HUMAN HEALTH RISK ASSESSMENT FOR LEGACY ARSENIC CONTAMINATION AROUND YELLOWKNIFE

FINAL REPORT

ÉVALUATION DES RISQUES POUR LA SANTÉ HUMAINE D'UNE CONTAMINATION À L'ARSENIC RÉSIDUEL DANS LA RÉGION DE YELLOWKNIFE

RAPPORT FINAL

Canada

Government of Northwest Territories
Gouvernement des Territoires du Nord-Ouest

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Les anciennes mines Giant et Con se trouvent à Yellowknife, aux Territoires du Nord-Ouest (TNO), à moins de cinq kilomètres (5 km) du centre-ville. La mine Giant a produit de l'or de 1948 à 1999, et la mine Con, de 1938 à 2003. Le traitement (grillage) du minerai sur les deux sites générait de la poussière contenant de l'arsenic soluble à une forte concentration, et on estime que les deux mines ont rejeté plus de 20 000 tonnes d'arsenic dans l'atmosphère pendant leur exploitation.

Pour répondre aux membres du public et aux gouvernements et organisations autochtones qui se demandaient si la pratique d'activités récréatives et traditionnelles aux alentours des mines Giant et Con exposait les participants à de l'arsenic résiduel, le ministère de l'Environnement et des Ressources naturelles (MERN) des Territoires du Nord-Ouest (TNO) a effectué une évaluation du risque pour la santé humaine (ÉRSH), en collaboration avec le bureau régional des TNO de Relations Couronne-Autochtones et Affaires du Nord Canada (RCAANC).

L'ÉRSH est un processus scientifique utilisé pour décrire et estimer la probabilité de risques (effets néfastes sur la santé) pour les humains découlant de l'exposition à des contaminants environnementaux (produits chimiques). La présente évaluation détermine les principaux produits chimiques en présence, les catégories de personnes exposées et la voie d'exposition. Ces trois facteurs servent à quantifier le risque. À noter que l'évaluation n'examine pas directement les liens de cause à effet relatifs aux problèmes de santé actuels. Ce sont des études épidémiologiques qui ont établi les liens entre l'exposition et ses conséquences sur la santé, notamment par la comparaison des résultats de sondages menés dans une ville ou une population exposée et dans une ville ou une population non exposée. Le Programme de suivi des effets sur la santé de Yellowknife, qui englobe la ville de Yellowknife, la Première Nation des Dénés Yellowknives (PNDY) et l'Alliance des Métis du Slave Nord et qui a publié ses résultats préliminaires au printemps 2019, fait partie de ces études. Le Programme et les résultats de cette ÉRSH aideront l'administratrice en chef de la santé publique à mettre à jour ses directives officielles aux résidents et aux visiteurs concernant les précautions à prendre pour éviter de s'exposer à une concentration élevée d'arsenic dans la région de Yellowknife.

L'objectif de l'ÉRSH est de quantifier les risques de l'exposition à l'arsenic résiduel dans l'environnement chez les gens qui fréquentent les zones entourant Yellowknife, Ndilǫ et Dettah pour leurs activités traditionnelles et récréatives et qui vivent dans des chalets ou des maisons autour des lacs intérieurs de ce secteur. L'exposition des résidents de zones peuplées, dont Yellowknife, Ndilǫ et Dettah, à différents contaminants résiduels est décrite dans l'évaluation des risques pour la santé humaine et l'environnement (ERSHE) du plan d'assainissement de la mine Giant et ne l'est donc pas explicitement dans la présente évaluation. Toutefois, pour la mise en contexte de l'exposition à l'arsenic des personnes vivant dans la région de Yellowknife, les risques individuels indiqués dans l'ERSHE ont été combinés aux risques associés aux activités récréatives et traditionnelles.

Consultation communautaire

Le public et les membres de la PNDY et de l'Alliance des Métis du Slave Nord ont été consultés lors de rencontres en personnes et au moyen d'un sondage en ligne. La démarche visait à créer des scénarios pour l'ÉRSH et à connaître les usages de la terre dans l'aire d'étude. Cette aire couvre les territoires utilisés depuis des temps immémoriaux par la PNDY et depuis moins longtemps par l'Alliance. L'exploitation minière y a modifié les usages de la terre et les secteurs où on les pratique.

Le gouvernement des Territoires du Nord-Ouest (GTNO) a discuté avec les peuples autochtones locaux pour faire en sorte que l'ÉRSH réponde à leurs questions et pour définir les aires qui servent à des activités traditionnelles. Il a également formé un comité consultatif des communications sur les risques pour comprendre les préoccupations de la population et rédiger avec lui des messages et des communications sur les risques en lien avec l'arsenic. La communauté a demandé le prélèvement de tissus supplémentaires de poissons et de petit gibier, ainsi que l'analyse d'échantillons provenant d'yeux, d'organes, de graisse sous-cutanée et de chair de poissons. L'équipe a prélevé d'autres échantillons sur des poissons de lacs situés dans l'aire d'usage traditionnel actuelle (lacs Mason et Duck) et a analysé le tout. Elle a aussi analysé des tissus de rat musqué prélevés aux lacs Duck et Hay et dans d'autres zones de chasse de la baie de Yellowknife. Ces échanges ont amené un élargissement de l'aire d'usage traditionnel. Enfin, des échantillons d'ombre arctique du ruisseau Baker ont été recueillis en 2020, car les peuples autochtones locaux s'inquiétaient des risques liés à la consommation de ce *poisson. L'exposition aux contaminants découlant de cette consommation a fait l'objet d'une analyse distincte.*

Aire d'étude

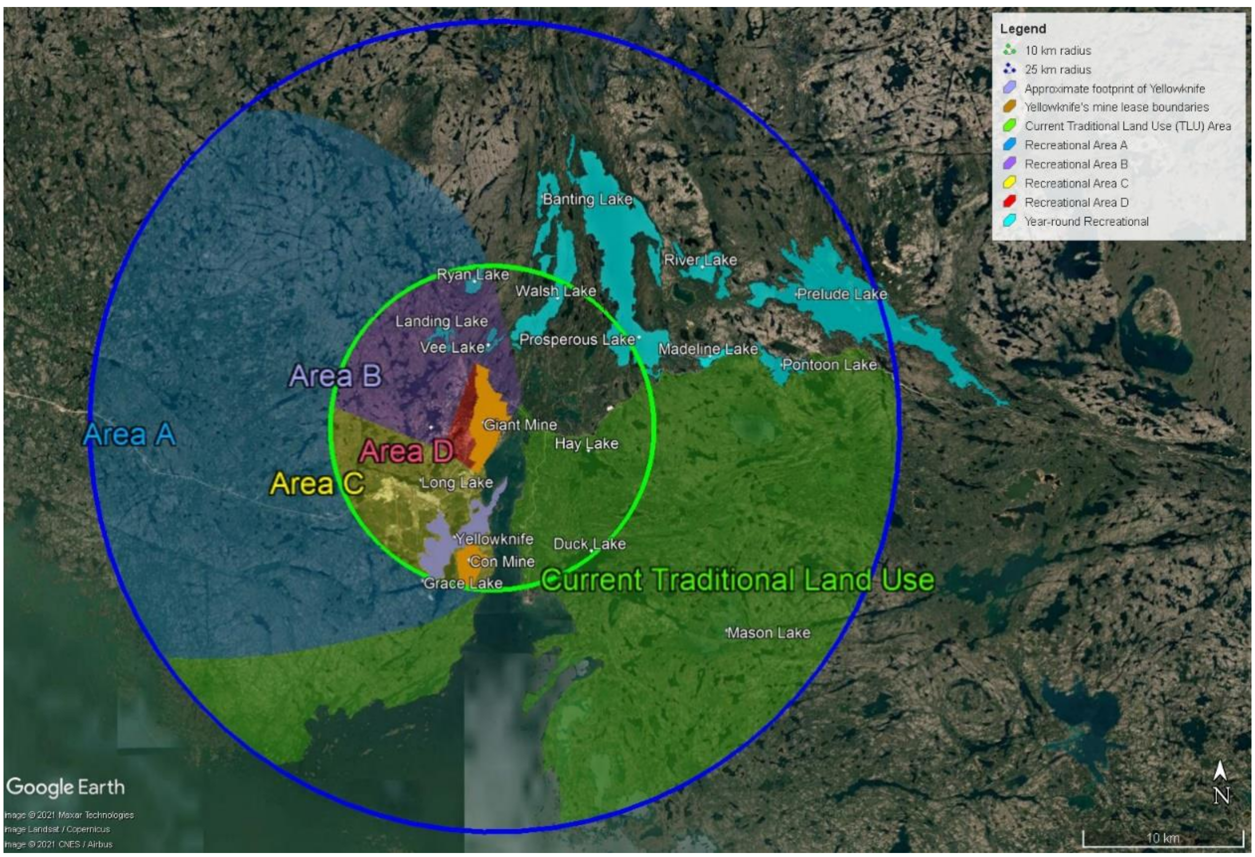
L'aire d'étude de l'ÉRSH comprend les aires d'usage récréatif et traditionnel de la terre situées dans un rayon de 25 km de la mine Giant. Compte tenu des résultats de nombreuses études sur la concentration d'arsenic dans les milieux naturels, les territoires se trouvant à plus de 25 km servent de référence. L'exposition associée à la pratique occasionnelle d'activités récréatives telles que la randonnée, la nage et la pêche a été évaluée dans les quatre secteurs suivants (voir la figure ES.1) :

1. *Secteur A : Zone d'étude de l'ouest, dans un rayon de 10 à 25 km autour du site de la mine Giant. Les peuples autochtones locaux ont signalé pêcher dans de nombreux petits lacs sans nom dans cette région, particulièrement à l'ouest de Yellowknife, le long de la route 3.*
2. *Secteur B : Zone d'étude du nord-ouest, dans un rayon de 10 km autour du site de la mine Giant. Le sondage a révélé que les lacs Martin, Vee et Ryan sont les plus fréquemment visités du secteur. On trouve des chalets ou des maisons aux lacs Landing et Ryan, et une maison-bateau sur le lac Vee.*
3. *Secteur C : Zone d'étude de l'ouest, dans un rayon de 10 km autour du site de la mine Giant, dans les environs de la ville de Yellowknife, et à proximité de la mine Con. Le seul lac du secteur où les répondants ont dit pêcher ou nager était le lac Long.*
4. *Secteur D : Zone située directement à l'ouest et la plus proche du site de la mine Giant, le long de la route Ingraham. Les répondants utilisent relativement peu cette zone, et y pratiquent principalement la randonnée et la course.*

L'ÉRSH s'est aussi penchée sur l'exposition en contexte récréatif durant toute l'année des personnes vivant dans des chalets ou des maisons autour des lacs intérieurs de l'aire d'étude (lacs Vee, Landing, Ryan, Walsh, Banting, Prosperous, Madeline, Pontoon, Prelude et River). Il faut cependant préciser que ces lacs, à l'exception des lacs Vee, Landing et Ryan, se situent hors de la zone considérée comme sujette à l'influence de la contamination résiduelle. L'emplacement de chacun est représenté à la figure ES.1.

Une aire d’usage traditionnel de la terre par les peuples autochtones locaux a été trouvée dans un rayon de 25 km de la mine Giant, au sud-est (figure ES.1). Les gens ont déclaré qu’ils pêchaient dans les lacs Duck et Mason et qu’ils se livraient à la récolte dans les environs de ces deux lacs et du lac Hay. La pêche a généralement lieu en hiver, quand l’accès aux lacs est facilité. La consultation a aussi révélé que la zone au sud-ouest de la mine Con servait pour des activités traditionnelles; c’est pourquoi elle a été incluse dans l’aire d’usage traditionnel visée par l’évaluation. L’examen de l’exposition occasionnelle (secteurs A à D) et durant toute l’année (lacs intérieurs ayant des maisons ou des chalets sur leurs rives) dans les aires d’usage récréatif englobe également les activités traditionnelles qui y sont menées par les peuples autochtones locaux.

Figure ES.1 ***Aire d’étude de l’évaluation du risque pour la santé humaine***



Résumé de l’information disponible

Plusieurs études menées par des chercheurs indépendants, des ministères et des universités ont déjà eu lieu dans l’aire d’étude, dont le programme volontaire sur les aliments traditionnels, créé en 2016 et 2017 avec la PNDY, l’Alliance des Métis du Slave

Nord et d'autres membres de la collectivité yellowknifienne comme appui à l'évaluation des risques pour la santé humaine et l'environnement (ERSHE) du plan d'assainissement de la mine Giant. Le GTNO a fait d'autres prélèvements d'eaux de surface, de sédiments, de tissus de poissons et de tissus de rat musqué en 2018, 2019, 2020 et 2021 pour pallier les données jugées manquantes selon une procédure d'examen et la consultation communautaire.

Évaluation du risque pour la santé humaine

L'ÉRSH a suivi les directives de Santé Canada et examiné les conditions actuelles dans l'aire d'étude. Un processus de dépistage a montré que l'arsenic et l'antimoine étaient les principaux contaminants présents. L'équipe a aussi quantifié le mercure chez les poissons des lacs intérieurs parce qu'on sait que les petits lacs nordiques comme le lac Pocket ont une concentration élevée de mercure et parce que le ministère de la Santé et des Services sociaux des TNO s'intéressait à la concentration de mercure dans le poisson.

L'ÉRSH a examiné les risques de l'exposition à l'arsenic et à l'antimoine chez les personnes qui chassent, qui récoltent des plantes et qui participent à des activités extérieures comme la course, la randonnée et la nage dans les aires d'usage récréatif étudiées. L'exposition découlant de la consommation régulière de poissons et d'eau potable provenant de lacs intérieurs dans la région a également été prise en compte, tout comme les risques de l'exposition durant toute l'année des personnes qui habitent des maisons ou des chalets à proximité des lacs intérieurs du secteur.

Adoptant une approche à plusieurs milieux, l'évaluation a étudié toutes les voies d'exposition pertinentes : sol, poussière intérieure, sédiments, eau, aliments traditionnels et aliments achetés au supermarché. Elle a aussi tenu compte des niveaux d'exposition de référence. La figure ES.2 montre les voies d'exposition (façons dont les gens sont exposés) examinées.

Figure ES.2 Voies d'exposition étudiées dans l'évaluation du risque pour la santé humaine

À la demande du ministère de l'Infrastructure des TNO, l'équipe a évalué les risques de l'exposition potentielle à l'arsenic dans le sol pour les personnes qui travaillent en plein air le long de la route Ingraham (la route 4), entre Yellowknife et la rivière Yellowknife.

Résultats

Le risque que l'exposition à l'antimoine dans l'aire d'étude ait un effet sur la santé autre que cancérogène est négligeable.

L'arsenic s'est avéré la principale préoccupation du point de vue de la santé et causerait le cancer. C'est pourquoi l'ÉRSH a mesuré l'augmentation du risque dans la région, par rapport au niveau de référence, que cause l'exposition à l'arsenic contenu dans le sol, la poussière intérieure (chalets et maisons), l'eau, les sédiments et les aliments traditionnels. Voici ses conclusions à ce sujet :

- *La pratique occasionnelle d'activité d'activités récréatives (randonnée, course, nage, etc.) et traditionnelles pose un risque très faible à faible (comme passer* *chaque année une radiographie dentaire ou thoracique ou une tomodensitométrie partielle) et peut être maintenue en toute sécurité.*

- *Vivre au bord d'un lac intérieur de l'aire d'étude et manger des aliments provenant des environs pose également un risque très faible.*
- *L'eau des lacs dont la concentration d'arsenic ne dépasse pas les recommandations pour la qualité de l'eau potable, comme celle des lacs Walsh, Banting, Prosperous, Madeline, Pontoon, Prelude, River, Hay, Duck et Mason, est salubre à condition d'être bouillie ou traitée.*
- *Il ne faut pas boire l'eau des lacs Landing et Ryan puisque la concentration d'arsenic y dépasse les recommandations pour la qualité de l'eau potable.*
- *La consommation de grand corégone des lacs de l'aire d'étude pose un risque très faible.*
- *La population peut consommer les yeux, la peau, la couche de graisse et les organes des poissons vivant dans les lacs intérieurs, car les risques pour la santé sont très faibles.*
- *Manger environ trois grands brochets du lac Ryan par année représente un risque très faible, et en manger le double, un risque faible.*
- *Parmi les poissons du lac Mason, il est moins risqué de manger du grand corégone ou de la truite que du grand brochet ou de la lotte.*
- *Les baies de la région de Yellowknife sont propres à la consommation.*
- *Les champignons cueillis à plus 10 km des sites miniers sont comestibles, sauf ceux de la famille des* Tricholomataceae*, y compris le tricholome à grand voile (matsutake), les champignons clitocybes et l'armillaire pesant, qui doivent avoir poussé à plus de 25 km des mines.*

L'administratrice en chef de la santé publique s'est intéressée à la présence de mercure dans le poisson et a demandé à ce que l'ÉRSH l'évalue. Les analyses ont démontré que la concentration de mercure dans les poissons de tous les lacs intérieurs se situait sous la limite maximale de Santé Canada pour la vente au détail, qui est de 0,5 mg/kg en poids humide, sauf un échantillon provenant d'un gros spécimen de grand brochet du lac Mason et 14 des 18 échantillons de grands brochets du lac Martin inférieur. Aucun des tissus de grands corégones vivant dans le lac Martin inférieur ne dépassait la limite de Santé Canada pour la vente au détail. Par conséquent, l'administratrice en chef de la *santé publique a émis un avis concernant la consommation de grands brochets du lac Martin inférieur.*

Selon l'analyse distincte de l'exposition à l'arsenic dans l'ombre arctique menée pour répondre au questionnement des peuples autochtones locaux, la consommation d'ombres arctiques du ruisseau Baker ne présente pas de risque pour la santé, et la population peut continuer à manger les poissons de cette espèce pêchés dans la région de Yellowknife.

L'évaluation concernant les personnes qui travaillent le long de la route Ingraham (la route 4) révèle que les risques de l'exposition à l'arsenic dans la terre lors de l'exécution de différents travaux routiers à proximité de la mine Giant sont négligeables. Les ouvriers devraient tout de même suivre des pratiques de travail sûres, y compris le port d'équipement de protection individuelle et l'utilisation d'équipement de sécurité, selon les exigences de l'employeur. De plus, le port de gants limite davantage l'exposition dermique à l'arsenic contenu dans le sol.

EXECUTIVE SUMMARY

The Giant and Con Mine sites are located in Yellowknife, Northwest Territories (NT), within five kilometers (5 km) of the city center. The former Giant Mine produced gold from 1948 until 1999, while the former Con Mine produced gold from 1938 and 2003. The processing (roasting) of ore at the two sites produced dust containing high levels of soluble arsenic, and it is estimated that more than 20,000 tonnes of arsenic were released to the atmosphere during the operation of the mines.

A human health risk assessment (HHRA) was completed in response to concerns raised by members of the public and Indigenous governments and organizations regarding exposure to legacy arsenic contamination from participating in recreational and traditional activities in areas surrounding the Giant and Con Mine sites. This HHRA was led by the Government of the Northwest Territories Department of Environment and Natural Resources (GNWT ENR) in partnership with the NT Regional Office of Crown Indigenous Relations and Northern Affairs Canada (CIRNAC).

