Dilution in GW & SW	high

Figure 4 : Hydrological and hydrogeological contexts of Eastern Canada and the Prairies

In eastern Canada (ON, QC, NB), recharge rates (250-400 mm) in surficial deposits (such as sand) is higher, in general, than in the Prairies (AB, SK and MN) (25-80 mm), and receptors in those regions will be more vulnerable to potential impacts. In eastern Canada, higher yearly precipitations also result in higher source dissolution occurring at the soil surface. Coastal BC (ex.

Chilliwack) should be treated with the same approach as eastern provinces, based on the elevated yearly precipitations.

In the Prairies (AB, SK and MN), this situation is reversed (Figure 4). The lower amount of yearly precipitation results in lower source dilution occurring at the soil surface and lower recharge. Finally, the low aquifer transit time impedes diffusion and dilution into groundwater and surface water, and receptors are less vulnerable.

Recharge rates are best determined locally by installing level loggers into selected GW sampling wells. These wells should be located at high interest sampling locations, and screened into the hydrogeological unit of interest. Level loggers should be installed on a long-term basis, and paired with a barometric pressure logger to account for barometric pressure variations. It is recommended to have one pair of loggers (water level and barometric pressure) per RTA. If more than one stratigraphic unit of interest exists, than one pair of loggers should be installed in each unit of interest (ex. A local, surficial aquifer used for livestock watering and a deep regional aquifer used for potable water supply).

Minimal GW sampling frequency at high interest sampling locations and in surficial aquifers follows the same recommendations as SW sampling: twice a year for Eastern provinces and coastal BC, and once a year for the Prairies. However, the timing of the sampling should be based on groundwater recharge data, as collected by level loggers. Samples in a specific hydrogeological unit should be collected when GW levels in this unit are at their highest values, corresponding to the time where recharge is the greatest, usually following the spring recharge (ex. May/June). In the absence of level logger data, historical trends (MC concentrations or water levels) can be used, or the timing of GW sampling can be accorded with the timing of SW sampling. In confined aquifers, since those are generally less vulnerable, collecting one GW sample per year at high interest sites appears sufficient.

Figure 5 shows an example of a hydrograph produced with level logger data at Wainwright CFB. This hydrograph shows GW levels at their highest values around the month of June. In that case, GW sampling should be planned around that period.