An HHRA is a scientific process used to describe and estimate the likelihood of potential risks (i.e., adverse health effects) to humans resulting from exposure to environmental contaminants (i.e., chemicals). The risk assessment is used to determine what the chemicals of importance are, who is being exposed, and how they are being exposed. All three of these components are considered in the assessment of risk. It should be noted that the HHRA does not provide a direct assessment of cause and effect concerning current health problems or effects. Any link between exposure and actual health effects comes from epidemiological studies, which include surveys of health problems in a community, and compares them to health problems in other cities and populations where the same type of exposure does not occur. The Yellowknife Health Effects Monitoring Program (YKHEMP) that has been established for the City of Yellowknife, the Yellowknives Dene First Nation (YKDFN) community, and the North Slave Métis Alliance (NSMA) and which released its baseline findings in spring of 2019, is a component of these epidemiological studies. The findings from this HHRA, in conjunction with the YKHEMP, will inform future updates to official advice from the Chief Public Health Office to residents and visitors about precautions they can take to avoid exposure to elevated arsenic around Yellowknife.

The objective of this HHRA is to quantify the risks from exposure to legacy arsenic contamination in the environment for people using the areas around Yellowknife, Ndilǫ, and Dettah for traditional and recreational activities, as well as living in cabins or houses on inland lakes in the area. Exposures from legacy contamination to people living in populated areas, including the City of Yellowknife, Ndilǫ, and Dettah, were presented in the Giant Mine Remediation Plan Human Health and Ecological Risk Assessment (GMRP HHERA) and were therefore not evaluated explicitly in the current assessment; however, to provide context to arsenic exposure associated with living in the Yellowknife area, the risks from the GMRP HHERA for a resident were added to the risks associated with recreational and traditional activities.

Community Engagement

Engagement with the public and members of the YKDFN and NSMA was conducted at in-person meetings and through an on-line survey to develop scenarios for the HHRA and to understand the land uses in the study area. The study area covers lands used by the

YKDFN since time immemorial and more recently by the NSMA. The mining activities in the area changed the ways and areas in which the land was used.

The GNWT has also been involved in discussions with local Indigenous peoples to ensure that their concerns are addressed in this HHRA and to aid in defining the areas used for current traditional activities. In addition, the GNWT formed a Risk Communications Advisory Committee to understand community concerns and to work together on addressing messaging and communications on risks related to arsenic. Concerns were raised related to collection of additional fish and small game samples and to analyze fish eyes, organs, and the fatty layer under the skin as well as the flesh. Additional fish samples were collected from lakes in the current Traditional Land Use (TLU) area (Mason and Duck lakes) and the different tissues were analyzed. In addition, muskrat samples were collected and analyzed from Duck Lake, Hay Lake, and other harvesting areas in Yellowknife Bay. The current TLU area was also expanded based on these discussions. Furthermore, samples of Arctic grayling from Baker Creek were collected in 2020 in response to concerns from local Indigenous peoples about the risk of eating Arctic grayling. A separate analysis has been completed to evaluate exposure from eating Arctic grayling.

Study Area

The study area considered in the HHRA was defined to include recreational and traditional land use areas within a 25 km radius of the Giant Mine site. Based on the results of numerous studies on concentrations of arsenic in environmental media, areas outside of 25 km are considered to be at background. Exposures associated with occasional recreational activities such as hiking, swimming, and fishing were evaluated at the following four different subareas (see Figure ES.1):

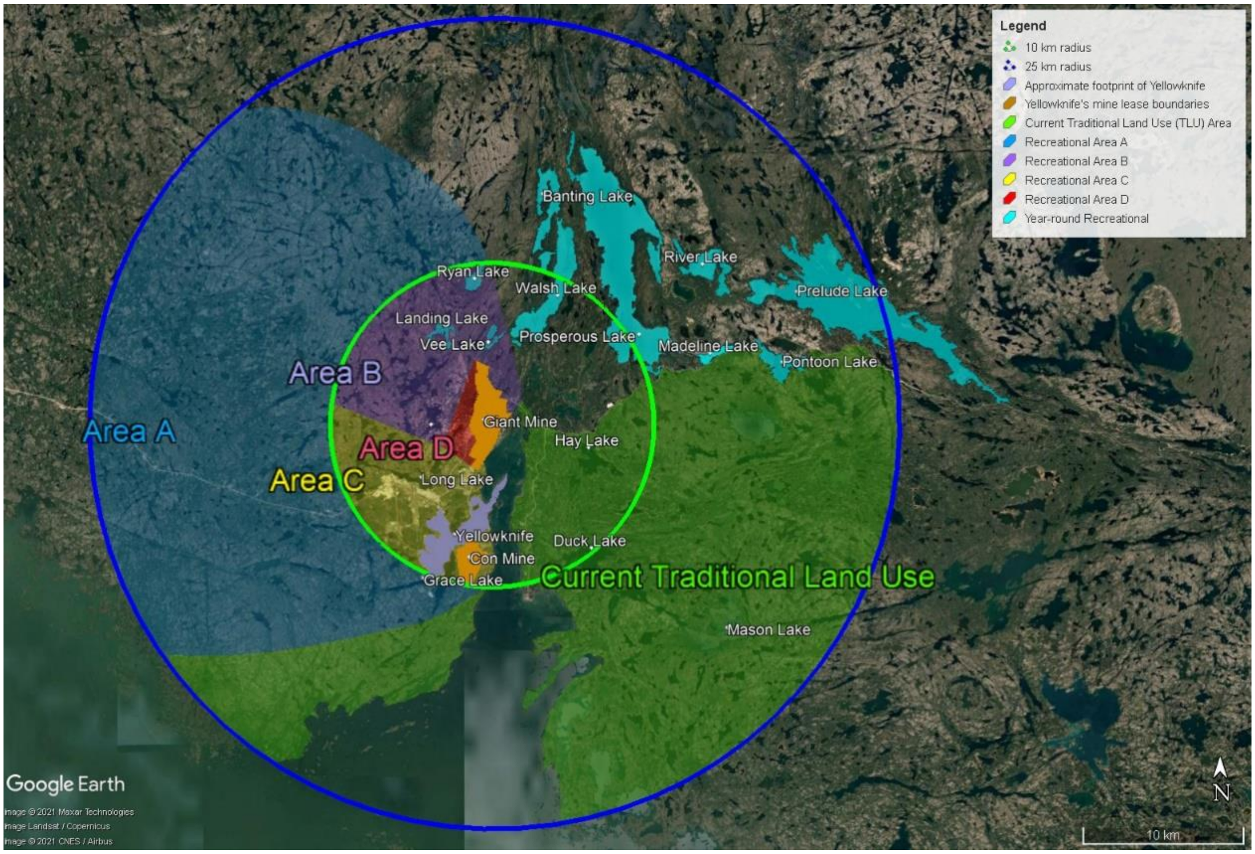
5. *Area A: The western study area within a 10 km to 25 km radius of the Giant Mine site. Local indigenous peoples reported fishing in many of the small unnamed lakes in this area, particularly west of Yellowknife along Highway 3.*
6. *Area B: The northwestern study area, within a 10 km radius of the Giant Mine site. The survey results indicated that Martin, Vee, and Ryan lakes are the most commonly visited lakes in this area. There are also cabins and/or houses on Landing and Ryan lakes, and a houseboat on Vee Lake.*

7. *Area C: The western study area within a 10 km radius of the Giant Mine site, surrounding the City of Yellowknife and close to Con Mine. The only lake in which respondents reported fishing from or swimming in within this area is Long Lake.*
8. *Area D: The area directly west of and closest to the Giant Mine site along the Ingraham Trail. Survey respondents reported relatively low use of this area, limited mainly to hiking and running.*

The HHRA also evaluated year-round recreational exposure to residents of houses and/or cabins on inland lakes in the study area (i.e., Vee, Landing, Ryan, Walsh, Banting, Prosperous, Madeline, Pontoon, Prelude, and River lakes); however, it should be noted that these lakes, with the exception of Vee, Landing, and Ryan lakes, are outside of what is considered to be the area influenced by legacy contamination. The lakes are shown in Figure ES.1.

A specific traditional land use (TLU) area was identified within a 25 km radius to the southeast of the Giant Mine site where current traditional land uses by local Indigenous peoples occur (Figure ES.1). People said that they fish in and harvest around Duck and Mason lakes, and harvest around Hay Lake. Fishing generally occurs in the winter time when the lakes are easier to access. The area to the southwest of Con Mine was also identified during engagement as an area used for traditional activities; therefore, it was included in the definition of the current TLU area for the purposes of the assessment. The consideration of occasional (areas A through D) and year-round (inland lakes with houses/cabins) exposures in the recreational area also encompasses local Indigenous peoples who would conduct traditional activities in those areas.

Figure ES.1 ***Study area for the human health risk assessment***



Summary of Available Information

There have been a number of investigations in the study area by independent researchers, government departments, and universities, including the voluntary country foods program that was initiated with the YKDFN, NSMA, and other members of the Yellowknife community in 2016 and 2017 in support of the Giant Mine Remediation Plan Human Health and Ecological Risk Assessment (GMRP HHERA). Additional sampling of surface water, sediment, fish, and muskrat was completed by the GNWT in 2018, 2019, 2020, and 2021 to infill any data gaps identified through the community engagement and a data gaps review.

Human Health Risk Assessment

The HHRA followed guidance outlined by Health Canada and addresses current conditions in the study area. Arsenic and antimony were identified as the key contaminants through a screening process. Mercury was considered in the assessment *for fish from inland lakes since higher concentrations of mercury are known to occur in small northern lakes such as Pocket Lake and GNWT Health and Social Services was interested in mercury concentrations in fish.*

The HHRA considered risks from exposure to arsenic and antimony to people hunting, harvesting, and participating in outdoor activities such as running, hiking, and swimming in the identified recreational areas. Exposure from eating fish and periodically drinking water from inland lakes in the area were also considered. Risks were also evaluated for year-round exposure to people living at inland lakes in the area with houses or cabins.

The HHRA took a multi-media approach, which considered exposure from all relevant environmental pathways such as soil, indoor dust, sediment, water, country foods, and supermarket foods. Background exposures were also taken into account in the assessment. Figure ES.2 shows the ways that people are exposed (exposure pathways) that were considered in the assessment.

Figure ES.2 Exposure pathways for the human health risk assessment

At the request of the GNWT Department of Infrastructure, an additional evaluation was also completed for potential risks to outdoor workers that may be exposed to arsenic in soil along the Ingraham Trail/Highway 4, between Yellowknife and the Yellowknife River.

Results

The risks for non-carcinogenic health effects from exposure to antimony in the study area were examined and found to be negligible.

Arsenic was identified as the key concern from a health perspective and it is considered to cause cancer; therefore, the risk assessment evaluated the incremental, above-background, risk from exposure to arsenic in soil, indoor dust (in cabins/houses), water, sediment, and country foods in the area. The results of this assessment for arsenic demonstrate that:

- *occasional recreational (for example hiking, running, swimming) and traditional activities represent risks in the very low to low risk range (equivalent to having dental and chest x-rays or a partial CT scan on an annual basis) and can safely continue;*
- *living on the inland lakes in the study area and eating food from the area also represents a very low risk;*
- *drinking water from lakes with arsenic concentrations below the drinking water guideline, such as Walsh, Banting, Prosperous, Madeline, Pontoon, Prelude, River, Hay, Duck, and Mason lakes, is safe as long as you boil or treat the water;*
- *people should not drink water from Landing and Ryan lakes as the arsenic concentrations are above the drinking water guideline;*
- *eating lake whitefish from lakes in the study area represents a very low risk;*
- *people can eat the eyes, skin/fatty layer, and organs of fish from inland lakes as it represents a very low risk;*
- *eating about 3 northern pike in a year from Ryan Lake represents a very low risk which increases to a low risk if you eat twice as much;*
- *a lower risk is associated with eating whitefish or trout from Mason Lake than from eating northern pike and burbot from the lake;*
- *berries collected around the Yellowknife area are safe to eat; and*

- *mushrooms can be eaten outside of 10 km from the legacy mining areas with the exception of mushrooms from the Tricholomataceae family including pine mushrooms (tricholoma), common funnel mushrooms (clitocybe), and white mushrooms (matsutake) which should only be consumed if collected from greater than 25 km from the legacy mining areas.*

The Chief Public Health Office identified mercury as a constituent of interest in fish and requested that it be evaluated in the HHRA. The study determined that mercury in fish in all of the inland lakes was below the Health Canada Maximum limit of 0.5 mg/kg wet weight (ww) for retail fish with the exception of 1 large northern pike sample from Mason Lake and 14 out of 18 northern pike samples in Lower Martin Lake. All lake whitefish samples in Lower Martin Lake were below the Health Canada Maximum Limit for retail fish. The Chief Public Health Office has issued an advisory for eating northern pike in Lower Martin Lake.

The separate analysis of exposure to arsenic in Arctic grayling that was conducted in response to concerns from local Indigenous peoples found that exposure to arsenic from eating Arctic grayling from Baker Creek does not represent a health concern and that people can continue to eat Arctic grayling caught in the Yellowknife area.

The results of the separate evaluation of workers exposed along the Ingraham Trail/Highway 4 indicate there are negligible risks from exposure to arsenic in soil while conducting various roadwork activities in the vicinity of the Giant Mine. Workers should nonetheless follow safe work practices, including the use of personal protection and safety equipment as required by the employer. The use of gloves on the job will further minimize the dermal exposure to arsenic in soil.

LIST OF ACRONYMS

CCME	Canadian Council of Ministers of the Environment
COPC	Constituent of Potential Concern
CSM	Conceptual Site Model
DMA	Dimethylarsinic Acid
DWQG	Drinking Water Quality Guideline
ECCC	Environment and Climate Change Canada
ENR	Environment and Natural Resources
EPC	Exposure Point Concentration
FAO	Food and Agriculture Organization of the United Nations
FCSAP	Federal Contaminated Sites Action Plan
GMRP	Giant Mine Remediation Plan
GNWT	Government of Northwest Territories
GNWT HSS	Government of Northwest Territories Health and Social Services
GSC	Geological Survey of Canada
HHERA	Human Health and Ecological Risk Assessment
HHRA	Human Health Risk Assessment
INAC	Indigenous and Northern Affairs Canada
IRIS	Integrated Risk Information System
MDL	Method Detection Limit
ML	Maximum Level
MMA	Methylarsonic Acid
NSMA	North Slave Métis Alliance
NT	Northwest Territories
RAF	Relative Absorption Factor
TLU	Traditional Land Use
TRV	Toxicity Reference Value
U.S. EPA	Environmental Protection Agency
WHO	World Health Organization
YGB	Yellowknife Greenstone Belt
YKDFN	Yellowknives Dene First Nation
YKHEMP	Yellowknife Health Effects Monitoring Program

GLOSSARY

Term	Description
Background	The typical level of a chemical present in naturally occurring or uncontaminated areas. For example, background concentrations of arsenic and other metals are higher in Yellowknife due to the geology of the area.
Bioavailability	The fraction of an administered dose that reaches the central blood compartment from the gastrointestinal tract.
Bioaccessibility	The quantity or fraction, which is released from the food matrix in the GI tract and becomes available for absorption.
Cancer	A disease that happens when cells in the body begin to grow and multiply out of control.
Carcinogen	An agent that has the potential to cause cancer.
Cautious	As used in the term cautious estimates, this is considered a pessimistic or an over-estimate of the level, effect or hazard, as the case may be.
Constituent	A substance that has the potential to alter the natural composition of air, water or soil.
Dermal	Refers to skin.
Dose	The amount of a substance to which a person is exposed over some time period. Dose is a measurement of exposure.
Exposure	The amount of a pollutant (chemical) present in a given environment that represents a potential health threat to living organisms.
Exposure Pathway	The path from sources of COPC via air, soil, water, or food to man and other species or settings.
Human Health Risk Assessment	The evaluation of whether there is likely to be an adverse health effect caused by the potential exposure to COPC in the environment.
Ingestion	Refers to swallowing.
Inhalation	Refers to breathing in air into the lungs.
Lifetime receptor	A theoretical person representing all life stages from infant to an adult, which is used to assess the risk of developing cancer. The lifetime receptor is used because often it takes a long time between exposure to a chemical and the development of cancer.
Oral	Refers to the mouth.
Pathway	The physical course a chemical or pollutant takes from its source to the exposed organism.

Receptor	A human exposed to a COPC released to the environment.
Risk	A measure of the probability that damage to life, health, property, and/or the environment will occur as a result of a given hazard.
Risk Assessment	Qualitative and quantitative evaluation of the risk posed to human health and/or the environment by the actual or potential presence and/or use of specific COPC.
Uncertainty	A quantitative expression of error.

1.0 INTRODUCTION

In 2018, Canada North Environmental Services Inc. (CanNorth) completed the Giant Mine Remediation Plan Human Health and Environmental Risk Assessment (GMRP HHERA), which evaluated the potential current and future (post-remediation) risks to people and wildlife from exposure to arsenic and other constituents from the Giant Mine site (CanNorth 2018). From a human health perspective, the evaluation focused on residents of Ndilǫ, Dettah, Latham Island, Ingraham Trail, and the City of Yellowknife in the Northwest Territories (NT) and considered exposure from air, dust, soil, sediment, water, country foods, and supermarket foods.

CanNorth was retained by the Government of Northwest Territories (GNWT) in cooperation with the Government of Canada to complete a human health risk assessment (HHRA) for areas around Yellowknife that were not considered in the GMRP HHERA. This assessment is in response to concerns raised by members of the public regarding legacy arsenic contamination in these areas.

The HHRA evaluated exposures of people to legacy contamination in soils, sediments, surface water, berries, mushrooms, medicinal plants, fish, and game in areas surrounding the Giant and Con Mine sites. The exposures were used to evaluate potential risks to people frequenting the areas around Yellowknife, Ndilǫ, and Dettah for traditional and day use activities, as well as living in cabins or houses on inland lakes.

1.1 Overview

The Giant Mine site is located about five kilometers (5 km) north of the Yellowknife city center, while the Con Mine site is located approximately two kilometers (2 km) south. Ore processing activities at the Giant Mine between 1948 and 1999 and at the Con Mine between 1938 and 2003, related to the extraction of gold, resulted in the creation of arsenic-bearing materials that were deposited in the surrounding terrestrial and aquatic environments through tailings spills and roaster stack emissions (Jamieson et al. 2017).

During the first three years of operation (1948 to 1951), roasting of arsenopyrite ore at the Giant Mine to aid in gold extraction led to the uncontrolled release of arsenic trioxide to the atmosphere. With the installation of emission control technologies in 1951, arsenic emissions were gradually reduced over time; however, it is estimated that more than 20,000 tonnes of arsenic were released to the atmosphere during the operation of the Giant Mine. These airborne emissions resulted in wide-spread contamination in the area. The winds predominantly were from the south and east resulting in contamination in the environment to the west and northwest of the mines (Palmer et al. 2015).

Roasting of ore was less common at Con Mine, and much of the arsenic trioxide generated was captured, treated onsite, and integrated with the tailings or sold and shipped. However, it has been estimated that 2,500 tonnes of arsenic was not captured by emission control technologies during the early years of production (1948 to 1970) and was released to the surrounding environment (Palmer et al. 2015).

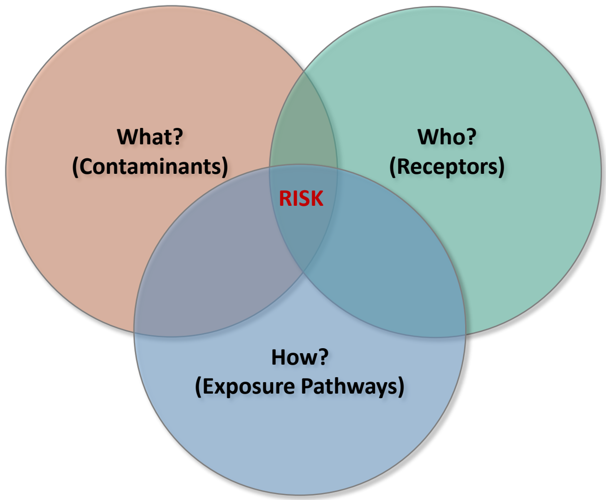
1.2 Definition of a Human Health Risk Assessment

An HHRA is a scientific process used to describe and estimate the likelihood of potential risks (i.e., adverse health effects) to humans resulting from exposure to environmental contaminants (i.e., chemicals). Figure 1.1 demonstrates that HHRA is a stepwise process to answer the following questions:

- What are we concerned about? What are the chemicals of concern?
- Who is being exposed?
- How are they being exposed? What are the exposure pathways?

All three of these components must be present in order for there to be a risk. It should be noted that the HHRA does not provide a direct assessment of cause and effect concerning current health problems or effects. Any link between exposure and actual health effects comes from epidemiological studies, which include surveys of health problems in a community, and compares them to health problems in other cities and populations where the same type of exposure does not occur. The Yellowknife Health Effects Monitoring Program (YKHEMP) within the Yellowknives Dene First Nation (YKDFN) communities of Ndilǫ and Dettah, the City of Yellowknife, and the North Slave Métis Alliance (NSMA), which released its baseline findings in the spring of 2019 (Cheung et al. 2020), is a component of these epidemiological studies. The findings from the this HHRA, in conjunction with the YKHEMP, will inform future updates to official advice from the Chief Public Health Office to residents and visitors about precautions they can take to avoid exposure to elevated arsenic around Yellowknife.

Figure 1.1 Schematic of risk assessment process



1.3 Review of GMRP HHERA

The GMRP HHERA (CanNorth 2018) evaluated risks to residents of Ndilǫ, Dettah, Latham Island, Ingraham Trail, and the City of Yellowknife from exposure to arsenic and antimony where they lived as well as from eating fish, game, berries, mushrooms, and medicinal plants from around the Yellowknife area.

The results of the GMRP HHERA demonstrated that:

- people can drink water from Back Bay and Yellowknife Bay as long as it is boiled or treated first;
- soil from around houses is the largest source of exposure and represents a negligible to a very low risk to people living in Yellowknife, along the Ingraham Trail, and Dettah and a low risk to people living in Ndilǫ;
- fish caught in Back Bay and Yellowknife Bay are safe to eat as they represent a negligible risk;
- berries collected in Ndilǫ and around the Yellowknife area are safe to eat;
- the practice of gathering plants for traditional medicines in the Yellowknife area can safely continue;
- traditional activities in the study area can safely continue and represent a low risk;

- wading in the shallow water/sediments around Latham Island, Ndilǫ, Dettah represents a negligible risk;
- camping in Fred Henne Park and swimming and wading in Long Lake can safely continue; and
- mushrooms can be eaten outside of 10 km from the legacy mining areas with the exception of mushrooms from the *Tricholomataceae* family including pine mushrooms (*tricholoma*), common funnel mushrooms (*clitocybe*), and white mushrooms (*matsutake*) which should only be consumed if collected from greater than 25 km from the legacy mining areas.

1.4 Objective and Scope

The GMRP HHERA did not evaluate potential exposures and risks to people from participating in recreational and traditional activities in the area. Thus, the current HHRA was conducted in response to concerns raised by members of the public regarding exposure to legacy arsenic contamination in the Yellowknife area.

The original scope of the assessment was to examine the legacy arsenic contamination around the Giant Mine site but the scope was expanded to include legacy arsenic contamination associated with the Con Mine site based on feedback from the public. In particular, there is an interest in the general area that would have been in the direction of the windblown contaminant plume from the mines, primarily to the west and northwest of Yellowknife (see Appendix E), as well as inland lakes with cabins/houses and the area that the YKDFN has specified they use for traditional activities (traditional land use [TLU] area). Previous studies have shown that arsenic concentrations in sediment (Galloway et al. 2015), surface water (Houben et al. 2016), and soil (Jamieson et al. 2017) are a function of distance and direction from the Mine sites, and the 2018 GMRP HHERA (CanNorth 2018) demonstrated that concentrations are essentially at background levels at a distance of 25 km from the Giant Mine site. Thus, the area within a 25 km radius of the Giant Mine site captures potential legacy contamination.

Occasional exposure from various outdoor recreational activities such as hiking, camping, swimming, and fishing within the 25 km radius of the Giant Mine site were evaluated, including the specific TLU area identified by the YKDFN to the south of Con Mine and to the east of Yellowknife (which includes Hay, Duck, and Mason lakes).

Consideration was also given to year-round exposure to residents of cabins and/or houses on inland lakes within this 25 km radius, including Vee, Landing, Ryan, Walsh, Banting, Prosperous, Madeline, Pontoon, Prelude, and River lakes. With the exception of Vee, Landing, and Ryan lakes, these lakes are to the northeast of Yellowknife and are outside of what is considered to be the area influenced by legacy contamination.

Since exposures from legacy contamination to people living in populated areas near the Giant and Con Mine sites such as the City of Yellowknife, Ndilǫ, and Dettah were evaluated in the 2018 GMRP HHERA (CanNorth 2018), these areas were not considered in the current HHRA. In response to concerns raised by the YKDFN about Arctic grayling, a separate analysis was completed to evaluate exposures to residents of Ndilǫ and Dettah associated with eating Arctic grayling caught upstream in Baker Creek. This analysis is presented in Appendix L.

This HHRA considered exposures from soil, sediment, water, and country foods. Background exposures from store-bought food were also taken into account in the assessment.

At the request of the GNWT Department of Infrastructure, a separate evaluation was also completed for potential risks to outdoor workers that may be exposed to arsenic in soil along the Ingraham Trail/Highway 4, between Yellowknife and the Yellowknife River (see Appendix K).

This risk assessment relied on a database of existing monitoring data, as well as supplemental surface water, sediment, fish, and muskrat data that were collected to infill data gaps. The complete database considered in this risk assessment is provided in Appendix A. The risk assessment followed guidance outlined by Health Canada (2012a) and addresses current conditions in the study area.

1.5 Community Engagement

Community engagement and input is a key component of risk assessment process to ensure that concerns from the community are adequately addressed. A community meeting was held in May 2018 in Yellowknife with interested members of the public from the City of Yellowknife, including staff representatives from the YKDFN. The objectives of the meeting were to:

1. present a summary of the available data from within the study area;
2. provide an overview of the planned HHRA approach; and
3. determine what people did in the study area and how often they did the activities.

Information related to item 3 was collected via a survey questionnaire (Appendix B), completed either by speaking directly with attendants at the in-person meeting or on-line during the month of May 2018 (73 on-line respondents). During the meeting it was identified that a separate land-use meeting should be held with YKDFN members. Additionally, one aggregate response to the survey was submitted electronically by NSMA staff, who answered questions based on TLU data collected through semi-structured interviews completed as part of a separate but related project. A summary of the results is also included in Appendix B. Ultimately, the questionnaire aimed to answer the following questions:

- Which inland lakes have houses and/or cabins, and how much time is spent at these houses and/or cabins?
- How much time do people spend in the study area?
- What recreational activities do people participate in while in the study area (e.g., swimming, hiking, fishing, hunting, etc.)? How often do they do this?

The GNWT has also been involved in discussions with representatives of the YKDFN to ensure that their concerns are addressed in this HHRA and to aid in defining the TLU area. In addition, the GNWT formed a Risk Communications Advisory Committee to understand community concerns and to work together to address messaging and communications on risks related to arsenic. Concerns raised in these meetings related to legacy arsenic have also been considered in this risk assessment. Some of these concerns related to collection of additional fish and small game samples and to analyze fish eyes, organs and the fatty layer under the skin as well as the flesh. Additional fish samples were collected from lakes in the TLU area (Mason and Duck lakes) by members of the YKDFN and the different tissues were analyzed. In addition, muskrat samples were also collected by members of the YKDFN from Duck Lake, Hay Lake, and other harvesting areas in Yellowknife Bay. The TLU area was also discussed and expanded during the initial Risk Communications Advisory Committee meeting. Furthermore, during these meetings the YKDFN expressed concerns about eating Arctic grayling which spend time in Baker Creek. Thus, samples of Arctic grayling from upstream in Baker Creek were collected in 2020 and a separate evaluation of exposure from this pathway was completed (see Appendix L).

2.0 SITE CHARACTERIZATION

A portion of the study area considered in the assessment, defined below in Section 2.2, is within the municipal boundaries of the City of Yellowknife, while some areas fall within the Akaitcho Dene asserted territory and are within the TLU area of the Tłı̨chǫ, known as Monfwi Gogha De Niitlee.

2.1 Physical Setting

The Yellowknife area is characterized by cool summers, very cold winters, and low humidity. Over the 2007 to 2016 period, the average annual temperature has been -3.7°C; the coldest month is January and July is the warmest month (ECCC 2017). Over this same period the annual precipitation has been 285 mm, with 176 mm as rain and 152 cm of snowfall (ECCC 2017). The average wind speed recorded at the Yellowknife airport between 1971 and 2000 was 14 km/hr (INAC/GNWT 2010). Yellowknife's monthly average wind speed varies little during the year with a range of 13 km/hr to 16 km/hr. Palmer et al. (2015) and Jamieson et al. (2017) indicates that predominant wind direction is from the east in all months except June, July, and August when winds are from the south.

2.1.1 Terrestrial Environment

Yellowknife and the surrounding area lie within the Canadian Shield Slave Structural Province, on the border of two Level IV ecoregions termed the Great Slave Upland and Great Slave Lowland (INAC/GNWT 2010). These ecoregions have largely discontinuous permafrost, and the forests consist primarily of jack pine and black spruce stands on nutrient-poor soils. The physical topography consists predominantly of exposed bedrock with discontinuous till and thin soils over bedrock. Mixed stands of jack pine, aspen, white spruce, and birch are also common forest types within the region. Wetlands are a dominant feature.

The Giant and Con Mine sites are located within the Archean-aged Yellowknife Greenstone Belt (YGB), located in the southeast corner of the Slave Province and extending north from Great Slave Lake for almost 50 km. The YGB is a geologic formation largely made up of volcanic rocks and mafic sills. It is known to be rich in gold deposits predominately hosted in arsenopyrite, leading to naturally elevated concentrations of arsenic in local, mineralized zones (Palmer et al. 2015; Cheung et al. 2020). The YGB is bounded to the west by younger rocks composed of granite and to the east by silica-bearing sedimentary rocks (INAC/GNWT 2010).

2.1.2 Aquatic Environment

There are hundreds of inland lakes within a 25 km radius of the Giant Mine site, many of which are used by local residents for boating and fishing. Some lakes have also been identified by residents of the City of Yellowknife as having cabins and/or houses along their shores. Subarctic lakes on the Canadian Shield typically have low dissolved solids concentrations since most terrestrial runoff travels through a shallow seasonally frozen active layer or over bedrock and there is little contribution from groundwater sources. Since water chemistry of these lakes is largely influenced by bedrock geochemistry, catchment surficial materials, and catchment vegetation, their buffering capacity is limited such that anthropogenic and climate change impacts may be magnified (Palmer et al. 2015).

Two large waterbodies, namely Back Bay and Yellowknife Bay of Great Slave Lake, are also within the study area; however, they were evaluated in the GMRP HHERA (CanNorth 2018) and therefore are not considered in this assessment.

2.2 Study Area

The study area considered in the assessment was defined to include recreational and TLU areas within a 25 km radius of the Giant Mine site (see Figure 2.1). While these areas have been defined for the purposes of this study, it is anticipated that recreational activities, and activities involving people with more traditional lifestyles, may occur across the study area and the scenarios selected encompass these activities.

Exposures from occasional recreational activities such as hiking, camping, swimming, and fishing were evaluated at the following four areas (see Figure 2.1):

1. Area A: The western part of the study area between 10 km and 25 km from the Giant Mine site. The NSMA reported fishing in many of the small unnamed lakes in this area, particularly west of Yellowknife along Highway 3.

2. Area B: The northwestern part of the study area, within a 10 km radius from the Giant Mine site. The survey results indicated that Martin, Vee, and Ryan lakes are the most commonly visited lakes in this area. There are also cabins and/or houses on Landing and Ryan lakes, and a houseboat on Vee Lake.
3. Area C: The western part of the study area within a 10 km radius from the Giant Mine site and close to the Con Mine site. The only lake in which respondents reported fishing from or swimming in within this area is Long Lake.
4. Area D: The area directly west of and closest to the Giant Mine site along the Ingraham Trail. Survey respondents reported relatively low use of this area, limited mainly to hiking and running.

Year-round exposure to residents of cabins and/or houses on inland lakes were also evaluated, including Vee, Landing, Ryan, Walsh, Banting, Prosperous, Madeline, Pontoon, Prelude, and River lakes as shown in Figure 2.1. These lakes are to the north and northeast of Yellowknife and are outside of what is considered to be the area influenced by legacy contamination, except for Vee, Landing, and Ryan lakes that are located within Area B. Although there is no permanent residence on Vee Lake, it was included in the assessment as there is a houseboat on the lake that is used for viewing the northern lights. While there is also day use of the inland lakes with cabins and/or houses, these exposures would be encompassed by the year-round exposure evaluated in the assessment.

The area to the east of Yellowknife within a 25 km radius from the Giant Mine site represents an area where the YKDFN currently conduct traditional activities such as hunting, harvesting, and fishing. The YKDFN harvest from Hay Lake and fish in Duck and Mason lakes, although mainly in the winter time when they are easier to access. The area to the southwest of Con Mine may also be used for traditional activities; although this has not been confirmed, it has been included in the definition of the TLU area (see Figure 2.1) for the purposes of this assessment. Members of the YKDFN have indicated that they also use the defined recreational areas for traditional activities and these exposures would be encompassed by the occasional recreational scenarios (areas A through D) and year-round (inland lakes with houses/cabins) exposures evaluated in the assessment.

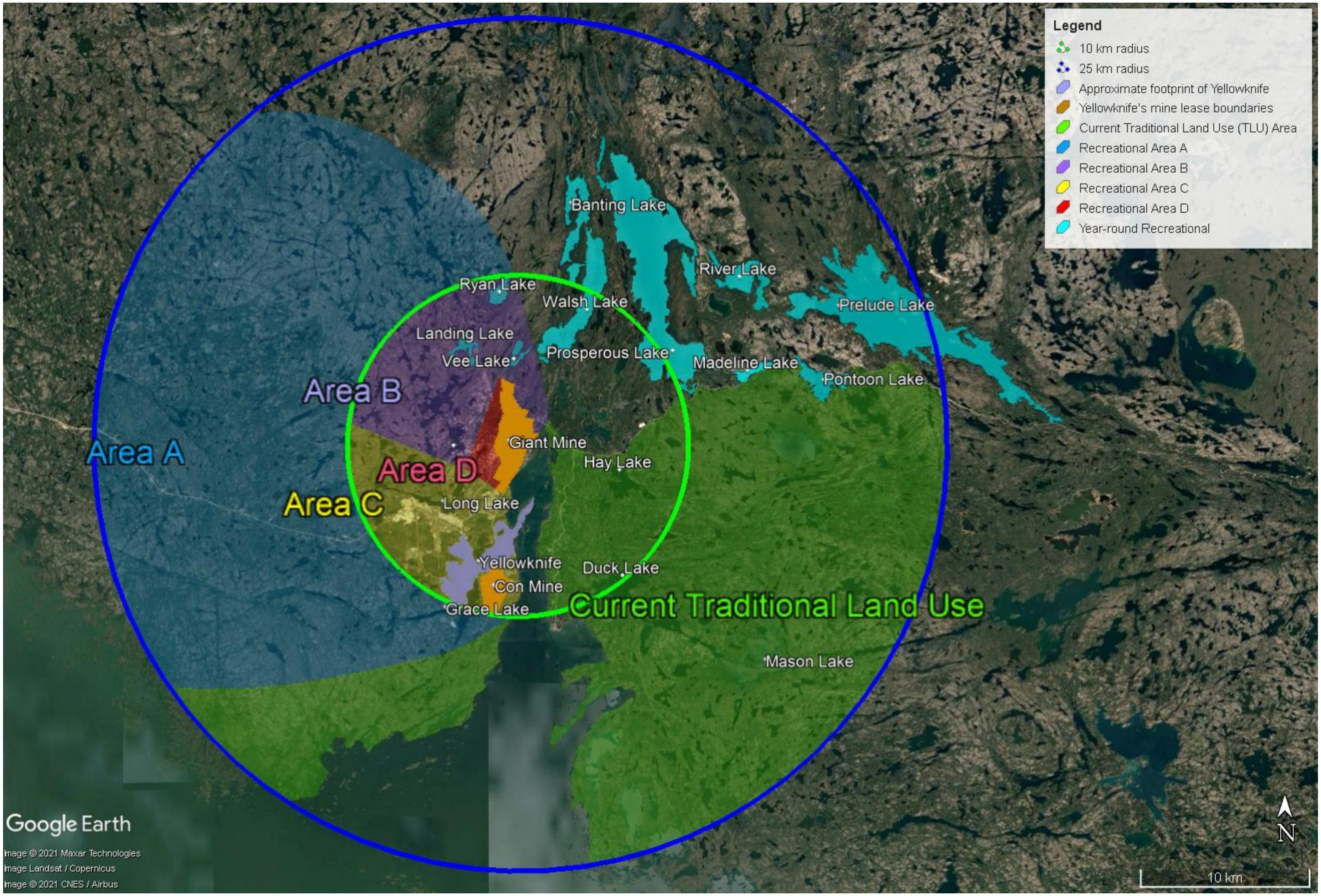
The recreational and TLU exposures evaluate the incremental arsenic exposures associated with the various activities. Additionally, incremental risks from living in the City of Yellowknife, Ndilǫ, and Dettah are also considered in association with the recreational and TLU activities. The incremental risks from living in the City of Yellowknife, Ndilǫ, and Dettah were obtained from the 2018 GMRP HHERA (CanNorth 2018). Antimony exposures in the GMRP HHERA were so low that the consideration of the recreational exposures presented in this HHRA will not result in any changes to the conclusion that antimony is not a cause for concern from legacy mining activities.

It should be noted that use of lakes within the study area by residents and visitors is guided by official advice from the Chief Public Health Office about precautions that can be taken to avoid exposure to elevated arsenic levels in the area. The advice is based on the most current environmental and human health data available and is adjusted as more information becomes available from ongoing monitoring or research activities.

An interactive map is maintained on the GNWT Health and Social Services (GNWT HSS) website[1]. Based on measured arsenic levels in surface water, the map outlines which lakes are considered safe for swimming, fishing, and harvesting berries, mushrooms, and other edible plants. Regardless of arsenic concentrations, it is recommended to not drink untreated water from any lake.

[1] https://www.hss.gov.nt.ca/en/newsroom/arsenic-lake-water-around-yellowknife

Figure 2.1 Study area for the human health risk assessment



2.3 Constituents of Potential Concern

For this assessment, a soil screening process was carried out to identify constituents of potential concern (COPC). The maximum measured soil concentrations in the study area were compared to the environmental quality guidelines for agricultural land use from the Canadian Council of Ministers of the Environment (CCME 2017). The use of the agricultural land use guideline represents the most conservative approach to screening COPC and background concentrations represented as the average concentration of background samples. This process is described in Appendix C. It should be noted that a soil concentration above a guideline does not necessarily mean that there is an actual risk to human health.

The screening process identified arsenic and antimony as the only two COPC on the basis of measured soil data in the study area. This is consistent with the GMRP HHERA (CanNorth 2018), which identified arsenic and antimony as the key COPC.