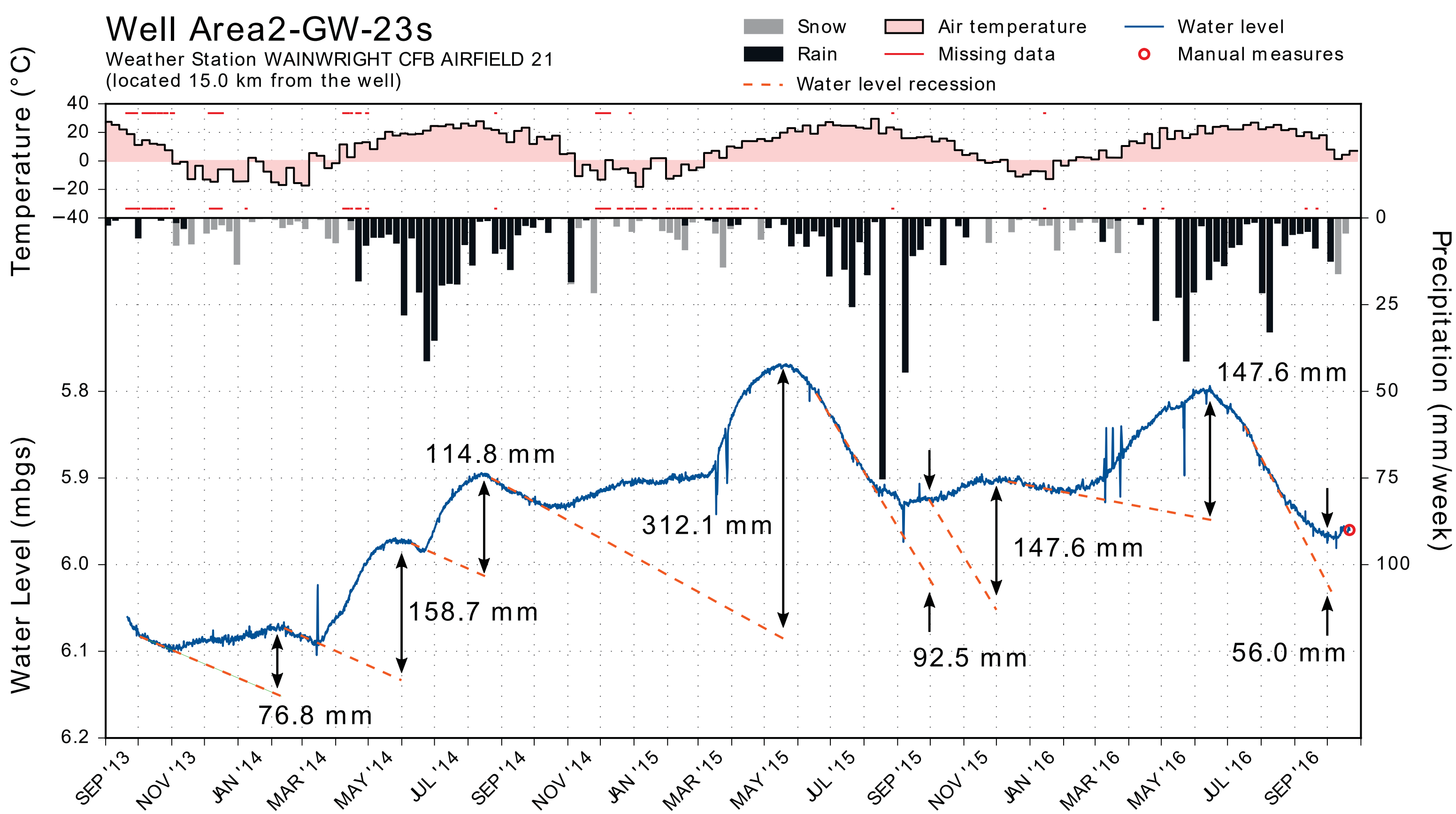


Figure 5. Hydrograph of well "Area2A-GW-23(s)" located at Wainwright CFB.

Additional considerations

- Very mobile products (RDX, CLO_4) are considered a concern all across Canada regardless of the intensity of precipitations, since they are persistent products and persist in groundwater for times long enough to reach receptors even in low-precipitation, low-dissolution and infiltration rates and low groundwater transit times into the saturated zone. On the other hand, HMX, TNT and NG are considered as intermediate mobility products and pose more of a concern in Eastern Canada, where physical factors are more favorable to their dissolution in groundwater and surface water.

- Initial multivariate analyses of water quality measurements taken at two CFBs indicate that sampling twice per year is likely insufficient for many variables showing high variability. In that case, higher frequency sampling (i.e. monthly) should be performed at a limited number of more sensitive stations in order to assess the merit of increased sampling frequency. After two years, statistical tests can be used to determine an optimal site-specific sampling frequency and timing.

- Event-based sampling should also be performed for SW bodies where recharge from runoff is significant. The purpose of such sampling is to assess water quality following significant runoff events during which runoff water has the potential of carrying contaminants of concern into the SW body. These event-based sampling events will ensure that results from the long term monitoring plan are also representative of such conditions where contaminants can be mobilised into surface water bodies. Rain events that warrant additional samplings should be based on such criteria:
    - Forecasted/observed rain amounts are deemed important (e.g. intensity > 5mm/hour and/or daily total > 25mm);
    - Rain that occurs after a very long dry period.

- A sampling point can be removed from the sampling program if a certain number of analysis (e.g. 8 analyses over two years) show that it is stable and not downgradient of a training activity that may leach munition constituent of concern.

- GW sampling frequency can be reduced if two wells, both considered as high interest, are located nearby. The strategy in that case will be to sample one of them alternately at every sampling campaign.

Table 1 : CAO 23-15 water quality reference values for anions and other metals associated with munitions constituents

Munitions Constituent	Symbol	MC Reference Value for Potable Water * (ppb)	Federal interim groundwater quality guidelines for federal contaminated sites (ECCC, rev. 2016) (ppb)	MC Reference Value of Water Quality for the Protection of Aquatic Life ** (ppb)		Notes
			Freshwater life - Fine	*Chronic*	*Acute*	
Metals						
Aluminium	Al	100	ph ≥ 6.5 = 100 ph ≤ 6.5 = 5	ph ≥ 6.5 = 100 ph ≤ 6.5 = 5	-	100 ppb for potable water is not applied to naturally occurring Al but rather is applied to water treatment plants using Al-based coagulants
Antimony	Sb	6	2000	-	-	
Arsenic	As	10	5	5	-	
Barium	Ba	1000	2900	-	-	
Beryllium	Be	-	5.3	-	-	
Bore	B	5000	1500	1500	29000	
Cadmium	Cd	5	Hardness < 17 mg/L = 0.04 Hardness ≥ 17mg/L ≤ 280 mg/L reference value must be calculated (see CCME website) Hardness > 280 mg/L = 0.37	Hardness < 17 mg/L = 0.04 Hardness ≥ 17mg/L ≤ 280 mg/L reference value must be calculated (see CCME website) Hardness > 280 mg/L = 0.37	Hardness < 5.3 mg/L = 0.11 Hardness ≥ 5.3 mg/L ≤ 360 mg/L reference value must be calculated (see CCME website) Hardness > 360 mg/L = 7.7	If hardness unknown use the most strict reference value
Chromium	Cr	50 (Cr total)	8.9 (Cr total)	Cr^{VI} = 1 Cr^{III} = 8.9	-	Potable Water Reference Value is for Total Chromium; however, adverse health effects due to Cr^{VI}
Cobalt	Co	-	-	-	-	
Copper	Cu	1000 (OE)	Hardness < 82 mg/L = 2 Hardness ≥ 82mg/L ≤ 180 mg/L reference value must be calculated (see CCME website) Hardness > 180 mg/L = 4	Hardness < 82 mg/L = 2 Hardness ≥ 82mg/L ≤ 180 mg/L reference value must be calculated (see CCME website) Hardness > 180 mg/L = 4	-	- Aesthetic HC DW Guideline exists (1000 ppb) but not considered a health risk. - Aquatic Toxicity is dependant on [$CaCO_3$]. If hardness unknown use the most strict reference value

Table 1 (continued): CAO 23-15 water quality reference values for anions and other metals associated with munitions constituents

Munitions Constituent	Symbol	MC Reference Value for Potable Water * (ppb)	Federal interim groundwater quality guidelines for federal contaminated sites (ECCC, rev. 2016) (ppb)	MC Reference Value of Water Quality for the Protection of Aquatic Life ** (ppb)		Notes
			Freshwater life - Fine	*Chronic*	*Acute*	
Metals (continued)						
Iron	Fe	300 (OE)	300	300	-	Aesthetic HC DW Guideline exists (300 ppb) but not considered a health risk
Lead	Pb	10	Hardness ≤ 60 mg/L = 1 Hardness > 60 mg/L ≤ 180 mg/L reference value must be calculated (see CCME website) Hardness > 180 mg/L = 7	Hardness ≤ 60 mg/L = 1 Hardness > 60 mg/L ≤ 180 mg/L reference value must be calculated (see CCME website) Hardness > 180 mg/L = 7	-	If hardness unknown use the most strict reference value
Manganese	Mn	50 (OE)	-	-	-	Aesthetic HC DW Guideline exists (50 ppb) but not considered a health risk
Mercury	Hg	1	0.026	0.026	-	
Molybdene	Mo	-	73	73	-	
Nickel	Ni	-	Hardness ≤ 60 mg/L = 25 Hardness > 60 mg/L ≤ 180 mg/L reference value must be calculated (see CCME website) Hardness > 180 mg/L = 150	Hardness ≤ 60 mg/L = 25 Hardness > 60 mg/L ≤ 180 mg/L reference value must be calculated (see CCME website) Hardness > 180 mg/L = 150	-	If hardness unknown use the most strict reference value
Selenium	Se	50	1	1	-	
Silver	Ag	-	0.25 (Ag total)	0.25 (Ag total)	-	
Thallium	Tl		0.8	0.8	-	
Tin	Sn	-	-	-	-	
Titane	Ti	-	100	-	-	
Uranium	U	20	15	15	33	
Zinc	Zn	5000 (OE)	30	30	-	Aesthetic HC DW Guideline exists (5000 ppb) but not considered a health risk

* Guidelines for Canadian Drinking Water Quality (Maximum Acceptable Concentrations), 2014.
** Canadian Council of Ministers of the Envronment (CCME) Water Quality Guidelines for the Protection of Aquatic Life

Table 1 (continued): CAO 23-15 water quality reference values for anions and other metals associated with munitions constituents

Munitions Constituent	Symbol	MC Reference Value for Potable Water (ppb)	MC Reference Value of Water Quality for the Protection of Aquatic Life (ppb)
Energetics/Propellants			
2,4 Dinitrotoulene	2,4-DNT	100[a]	910[d]
2,6 Dintirotoulene	2,6-DNT	40[a]	930[d]
High Melting Explosive	HMX	470[b]	330[e]
Nitroglycerine	NG	5[c]	10[f]
Perchlorate	ClO4-	3[b]	-
Royal Demolition Explosive	RDX	9[b]	236[g]
Trinitrotoulene	TNT	2[c]	120[d]

[a] Health Advisory: Drinking Water Equivalent Level (DWEL) - Drinking Water Standards and Health Advisories (US EPA, 2009)