Although mercury was not identified as a COPC on the basis of the soil screening process, it was included as a COPC for evaluation of fish flesh because higher concentrations of mercury are known to occur in small northern lakes and mercury has been identified as a potential concern in Pocket Lake (Thienpont et al. 2016). Additionally, GNWT HSS identified mercury as a constituent of interest for them and requested that it be evaluated in fish in this study.

2.4 Review of Existing Environmental Data

There have been a number of investigations on the off-site aquatic and terrestrial environments within the study area by government, independent researchers, and universities that have further informed the concentrations, movement, and behavior of arsenic.

The following sections provide a summary of the available data for arsenic and antimony which were identified as COPC in soil within the study area. Data on mercury in fish flesh are also summarized as mercury was identified as a COPC in fish. The complete dataset considered in the HHRA is provided in Appendix A, while summary statistics are provided in Appendix E.

2.4.1 Terrestrial Environment

2.4.1.1 Soil

Available studies were reviewed in order to compile soil data from within the study area. The focus was on data for samples from the top soil layer (i.e., top 10 cm) as this represents the layer to which people are most likely exposed, and also the layer that has been affected by historical aerial deposition.

The majority of the soil data were obtained from a study by Jamieson et al. (2017), although the dataset was infilled with data from a few other studies (Ollson 2000; Golder 2016a; ESG 2000; Obst 2014). The sample locations for the study area are presented in Figure 2.2. As seen from the figure, there are several samples available to characterize areas A through D as well as the TLU area. For the year-round recreational lakes with cabins and houses, there are fewer soil samples and no soil samples available around River Lake; however, as discussed in Section 4.5.4, this does not hinder the assessment.

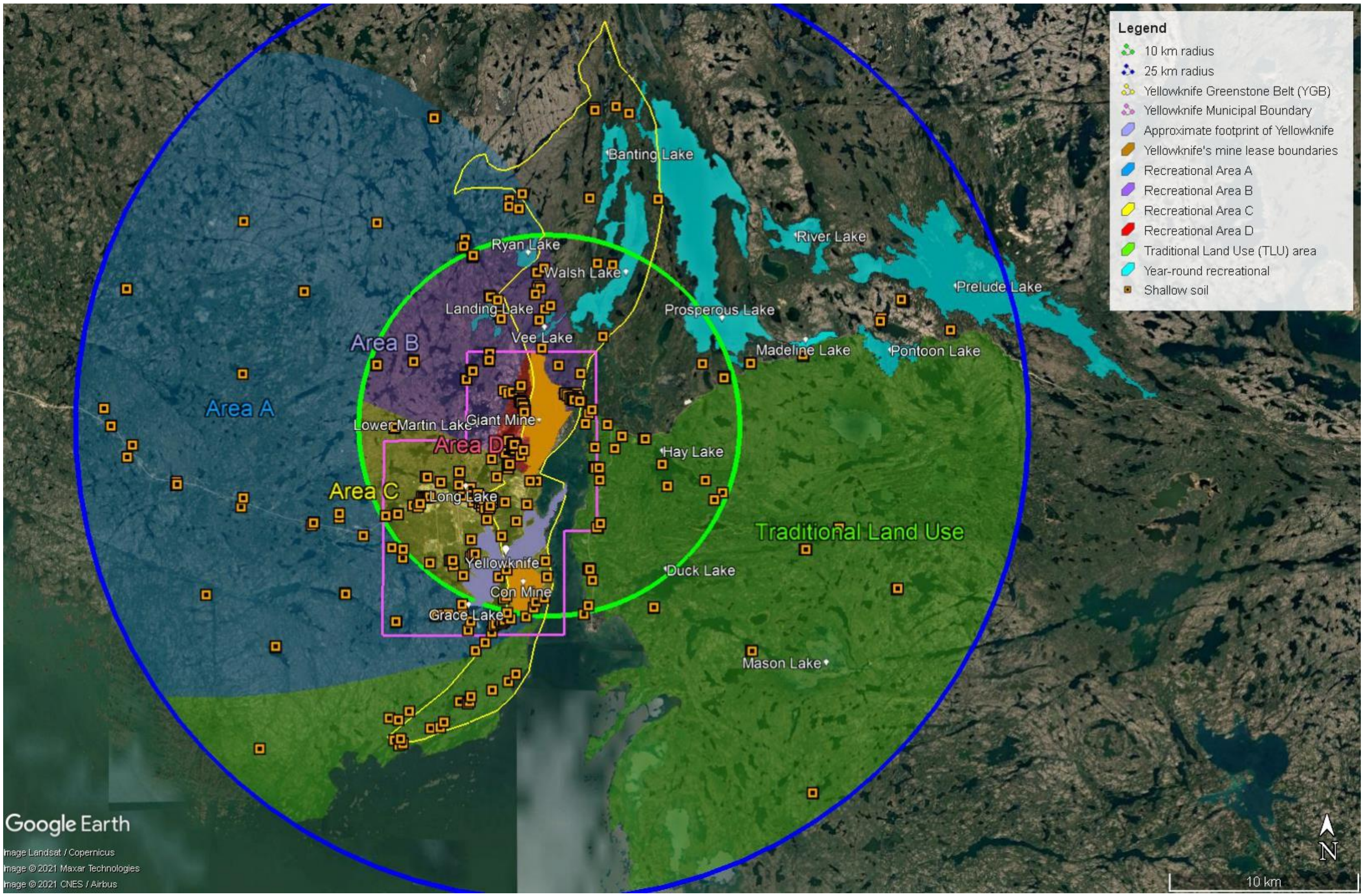
Owing to the naturally elevated concentrations of arsenic within the YGB, the GNWT has been working on developing an appropriate background concentration for arsenic in soil for use in remedial action planning. Stantec (2020) has derived a background dataset for arsenic in Yellowknife comprising data collected at depth (10 cm or more below ground) by the Geological Survey of Canada (GSC; Kerr 2001) and Jamieson et al. (2017). For application within a 25 km radius of the Giant Mine site, the following background concentrations were derived for the YGB and Yellowknife municipal boundary (shown in Figure 2.2):

1. 114 mg/kg for YGB and within the Yellowknife municipal boundary
2. 41 mg/kg for non-YGB and outside of the Yellowknife municipal boundary

It should be noted that these are 95% Upper Confidence Level of the Mean (95% UCLM) values and not averages. Further details are provided in the Stantec (2020) report. For areas beyond the 25 km radius, the natural background concentration of 10 mg/kg from the CCME (2001) is applicable. This is supported by an analysis of data outside of 20 km of Yellowknife in a recent study by Palmer et al. (2021) on the geochemical background of arsenic in soils.

For antimony, background samples were the same as those considered in the 2018 GMRP HHERA (CanNorth 2018) and are detailed in Appendix D. The background antimony concentration in soil is represented by a value of 0.56 mg/kg.

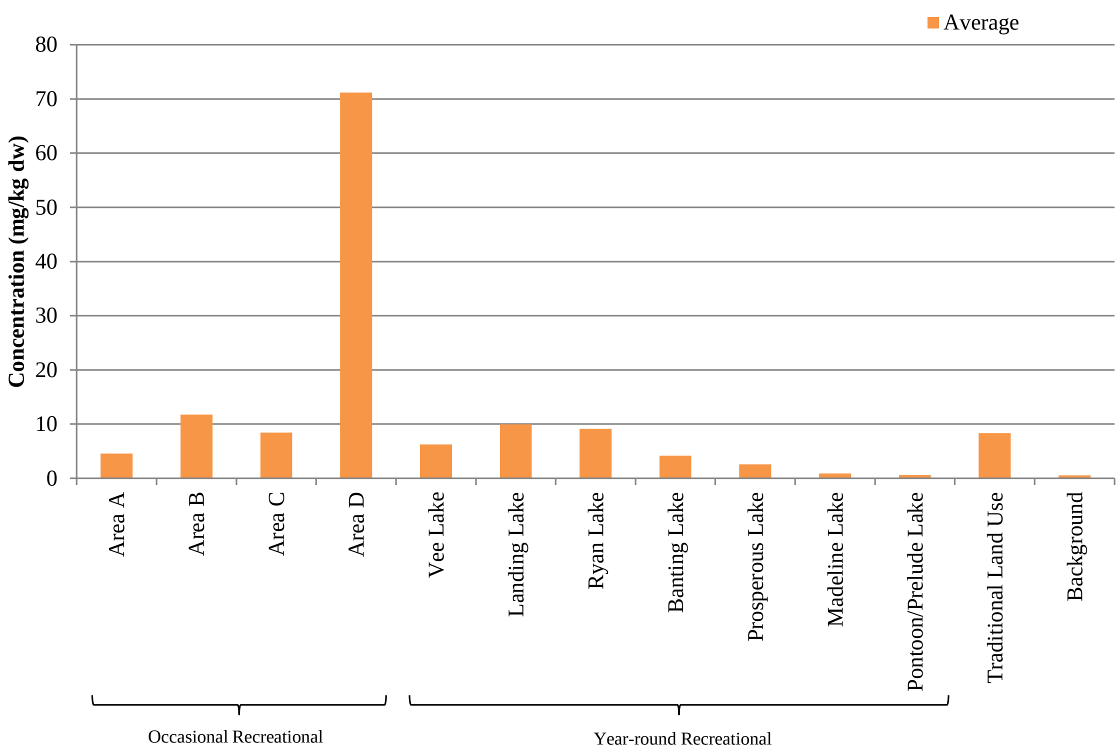
Figure 2.2 Shallow soil sampling locations from within the study area



The average soil concentrations in the study area are shown in Figure 2.3 (antimony) and Figure 2.4 (arsenic).

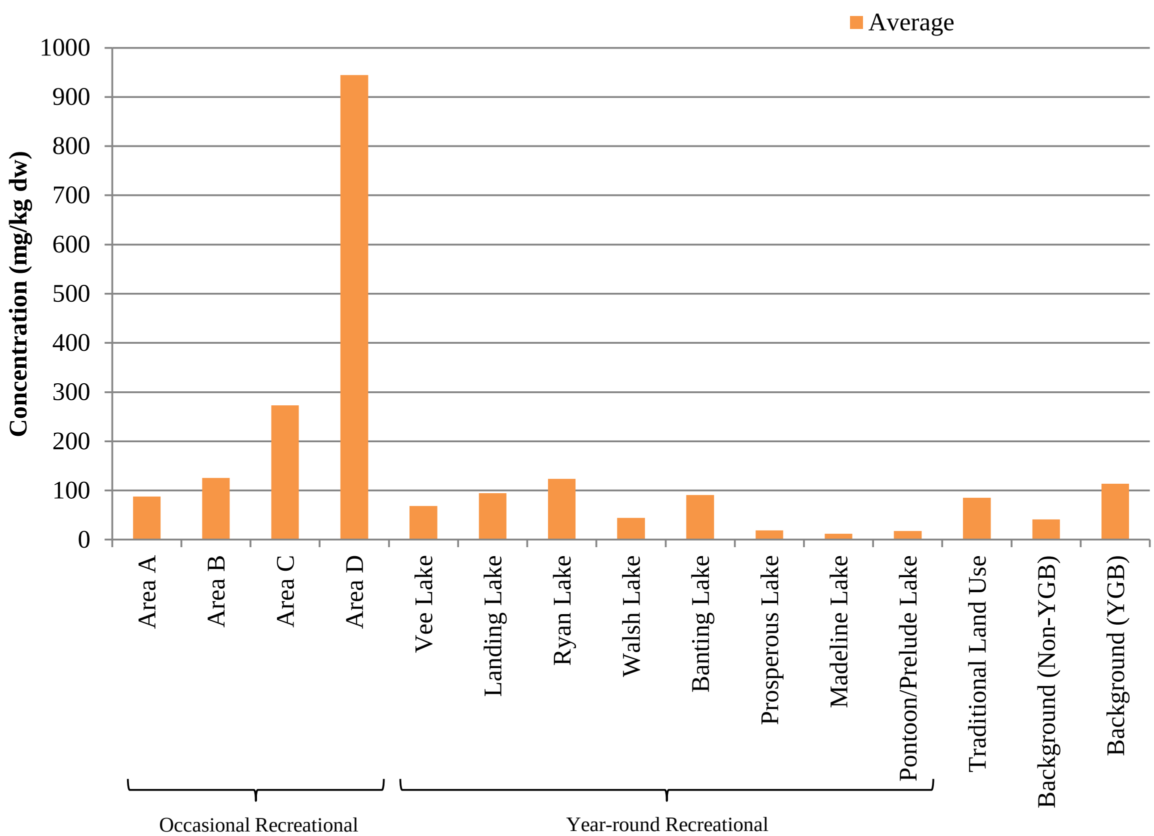
As seen in the figures, concentrations of arsenic and antimony generally decrease with increasing distance from the Giant and Con Mine sites, with the lowest average concentrations measured around Prosperous, Madeline, and Prelude/Pontoon lakes. The average concentrations of both antimony and arsenic are highest within Area D. It is noted that concentrations are influenced not only by the proximity of the areas to the Giant and Con Mine sites but also by the concentrated sampling efforts of soil pockets in the bedrock by Jamieson et al. (2017) from a relatively small area just west of the Ingraham Trail, north of Handle Lake. These soil pockets act as sinks and have thererefore been found to have elevated arsenic concentrations (Palmer et al. 2021).

Figure 2.3 Average antimony concentrations in soil within the study area



Note: There are no data for antimony in soil around Walsh or River lakes. Number of samples is 20 or more for occasional recreational and Traditional Land Use areas, and 5 or more for year-round recreational areas (except Madeline Lake [n=2] and Vee Lake [n=3]).

Figure 2.4 Average arsenic concentrations in soil within the study area



Note: There are no data for arsenic in soil around River Lake; background concentrations are 95% Upper Confident Level of the Mean (95% UCLM) values from Stantec (2020). Number of samples is 20 or more for occasional recreational and Traditional Land Use areas, and 5 or more for year-round recreational areas (except Madeline Lake [n=2]).

2.4.1.2 Berries, Medicinal Plants, and Mushrooms

Data for berries, medicinal plants (e.g., Labrador tea, rat root, juniper berries, etc.), and mushrooms were obtained from the voluntary country foods sampling program that was completed in support of the GMRP HHERA (CanNorth 2018). In all, 84 samples of berries, medicinal plants, and mushrooms were submitted from various people from the YKDFN, NSMA, and people living in Yellowknife. This represents a robust data set to be considered within this HHRA. Mushroom data for the high arsenic accumulators (*Tricholomataceae* family; 5 of the 84 samples) were not considered in this assessment as they were previously evaluated in the GMRP HHERA (CanNorth 2018). The GNWT HSS advice around mushrooms is also to not consume any that are collected from within a 10 km radius and these high accumulating samples were obtained from within that area.

Background samples were considered to be those obtained from areas outside of the 25 km radius of the Giant Mine site (see Appendix D for details), and included mushroom data from a study by Obst (2014) to supplement the background samples obtained as part of the voluntary country foods sampling program.

Figure 2.5 shows the locations of the berry, mushroom, and medicinal plant samples, which are mainly from within a 10 km radius of the Giant Mine site. The GMRP HHERA (CanNorth 2018) found that there were very little differences in the concentrations of arsenic and antimony in medicinal plants with sampling locations; thus, all data collected within 25 km were combined and used in the assessment, regardless of specific recreational area from where the samples were collected. The GMRP HHERA found that there was some influence on arsenic concentrations in berries and mushrooms with distance from the former Giant Mine (i.e., higher closer to the Mine site); nonetheless, the berry and mushroom data from 10 km and 25 km radius were also combined to provide a conservative estimate of exposure. This is a conservative approach as higher concentrations were measured in samples closer to the Giant Mine site than in the recreational and inland lake areas considered in the current HHRA. The consideration of mushroom samples from within 10 km is additionally conservative as it is contrary to the GNWT HSS advice to not eat mushrooms from within this radius.

Figure 2.6 shows the average antimony concentrations in berries, medicinal plants, and mushrooms, while Figure 2.7 shows this information for arsenic. As seen from the figures, the concentrations of antimony and arsenic in berries are lower than for medicinal plants and mushrooms. Antimony and arsenic concentrations are highest in medicinal plants. Raw data are provided in Appendix A, while summary statistics are provided in Appendix E.