[b] Health Canada Drinking Water Guidance or Screening Value

[c] Health Advisory: Life-time exposure - Drinking Water Standards and Health Advisories (US EPA, 2009)

[d] Applicable to surface water in the case of groundwater resurgence (unfiltered) - Ministère de la développement durable, environnement et Lutte contre les changements climatiques (MDDELC - Province of Quebec)

[e] Values from Talmage et al. (1999)

[f] Values from Sullivan et al. (1979)

[g] Interim Draft Guideline for the Protection of Aquatic Life (Environment Canada)

Table 1 (continued): CAO 23-15 water quality reference values for anions and other metals associated with munitions constituents

Munitions Constituent	Symbol	MC Reference Value for Potable Water * (ppb)	Federal interim groundwater quality guidelines for federal contaminated sites (ECCC, rev. 2016) (ppb)	MC Reference Value of Water Quality for the Protection of Aquatic Life ** (ppb)		Notes
			Freshwater life - Fine	*Chronic*	*Acute*	
Generals and inorganics parameters						
pH	**pH**	-	*6.5-9*	*6.5-9*	-	
Amoniac	NH_3	-	Variable (21 -231000) *(see factsheet http://ceqg-rcqe.ccme.ca/download/fr/53/)*	Variable (21-231000) *(see table http://st-ts.ccme.ca/fr/index.html?lang=fr&factsheet=5#aql_fresh_concentration)*	-	
Chloride	Cl-	250000 (OE)	*12000*	*120000*	*64000*	
Cyanide	CN^-	200	*5*	*5*	-	
Fluoride	F^-	1500	*120*	*120*	-	
Nitrate	NO_3	45000	*13000*	*13000*	*550000*	
Nitrite	NO_2	3000	*197* [a)]	*197* [a)]	-	[a)] this value corresponds to 0.06 mg N/L
Sulfate	SO_4^{2-}	500000	*100000*	-	-	
Sulfide	H_2S	50	*2*	-	-	

* Guidelines for Canadian Drinking Water Quality (Maximum Acceptable Concentrations), 2014.
** Canadian Council of Ministers of the Envronment (CCME) Water Quality Guidelines for the Protection of Aquatic Life

DOCUMENT CONTROL DATA

*Security markings for the title, authors, abstract and keywords must be entered when the document is sensitive

1. ORIGINATOR (Name and address of the organization preparing the document. A DRDC Centre sponsoring a contractor's report, or tasking agency, is entered in Section 8.) Institut National de la Recherche Scientifique, Centre Eau Terre et Environnement, 490 Rue de la Couronne, Québec, (Québec) G1K 9A9 Canada	2a. SECURITY MARKING (Overall security marking of the document including special supplemental markings if applicable.) CAN UNCLASSIFIED 2b. CONTROLLED GOODS NON-CONTROLLED GOODS DMC A

3. TITLE (The document title and sub-title as indicated on the title page.)

A practical guide for the development of a long-term monitoring program for water quality on canadian armed forces ranges and training areas

4. AUTHORS (last name, followed by initials – ranks, titles, etc., not to be used)

Martel, R.; Robert, T.; Saint-Hilaire, A.; Temgoua Tranquille, A-G.; Deschênes-Rancourt, C.

5. DATE OF PUBLICATION (Month and year of publication of document.)	6a. NO. OF PAGES (Total pages, including Annexes, excluding DCD, covering and verso pages.)	6b. NO. OF REFS (Total references cited.)
June 2018	25	0

7. DOCUMENT CATEGORY (e.g., Scientific Report, Contract Report, Scientific Letter.)

Contract Report

8. SPONSORING CENTRE (The name and address of the department project office or laboratory sponsoring the research and development.)

DRDC – Valcartier Research Centre
Defence Research and Development Canada
2459 route de la Bravoure
Quebec (Quebec) G3J 1X5
Canada

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)	9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)
	W7701-082245/001/QCL, Task authorization 55

10a. DRDC PUBLICATION NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.)	10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)
DRDC-RDDC-2018-C036	

11a. FUTURE DISTRIBUTION WITHIN CANADA (Approval for further dissemination of the document. Security classification must also be considered.)

Public release

11b. FUTURE DISTRIBUTION OUTSIDE CANADA (Approval for further dissemination of the document. Security classification must also be considered.)

12. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Use semi-colon as a delimiter.)

Groundwater; surface water; monitoring; ranges and training areas; energetic materials; metals

13. ABSTRACT/RESUME (When available in the document, the French version of the abstract must be included here.)

This document provides guidance on the development of a long-term range and training area water quality monitoring plan.

Ce document constitue un guide pour l'élaboration d'un plan de surveillance à long terme de la qualité de l'eau dans les secteurs d'entraînement