Figure 2.5 Berries, medicinal plants, and mushroom sampling locations

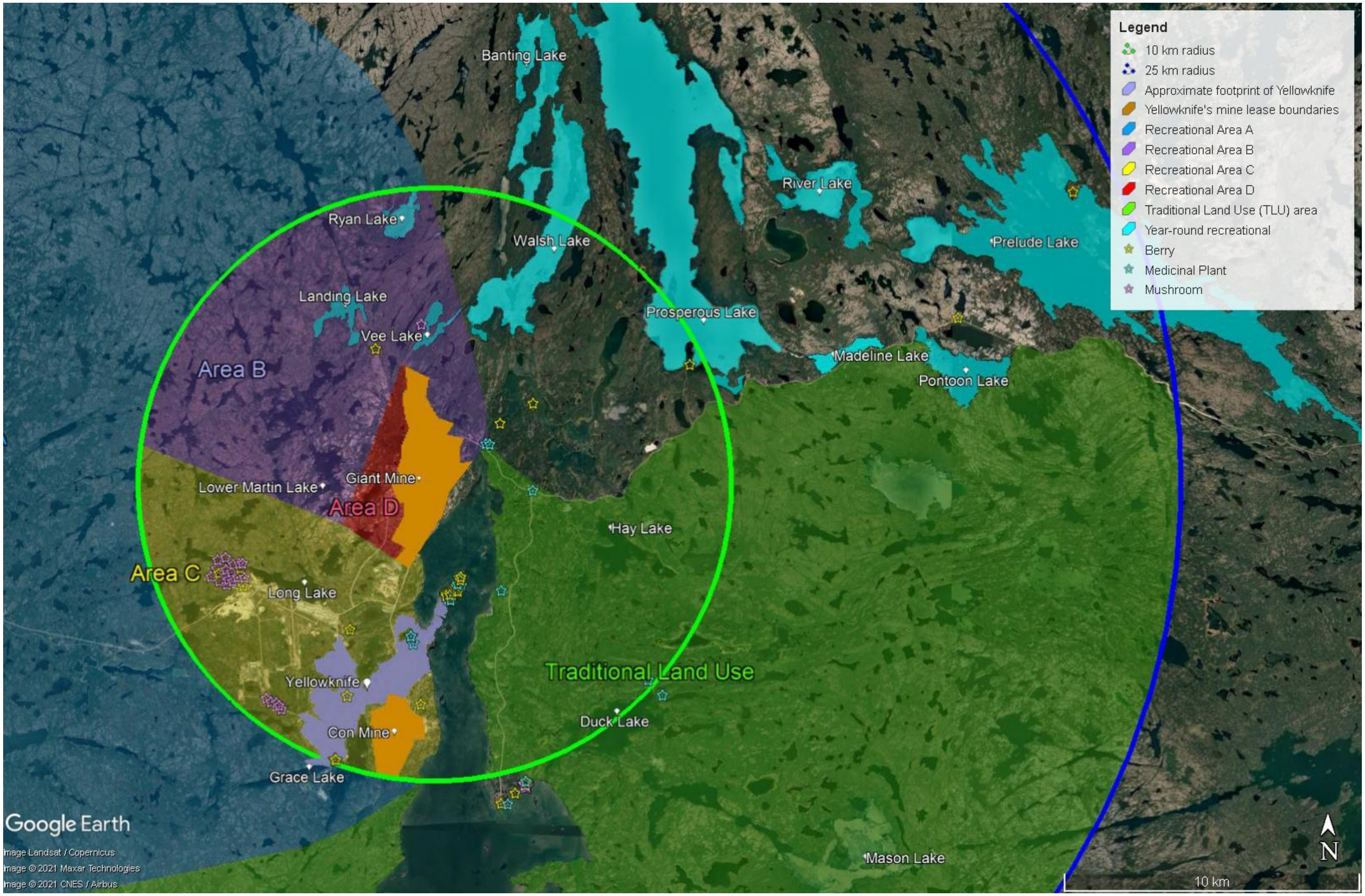
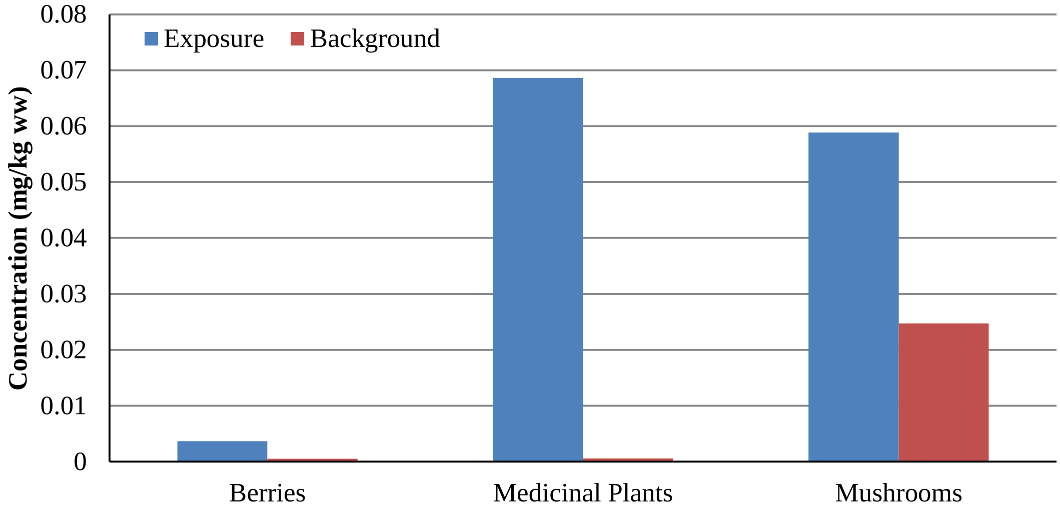
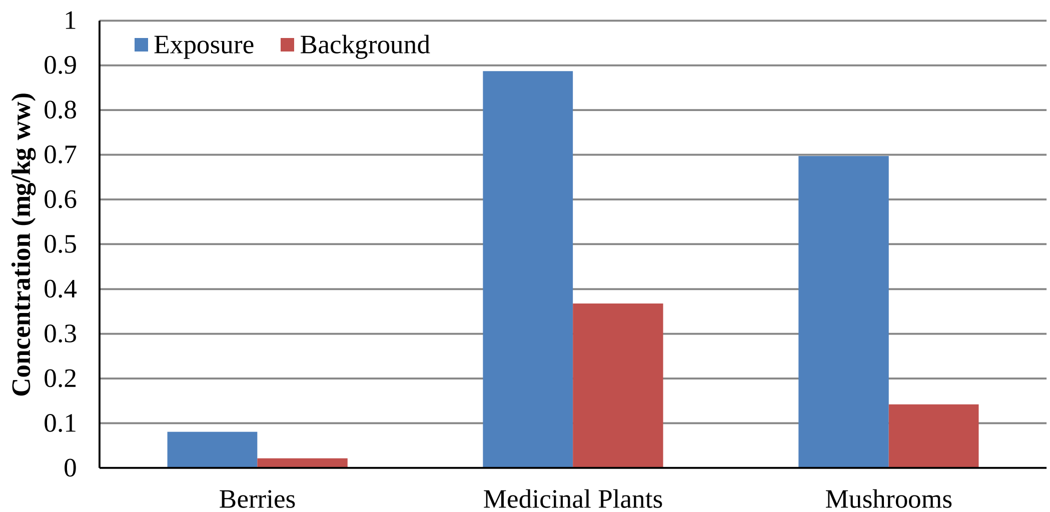


Figure 2.6 Average antimony concentrations in berries, medicinal plants, and mushrooms



Number of samples (exposure, background): Berries (31, 2), Medicinal Plants (24, 1), Mushrooms (24, 70).

Figure 2.7 Average arsenic concentrations in berries, medicinal plants, and mushrooms



Number of samples (exposure, background): Berries (31, 2), Medicinal Plants (24, 1), Mushrooms (24, 70).

2.4.2 Aquatic Environment

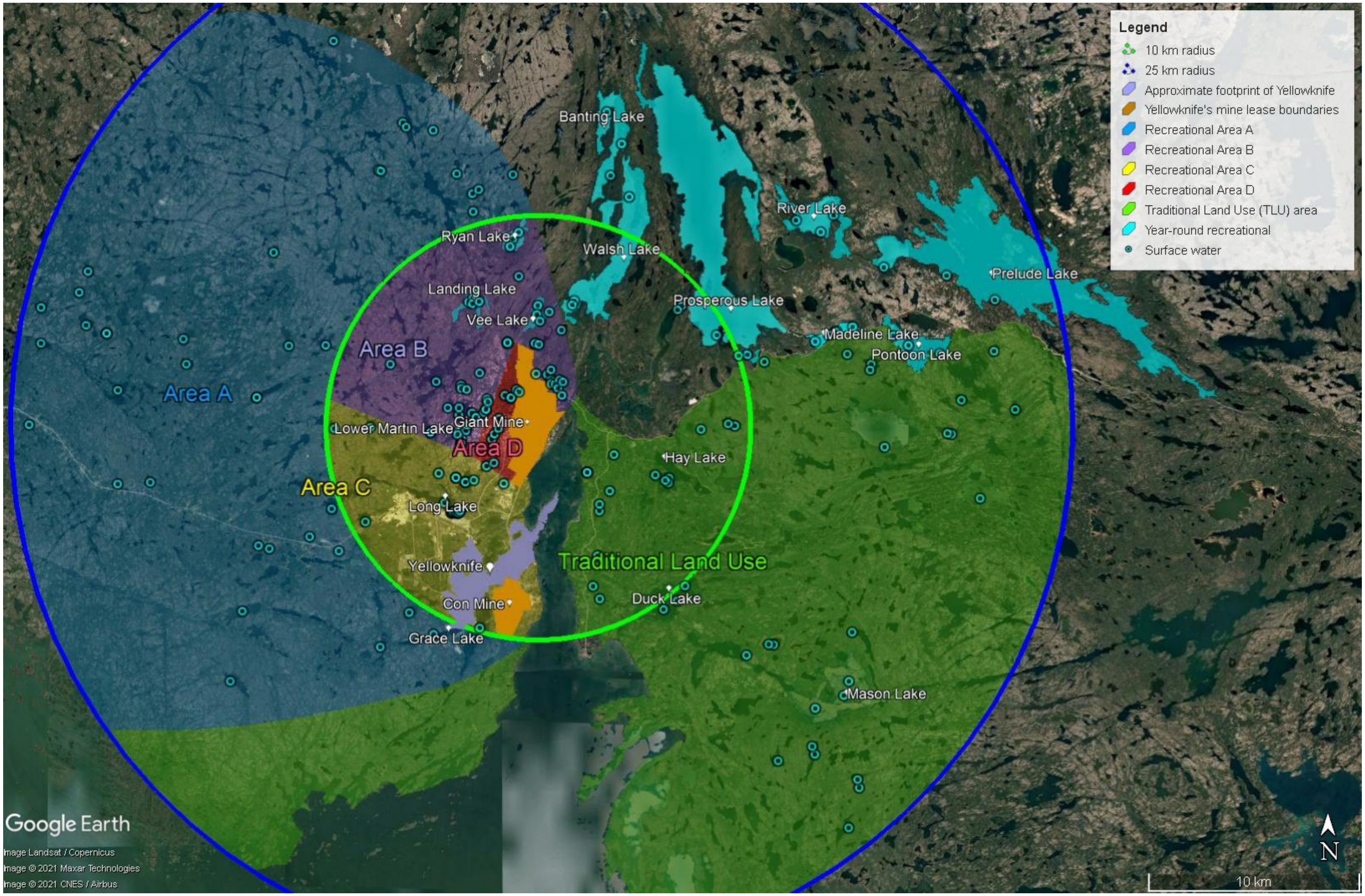
2.4.2.1 Surface Water

Available studies were reviewed in order to compile surface water data from inland lakes within the study area and from background locations. Background samples were considered to be those obtained from inland lakes and other small, unnamed waterbodies outside of the 25 km radius of the Giant Mine site (see Appendix D for details).

The majority of surface water data were obtained from a report prepared by the GNWT on the concentration of arsenic in lake waters around Yellowknife (Palmer et al. 2015). The dataset was infilled with data collected in 2010 from various inland lakes (Houben et al. 2016), and in 2013 and 2014 from just outside of the Giant Mine site (Stantec 2014a, 2015; Golder 2013, 2015, 2016b). In addition, the Water Resources department of the GNWT collected water samples at a number of the inland lakes in 2018, 2019, and 2020 in order to infill data gaps, in particular from lakes with houses/cabins and from within the TLU area (i.e., Hay, Duck, and Mason lakes).

The surface water sampling locations from within the study area are shown in Figure 2.8. As seen from the figure, there are data available for many of the lakes within Areas A to D and the TLU exposure area as well as for each of the inland lakes with cabins or houses. The raw data are provided in Appendix A, while summary statistics are provided in Appendix E.

Figure 2.8 Surface water sampling locations from inland lakes within the study area



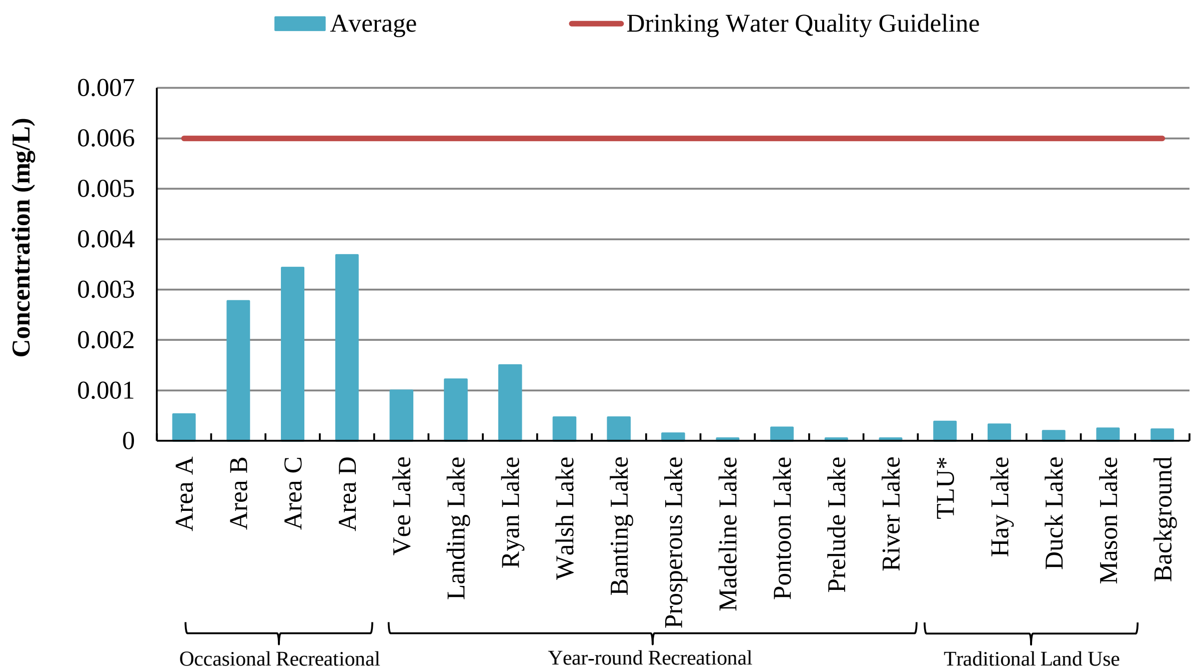
The average concentrations in surface water are shown in Figure 2.9 (antimony) and Figure 2.10 (arsenic), compared to the Canadian Drinking Water Quality Guidelines (DWQGs) from Health Canada (2017). For the TLU area, averages are shown for each of the three lakes most commonly used (i.e., Hay, Duck, and Mason lakes); an overall average, which includes data for the three lakes as well as smaller, unnamed lakes within the area, is also shown.

As seen in the figures below, concentrations of arsenic and antimony again generally decrease with distance from the Giant and Con Mine sites, with average concentrations highest in areas B, C, and D. The elevated average concentrations are the result of arsenic levels in small, unnamed lakes within the areas. For example, in Area B, the concentrations in larger lakes such as Martin and Lower Martin lakes range from 0.02 mg/L to 0.06 mg/L, which are much lower than the overall average for the area of 0.14 mg/L. Similarly, the arsenic concentrations in Long Lake (the most widely used lake within the area) are around 0.04 mg/L, compared to the overall average of 0.12 mg/L.

The average concentrations in lakes within Area A and the TLU area are similar to one another. Although the overall average concentration of arsenic for all lakes within the TLU area is just at the DWQG (0.013 mg/L versus 0.01 mg/L), this is as a result of the smaller, unnamed lakes within the area; the average concentrations for the lakes that are most commonly used for fishing and swimming (i.e., Duck and Mason lakes) are below the DWQG. For arsenic, average concentrations in Walsh, Banting, Prosperous, Madeline, Pontoon, Prelude, and River lakes are all below the DWQG. In Landing, Ryan, and Vee lakes, which are within Area B and near to the Giant Mine Site, the average arsenic concentrations are above the DWQG. For antimony, all of the average water concentrations are below the DWQG.

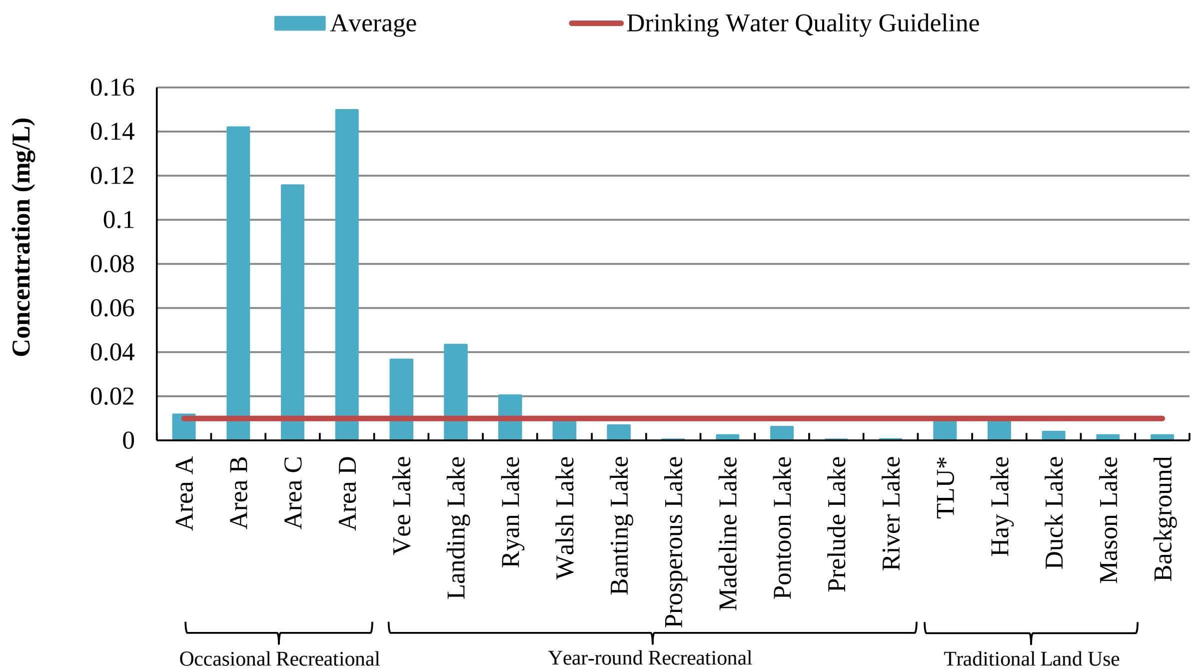
In lakes where the concentrations of antimony and arsenic are below the DWQG, it is safe to drink the water as long as you boil or treat it.

Figure 2.9 Average antimony concentrations in surface water from inland lakes within the study area



*Traditional Land Use (TLU) average based on data for Hay, Duck, and Mason lakes, as well as smaller, unnamed waterbodies within the area. Average concentrations are based on a minimum of 3 samples.

Figure 2.10 Average arsenic concentrations in surface water from inland lakes within the study area



*Traditional Land Use (TLU) average based on data for Hay, Duck, and Mason lakes, as well as smaller, unnamed waterbodies within the area. Average concentrations are based on a minimum of 3 samples.

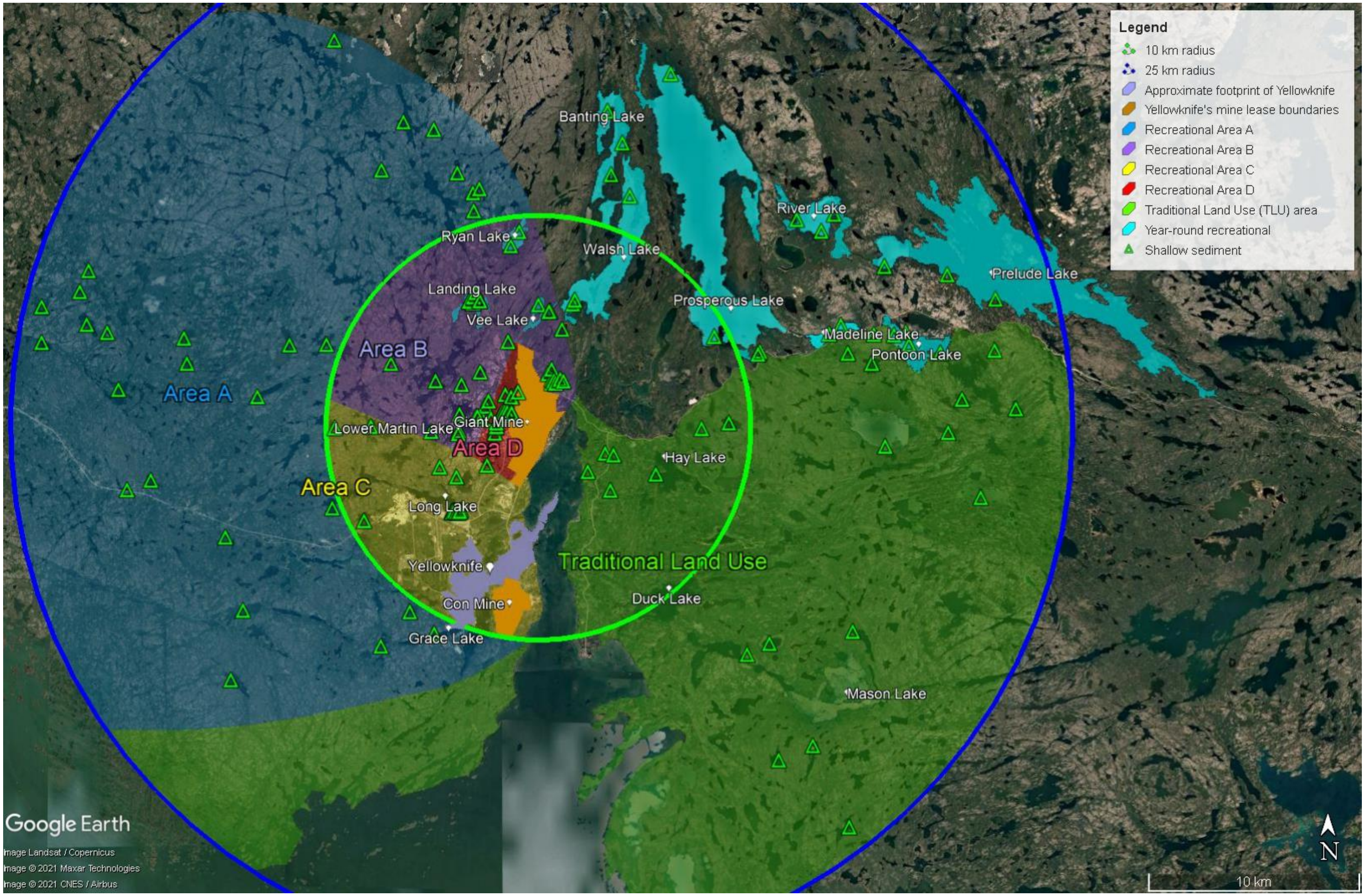
2.4.2.2 Shallow Sediments

Available studies were reviewed in order to compile sediment data from inland lakes in the study area. The focus was on samples that were obtained from the surface (i.e., top 10 cm), as this represents the layer to which people are most likely to be exposed while swimming or wading in the water. Background samples were considered those collected from inland lakes outside of the 25 km radius of the Giant Mine site (see Appendix D).

The majority of the sediment data were obtained from a report prepared by the GSC on the distribution of arsenic in sediments in lakes in the Yellowknife region (Galloway et al. 2015), infilled with data collected in 2013 and 2014 by Stantec (2014a, 2015) and Golder (2015, 2016a) from Lower Martin Lake. In addition, the Water Resources Division of the GNWT completed additional sediment sampling at a number of the inland lakes in 2018 in order to infill data gaps, in particular from lakes within the year-round recreational area.

Figure 2.11 shows the sediment sampling locations from the study area. As seen from the figure, there are sediment data available for many of the lakes within areas A to D and inland lakes with cabins or houses. There are sediment samples from lakes within the TLU area, including Hay and Mason lakes; however, no samples were collected in Duck Lake. The raw data are provided in Appendix A, while summary statistics are provided in Appendix E.

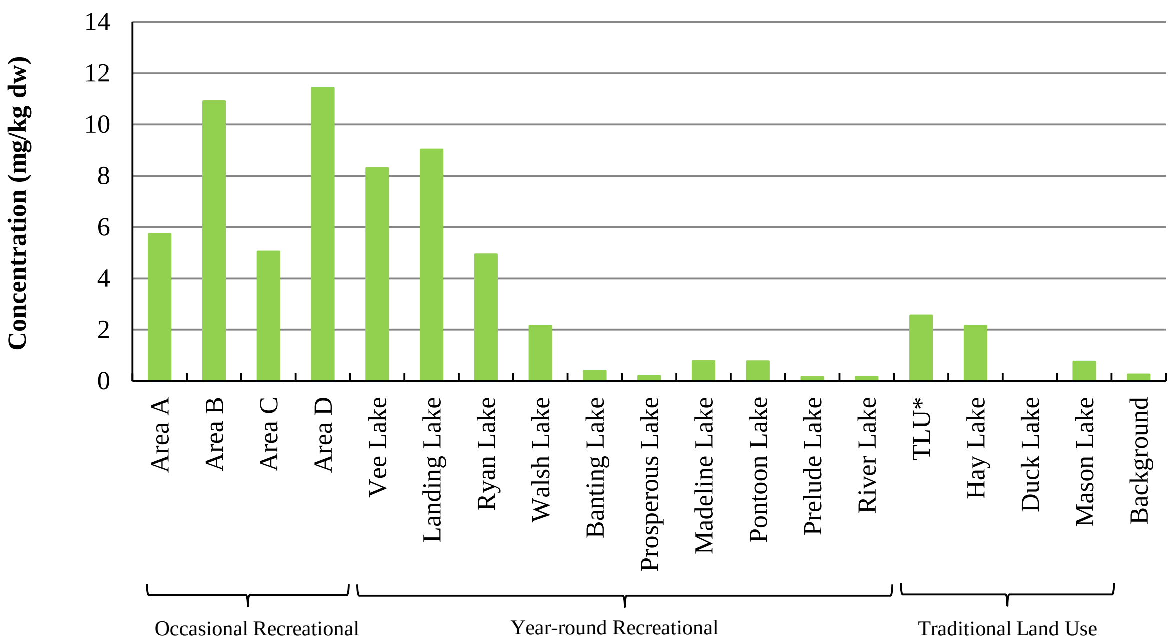
Figure 2.11 Shallow sediment sampling locations from the study area



The average sediment concentrations are shown in Figure 2.12 (antimony) and Figure 2.13 (arsenic).

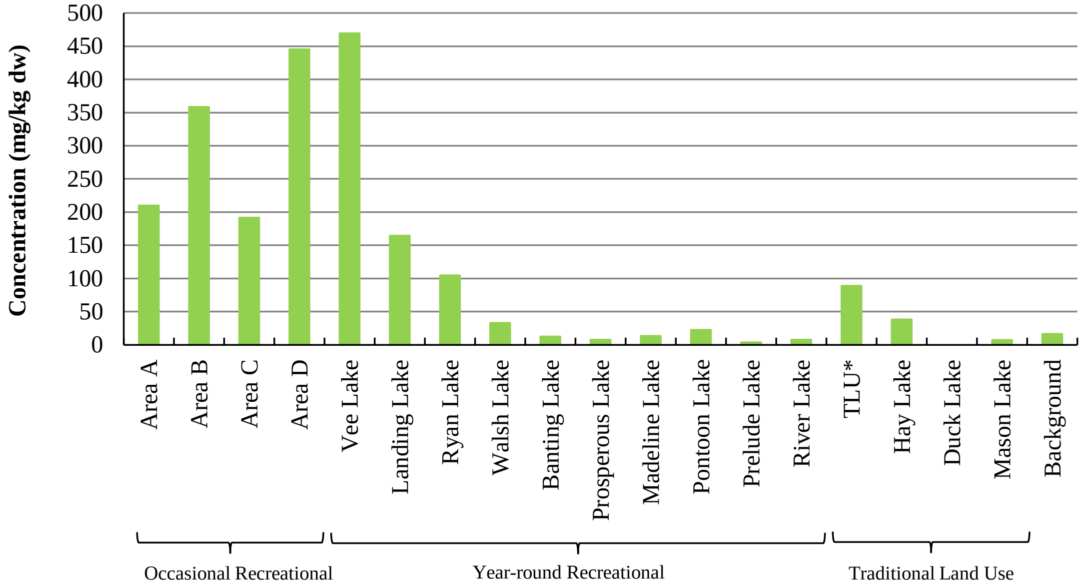
The figures show that the average concentrations of arsenic and antimony in shallow sediments in inland lakes follow very similar patterns as for other environmental media. As expected based on proximity to the Giant and Con Mine sites, the average concentrations are highest in areas B and D. It is interesting to note that, unlike for soil and surface water, the average sediment concentrations in Area A are higher than in Area C, even though the lakes in Area A are farther from the legacy mining areas. As was the case for surface water, the overall average antimony and arsenic concentrations in sediments in the recreational areas are the result of elevated concentrations in smaller, unnamed lakes in the area. Similarly, in the TLU area, the arsenic concentrations in smaller, unnamed lakes in the area are higher than those in Hay and Mason lakes.

Figure 2.12 Average antimony concentrations in shallow sediments from inland lakes within the study area



*Traditional Land Use (TLU) average based on data for Hay and Mason lakes, as well as other small, unnamed waterbodies within the area. There are no data for Duck Lake. Average concentrations are based on a minimum of 3 samples, except for Ryan Lake (n=2) and Madeline Lake (n=1).

Figure 2.13 Average arsenic concentrations in shallow sediments from inland lakes within the study area



*Traditional Land Use (TLU) average based on data for Hay and Mason lakes, as well as other small, unnamed waterbodies within the area. There are no data for Duck Lake. Average concentrations are based on a minimum of 3 samples, except for Ryan Lake (n=2) and Madeline Lake (n=1).

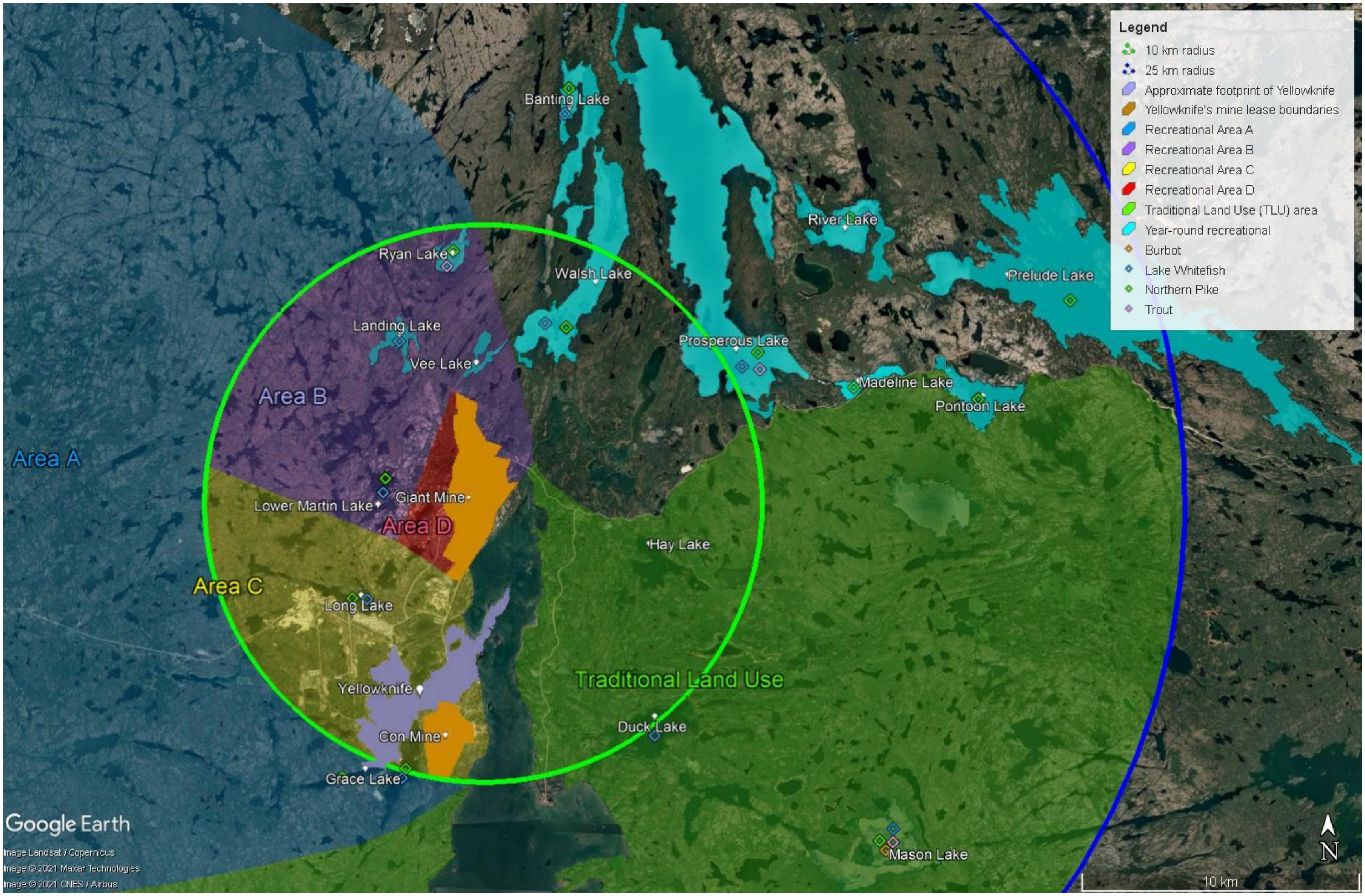
2.4.2.3 Fish

Fish Flesh

The data for fish flesh were largely from a report completed by Stantec (2014b) for northern pike and lake whitefish from Lower Martin Lake (Area B), and a study completed by the GNWT Environment and Natural Resources (ENR) Water Resources Division (Somers 2016; Tanamal et al. 2020) in which lake whitefish and northern pike were collected from Grace and Kam lakes (Area A), Lower Martin Lake (Area B), Banting and Walsh lakes (year-round recreational areas), and Small Lake (reference) and analyzed for total arsenic and arsenic speciation (see Section 4.4.1 for a discussion on speciation). The GNWT ENR also collected samples from community members in 2018, 2019, and 2021 of lake whitefish, northern pike, burbot, and lake trout from several inland lakes, including Duck and Mason lakes within the TLU area. This was an opportunistic collection of fish samples and not a scientifically designed study. From Figure 2.14, it can be seen that there are flesh data available for fish from the lakes within the recreational and TLU exposure areas, although there are only a few samples of lake trout and one burbot.

Background fish flesh samples were considered to be those obtained from inland lakes at a distance of greater than 25 km from the Giant Mine site, including Chitty Lake, Small Lake, and Cameron Falls (see Appendix D).

Figure 2.14 Fish flesh sample locations from within the study area



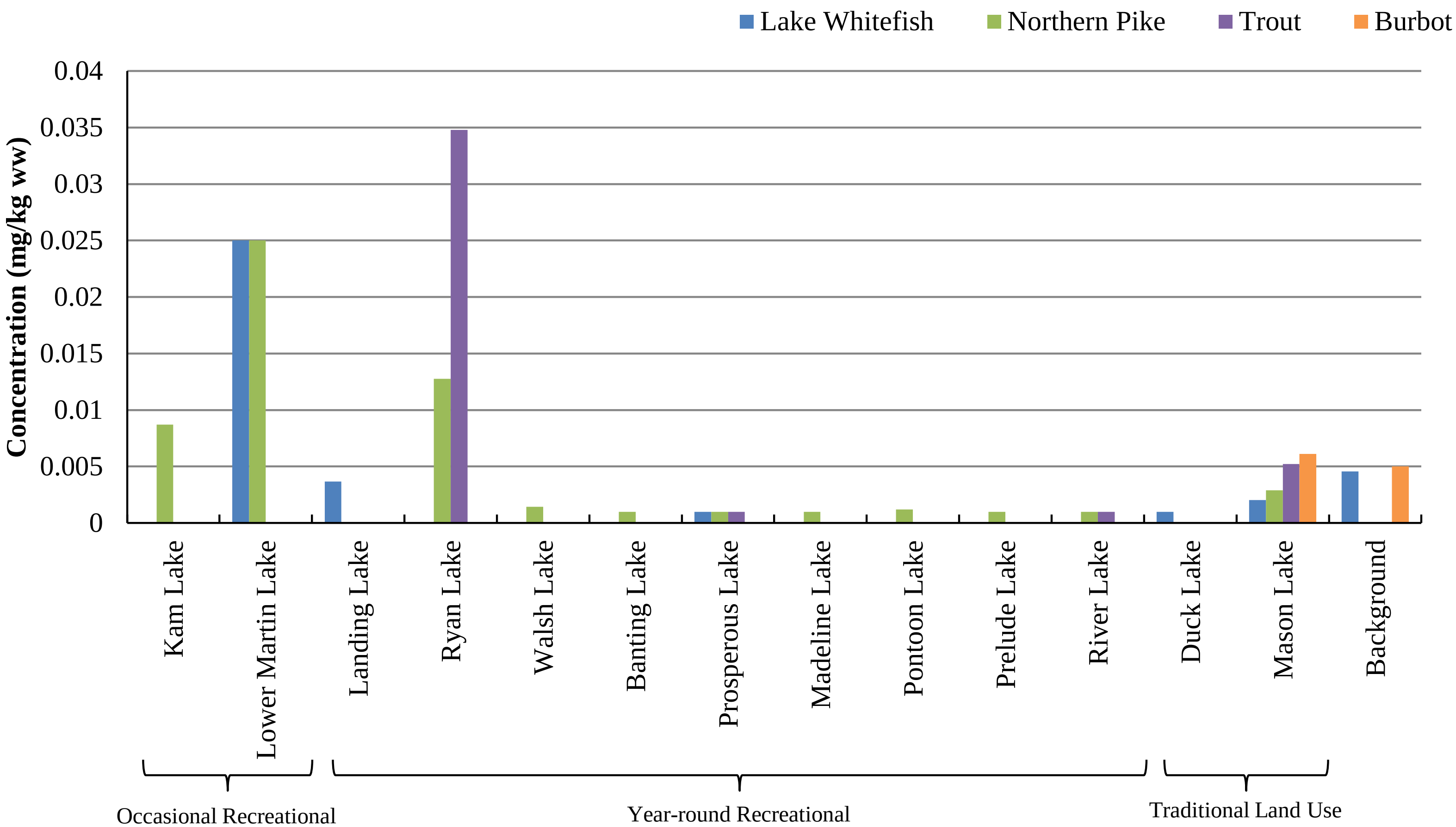
Note: locations are approximate and not representative of number of samples obtained from each lake.

The average flesh concentrations in lake whitefish, northern pike, and/or trout are provided in Figure 2.15 (antimony), Figure 2.16 (arsenic), and Figure 2.18 (mercury). As discussed in Section 2.3, mercury was considered as a COPC only for fish. The raw data are provided in Appendix A, while summary statistics are provided in Appendix E.

The figures below show that the average concentrations of antimony and arsenic are generally lower in fish from inland lakes outside of the areas of the wind direction from the legacy mining areas (i.e., year-round recreational lakes, identified in the figures) and higher in lakes closer to these legacy mining areas (i.e., Kam Lake and Lower Martin Lake, also identified in the figures).

Figure 2.15 shows that average antimony concentrations are below background for lakes other than Kam Lake (northern pike), Lower Martin Lake (lake whitefish and northern pike), and Ryan Lake (northern pike and trout). Trout and burbot from Mason Lake are marginally above background. The average antimony concentrations in flesh from fish from the same waterbody do not vary greatly from species to species, with the exception of fish from Ryan Lake; however, it must be noted that this is based on a single sample of trout from Ryan Lake.

Figure 2.15 Average antimony concentrations in fish flesh from inland lakes within the study area



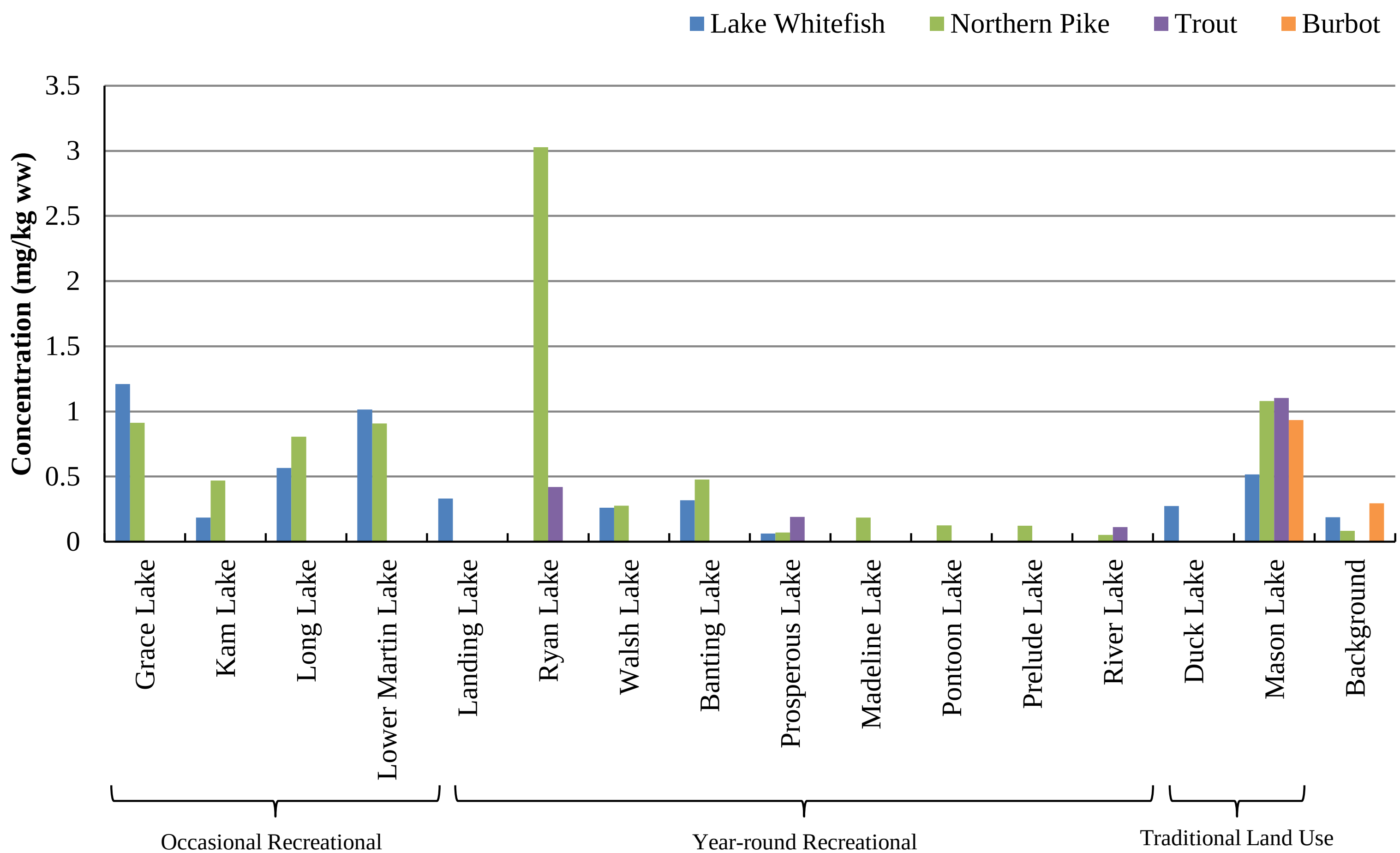
There are no data available for antimony in fish from Grace or Long lakes (occasional recreational area), Vee Lake (year-round recreational area), or Hay Lake (Traditional Land Use area). Number of samples is 3 or more for all species and lakes except for Kam Lake (northern pike [2]), Prosperous Lake (lake whitefish [2], northern pike [1], trout [2]), River Lake (northern pike [2], trout [1]), Ryan Lake (trout [1]), and Mason Lake (burbot [1], northern pike [1]).

For arsenic (Figure 2.16), northern pike flesh concentrations are generally higher than lake whitefish flesh concentrations except in Grace, Lower Martin, and background lakes. Arsenic is higher in trout as compared to other fish species within the same waterbody, with the exception of Ryan Lake where the average northern pike flesh concentration from three samples is over seven times higher than the single trout flesh concentration and is also higher than the arsenic concentrations in all other fish flesh samples from all other lakes. The reason for the elevated concentrations in northern pike is not known. Although Ryan Lake is closer to the legacy mining areas than some of the other lakes, the surface water (Section 2.4.2.1 and Figure 2.17) and sediment (Section 2.4.2.2) concentrations have low arsenic concentrations and thus other processes within the lake may be responsible for the elevated arsenic levels in the northern pike samples. Conversely, the opposite relationship is seen in Kam Lake where, the arsenic concentration[2] in water is higher than in other nearby lakes yet the arsenic concentrations in fish flesh are lower (Figure 2.16 and Figure 2.17).

Based on the available data, the arsenic concentrations in fish (lake whitefish [N=10], northern pike [N=1], trout [N=4], and burbot [N=1]) from Mason Lake are also elevated when compared to other lakes and background and are similar to levels measured in fish from lakes that are much closer to the legacy mining areas (i.e., Grace Lake, Long Lake and Lower Martin Lake). This is unexpected given its distance from the legacy mining areas and that measured surface water (Section 2.4.2.1 and Figure 2.17) and sediment (Section 2.4.2.2) concentrations are at background levels. Additionally, the Mason Lake fish flesh concentrations are above those in fish from Kam Lake, yet the concentration of arsenic in water in Kam Lake is almost 100 times higher than in Mason Lake (0.24 mg/L vs 0.002 mg/L; Figure 2.17). Thus other processes within the lake may be responsible for the elevated arsenic levels in the fish samples.

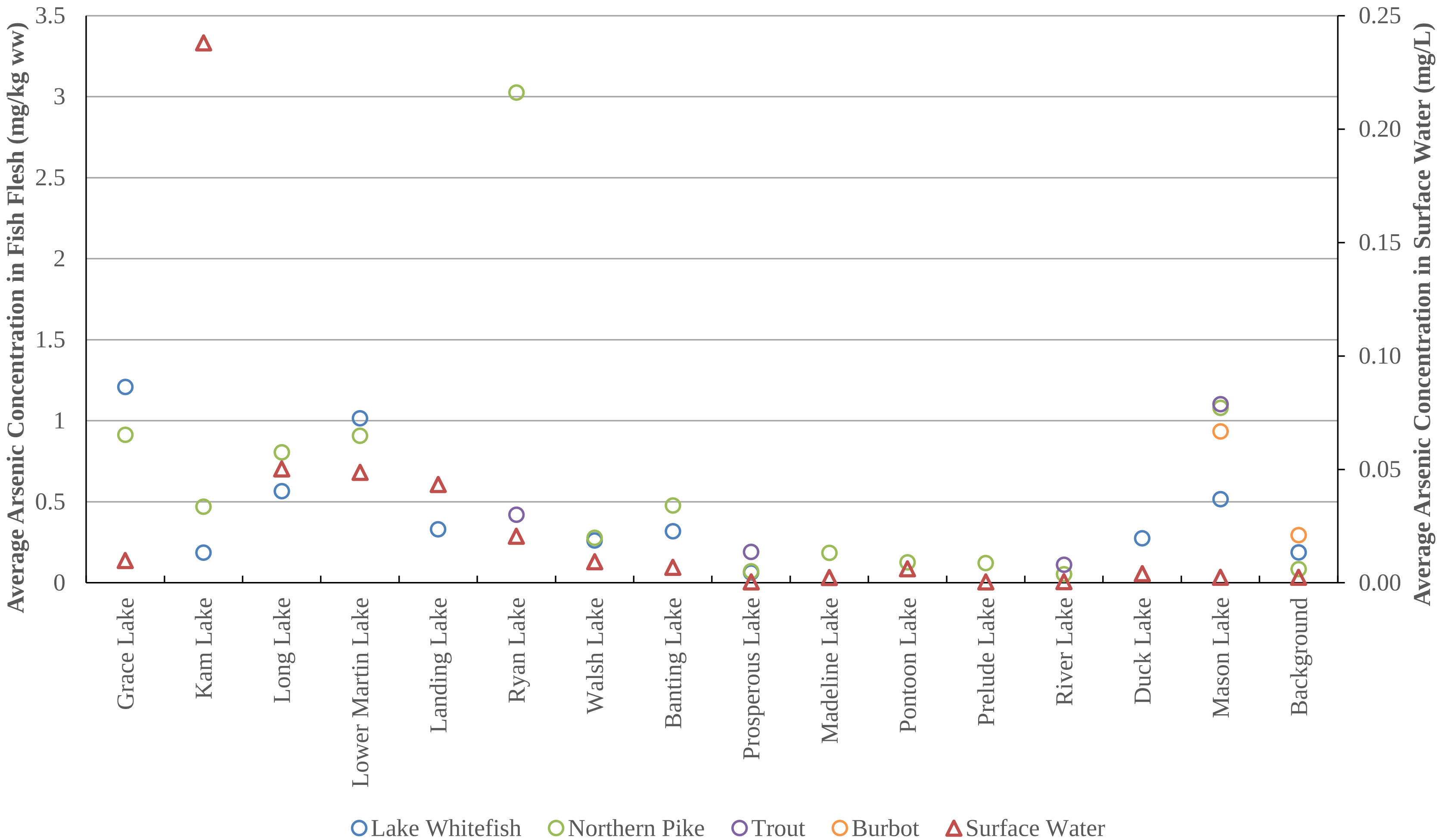
[2] Single Kam Lake surface water concentration of 0.24 mg/L is based on information from unknown study and date reported in the 'Map of Arsenic Concentrations Measured in Water Bodies in the Yellowknife Area (July 5, 2019)' from the Government of the NWT Department of Health and Social Services (https://www.hss.gov.nt.ca/en/newsroom/arsenic-lake-water-around-yellowknife).

Figure 2.16 Average arsenic concentrations in fish flesh from inland lakes within the study area



There are no data available for arsenic in fish from Vee Lake (year-round recreational area) or Hay Lake (Traditional Land Use area). Number of samples is 3 or more for all species and lakes except for Kam Lake (northern pike [2]), Prosperous Lake (lake whitefish [2], northern pike [1], trout [2]), River Lake (northern pike [2], trout [1]), Ryan Lake (trout [1]), and Mason Lake (burbot [1], northern pike [1]).

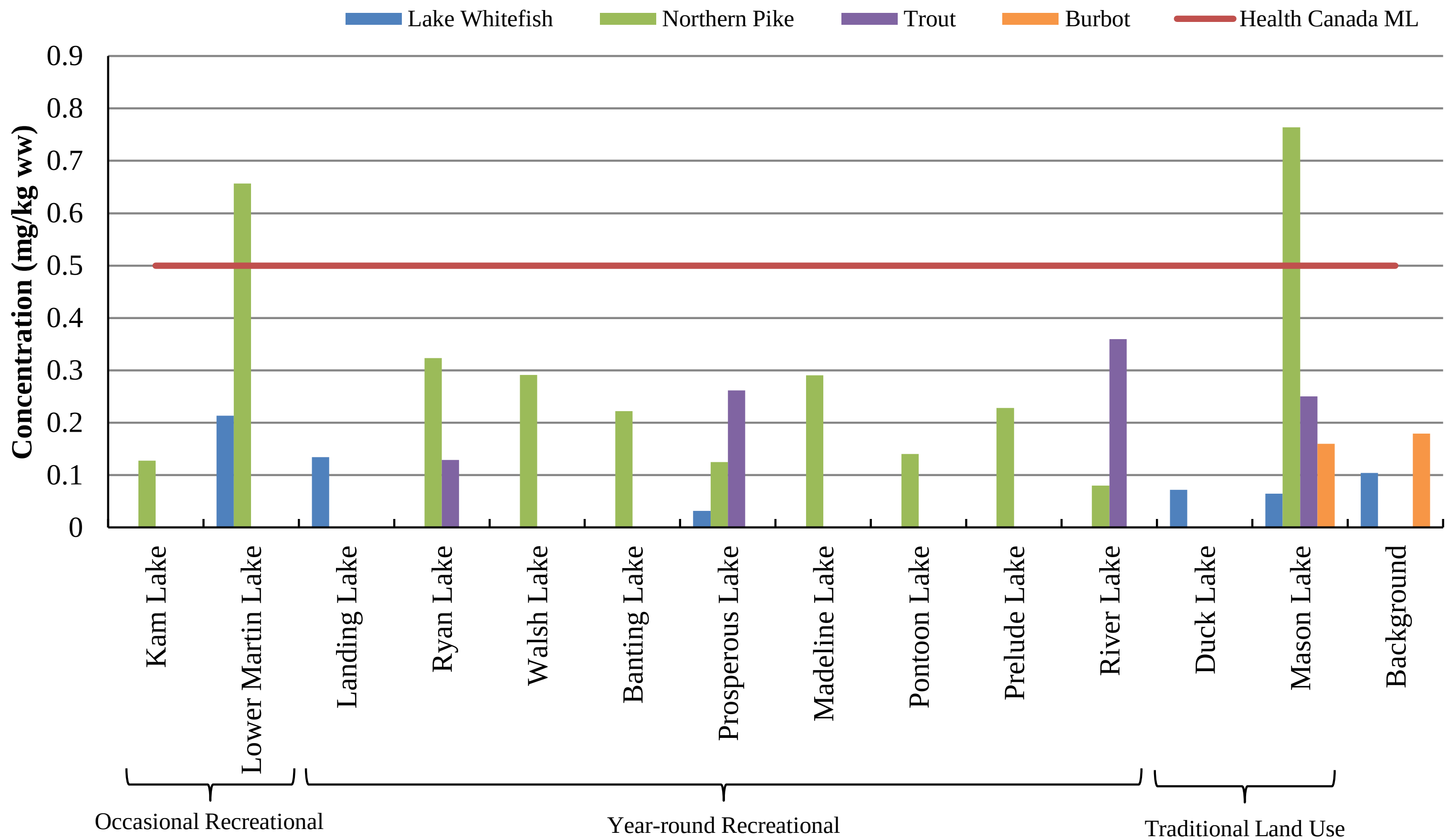
Figure 2.17 Average arsenic concentrations in fish flesh compared to surface water from inland lakes within the study area



Number of fish samples is 3 or more for all species and lakes except for Kam Lake (northern pike [2]), Prosperous Lake (lake whitefish [2], northern pike [1], trout [2]), River Lake (northern pike [2], trout [1]), Ryan Lake (trout [1]), and Mason Lake (burbot [1], northern pike [1]).

Figure 2.18 shows that mercury concentrations in the flesh of northern pike and trout are higher than in the flesh of lake whitefish. This is not surprising given that mercury bioaccumulates and northern pike and trout are predatory fish. With the exception of northern pike in Lower Martin and Mason lakes, the average flesh concentrations are below the Health Canada (2018a) Maximum Level (ML) for mercury in the edible portion of fish of 0.5 mg/kg ww. This ML for mercury is appropriate in this assessment as it is for people who are not subsistence consumers; although people in the area of Yellowknife may subsist on locally caught fish, based on survey results people obtain the majority of their fish from larger waterbodies such as Great Slave Lake. The elevated concentration of mercury in the single northern pike sample from Mason Lake may be attributed to the age of the fish, as it was noted to be large.

Figure 2.18 Average mercury concentrations in fish flesh from inland lakes within the study area



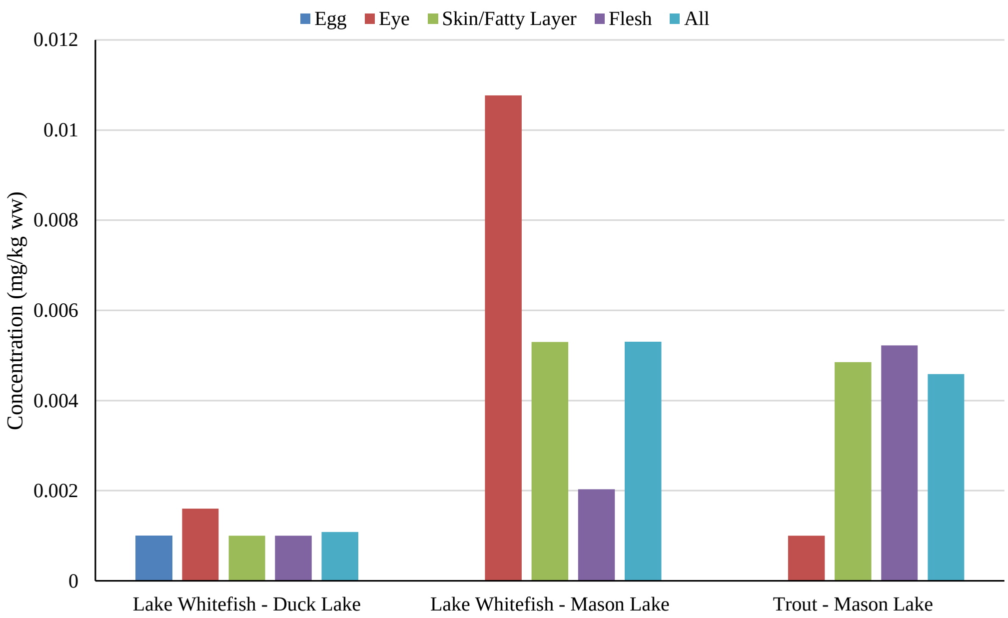
There are no data available for mercury in fish from Grace or Long lakes (occasional recreational area), Vee Lake (year-round recreational area), or Hay Lake (Traditional Land Use area). Health Canada (2018a) Maximum Level (ML) for mercury in the edible portion of fish. Number of samples is 3 or more for all species and lakes except for Kam Lake (northern pike [2]), Prosperous Lake (lake whitefish [2], northern pike [1], trout [2]), River Lake (northern pike [2], trout [1]), Ryan Lake (trout [1]), and Mason Lake (burbot [1], northern pike [1]).

Other Fish Tissues

During discussions, representatives of the YKDFN stated that they consume various other parts of the fish including eggs, eyes and the fatty layer under the skin. Thus, samples of eggs, eyes, and the skin/fatty layer were submitted for analysis from a subset of the trout (Mason Lake) and lake whitefish (Duck and Mason lakes) samples that were collected in 2019 and 2021 from the TLU area. There were 9 total eye samples, 3 egg samples, and 15 skin/fatty layer tissues. The raw data are provided in Appendix A, while summary statistics are provided in Appendix E. The average concentrations of antimony, arsenic, and mercury in the various tissue types (including flesh) are summarized in Figure 2.19, Figure 2.20, and Figure 2.21, respectively.

From Figure 2.19, there are essentially no tissue-specific variations in antimony concentrations in lake whitefish from Duck Lake. Interestingly, tissue-specific variations were noted for fish from Mason Lake, although the opposite pattern was noted between lake whitefish (highest in eye and lowest in flesh) and trout (lowest in eye and highest in flesh). When combined, the average antimony concentrations in all tissue types are similar between lake whitefish and trout in Mason Lake, and are higher than the concentrations in lake whitefish from Duck Lake.

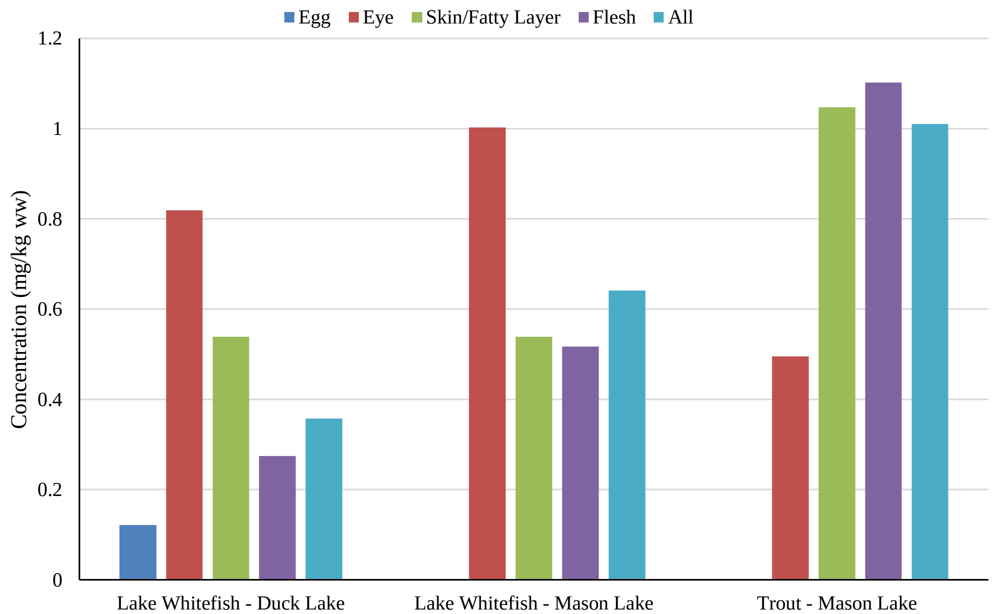
Figure 2.19 Average antimony concentrations in various fish tissues types from inland lakes within the study area



Number of samples is as follows:
Lake whitefish - Duck Lake: egg (3), eye (2), skin/fatty layer (2), flesh (7) Trout - Mason Lake: eye (1), skin/fatty layer (4), flesh (4)
Lake whitefish - Mason Lake: eye (6), skin/fatty layer (9), flesh (10)

In Duck Lake, the concentration of arsenic varies by tissue type. For example, arsenic concentrations in the skin/fatty layer of lake whitefish are approximately double those in the flesh. In Mason Lake the concentrations in the skin/fatty layer and flesh are similar for both lake whitefish and trout (Figure 2.20).

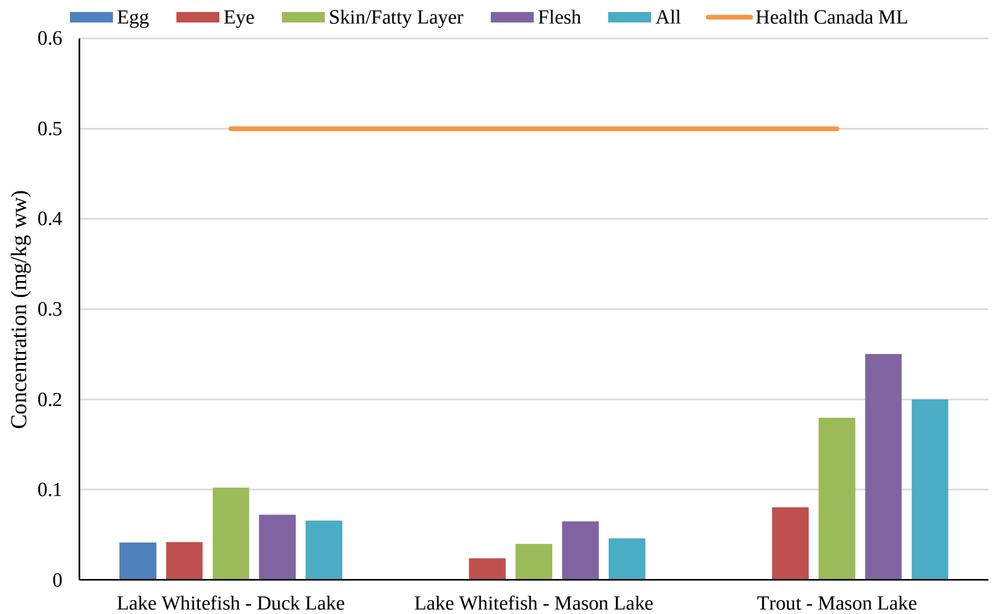
Figure 2.20 Average arsenic concentrations in various fish tissues types from inland lakes within the study area



Number of samples is as follows:
Lake whitefish - Duck Lake: egg (3), eye (2), skin/fatty layer (2), flesh (7) Trout - Mason Lake: eye (1), skin/fatty layer (4), flesh (4)
Lake whitefish - Mason Lake: eye (6), skin/fatty layer (9), flesh (10)

The same data are shown in Figure 2.21 for mercury. Unlike for arsenic and antimony, the mercury concentrations in lake whitefish from Duck Lake appear to be no different than those in lake whitefish from Mason Lake, and the concentrations do not appear to vary greatly with tissue type. The concentrations are all below the Health Canada (2018a) ML of 0.5 mg/kg ww.

Figure 2.21 Average mercury concentrations in various fish tissues types from inland lakes within the study area



Number of samples is as follows:
Lake whitefish - Duck Lake: egg (3), eye (2), skin/fatty layer (2), flesh (7) Trout - Mason Lake: eye (1), skin/fatty layer (4), flesh (4)
Lake whitefish - Mason Lake: eye (6), skin/fatty layer (9), flesh (10)

2.4.3 Game

Data for game were largely obtained from the voluntary country foods sampling program that was initiated in support of the GMRP HHERA (CanNorth 2018), which collected samples of flesh and organs for the following game:

- ducks (lesser scaup, white winged scoter, black duck, mallard, Canada goose)
- muskrat and beaver
- hare
- ptarmigan and spruce grouse
- moose

Only the flesh samples are considered in this HHRA. Eating organs was considered in the GMRP HHERA (CanNorth 2018) which demonstrated that eating organs (liver, heart, gizzard) added very little to the arsenic and antimony exposure and therefore is not evaluated in this assessment.

Several samples of muskrat flesh were obtained from the TLU area and Yellowknife Bay in 2020 by local harvesters from the YKDFN as it was noted that the YKDFN harvest from around this area.

Figure 2.22 shows the locations from which samples of game flesh were obtained that were considered in the assessment. Similar to other media, background samples of game were considered to be those obtained from beyond the 25 km radius (50 km or more for moose due to their large home range) and are presented in Appendix D.

The data for game by type (rabbit, muskrat/beaver, grouse/ptarmigan, ducks, moose) from all areas within a 25 km radius (50 km for moose) were combined since the concentrations do not vary by location. This same approach was used in the GMRP HHERA (CanNorth 2018). Similarly, data for game from areas greater than 25 km from the Giant Mine site (50 km for moose) were combined to represent background. The raw data are provided in Appendix A, while summary statistics are provided in Appendix E.

Figure 2.23 and Figure 2.24 present the antimony and arsenic concentrations in the flesh of game, respectively. Concentrations of both antimony and arsenic are higher for samples obtained from within 25 km of the Giant Mine site (50 km for moose) than for those obtained from background locations, except for beaver where the background concentrations are higher based on a single sample obtained from Drybones Bay. Given the elevated background concentrations in beaver flesh and the limited number of beaver samples from the study area in comparison to muskrat (i.e., 3 versus 9), muskrat was selected as the surrogate species for small aquatic mammals in the HHRA.

Figure 2.22 Game flesh sampling locations from the study area

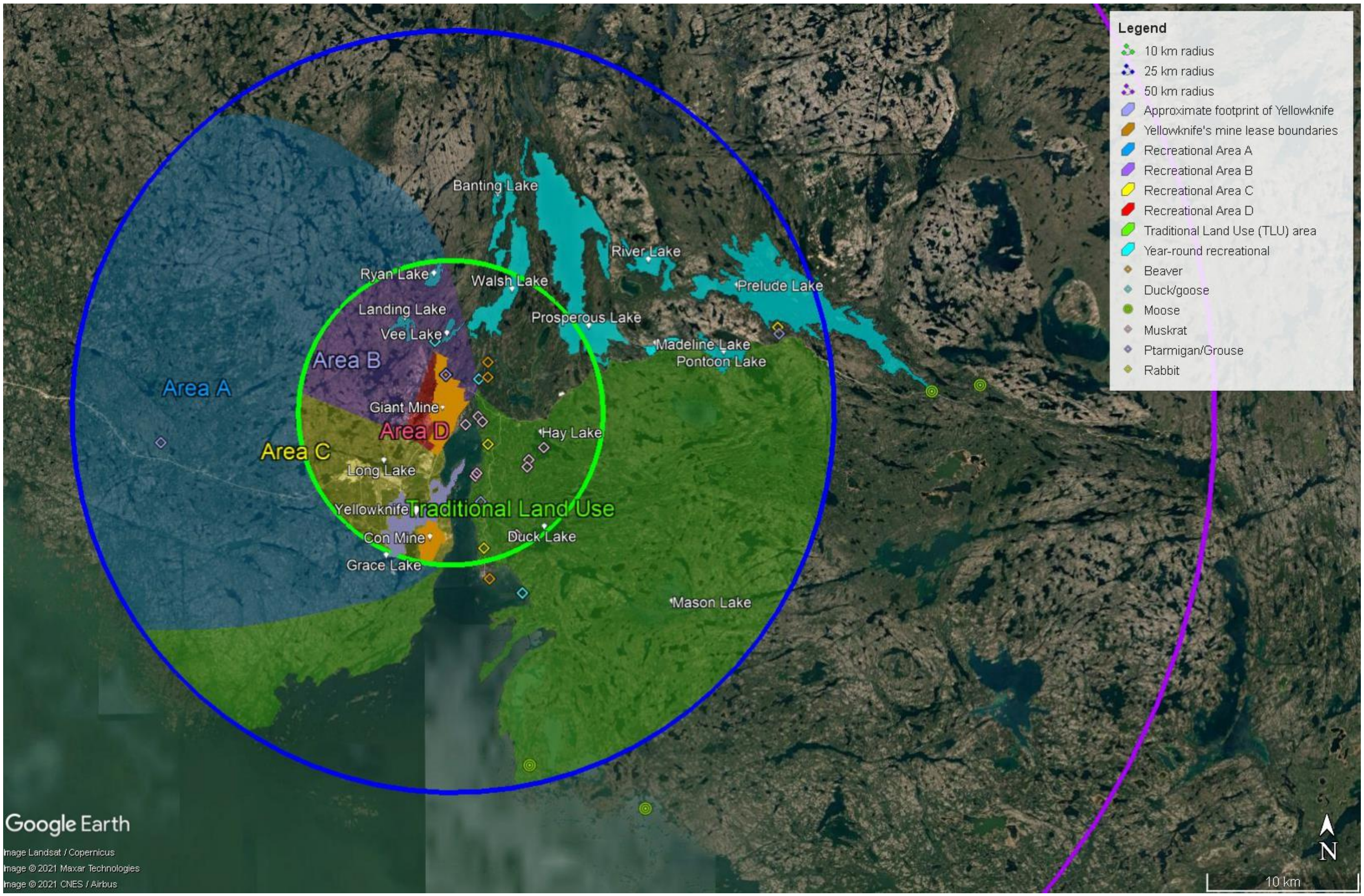
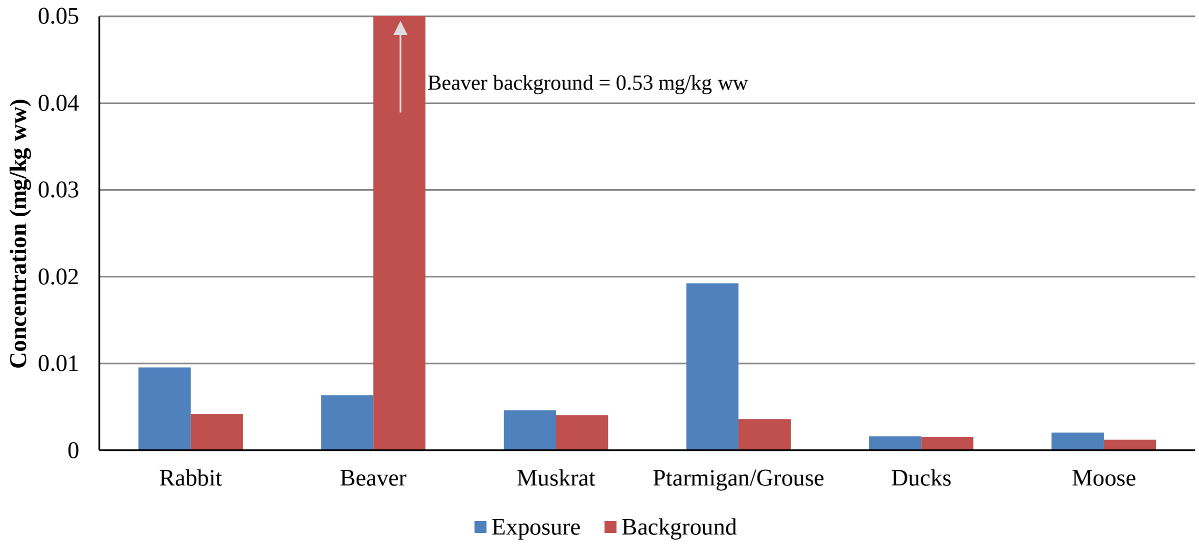
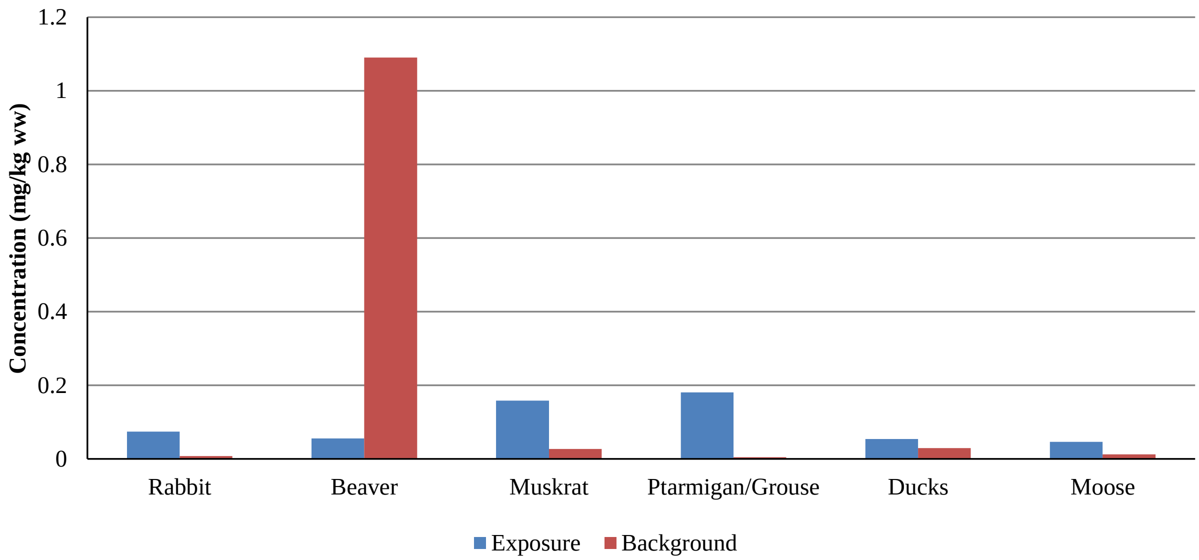


Figure 2.23 Average antimony concentrations in game flesh within the study area



Note that the muskrat data were used in lieu of beaver data as a surrogate for all small aquatic animals owing to the elevated background concentration based on a single sample.
Number of samples (exposure, background): Rabbit (3, 4), Beaver (3, 1), Muskrat (9, 2), Ptarmigan/Grouse (6, 6), Ducks (4, 2), Moose (4, 3).

Figure 2.24 Average arsenic concentrations in game flesh within the study area



Note that the muskrat data were used in lieu of beaver data as a surrogate for all small aquatic animals owing to the elevated background concentration based on a single sample.
Number of samples (exposure, background): Rabbit (3, 4), Beaver (3, 1), Muskrat (9, 2), Ptarmigan/Grouse (6, 6), Ducks (4, 2), Moose (4, 3).

3.0 PROBLEM FORMULATION

The Problem Formulation develops the foundation for the risk assessment and provides an understanding of the people that are exposed, scenarios considered, and ways in which people are exposed. All of these components are summarized within a conceptual site model (CSM).

Development of the CSM took into account information from the community engagement as well as input from the YKDFN. Although a formal land use survey was not completed with the YKDFN, the GNWT has been involved in ongoing discussions with representatives of the YKDFN who have provided input on areas that are heavily used by its members for traditional activities such as hunting, fishing, and gathering. In addition, through the Risk Communications Advisory Committee meeting, representatives of the YKDFN provided input to the study team in terms of various activities they conduct in the area around Yellowknife, examined the initial study area maps that were produced, and indicated that the original TLU area should be expanded. During this meeting, the YKDFN also stated the parts and types of fish they eat and their concerns around eating fish, including Arctic grayling from Baker Creek. This information has been incorporated into the assessment. An evaluation of risk from eating Arctic grayling from Baker Creek is provided in Appendix L.

3.1 Human Receptor Identification

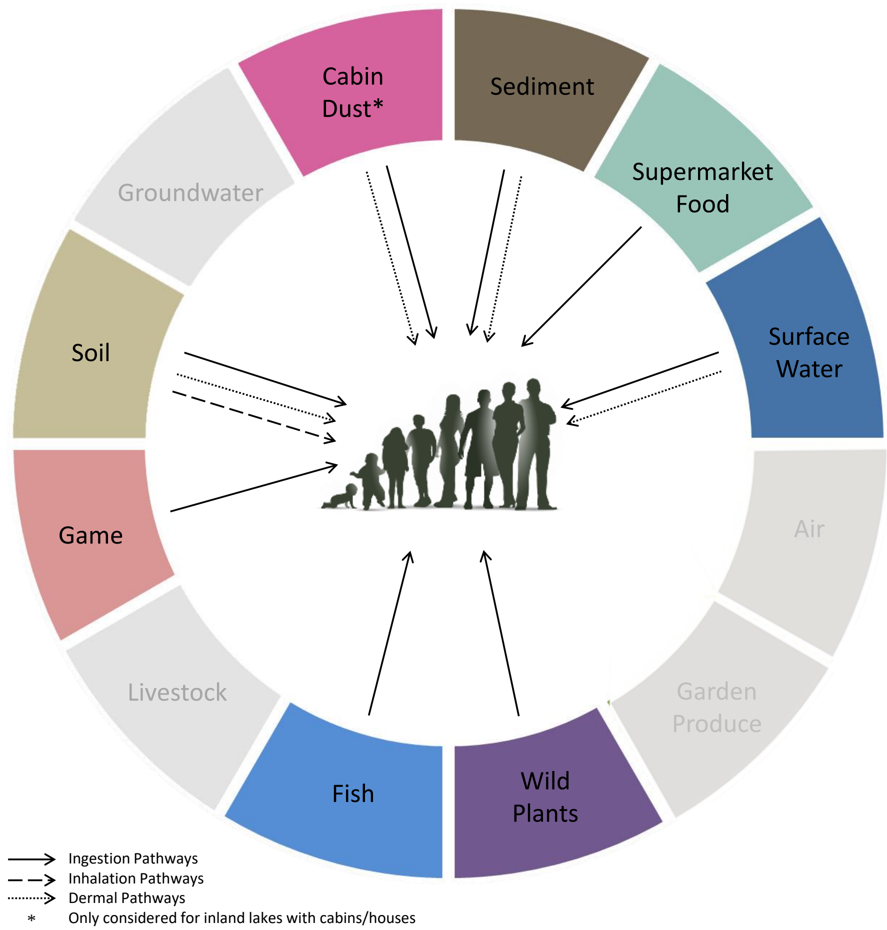
Based on information collected as part of the community engagement survey completed in May 2018, it was determined that people living in Yellowknife, Ndilǫ, and Dettah generally use one or more of the recreational areas (Areas A to D) for activities such as running, walking, picnicking, and camping, as well as hunting and fishing. There are also several people who inhabit houses or cabins on inland lakes in the area year-round. Thus, people of all age groups from toddler to Elder were considered in the assessment.

Exposures to infants were not evaluated because it is assumed that they would be mainly consuming breast milk and would not be exposed to soils and other environmental media, including dust on surfaces and floors in houses/cabins on inland lakes. This is the same approach that was adopted in the GMRP HHERA (CanNorth 2018). It is not expected that arsenic would be found at high concentrations in breast milk. Samanta et al. (2007) supports this statement with the finding that breast milk had low concentrations of arsenic even when women were being exposed to high levels of arsenic in their drinking water (up to 1.4 mg/L). Carignan et al. (2015) conducted a study that compared breastfed infants to formula-fed infants and determined that breastfed infants had lower arsenic exposure than formula-fed infants. These studies support the exclusion of infants.

3.2 Exposure Pathways

The ways that people become exposed (exposure pathways) to antimony and arsenic in the study area through the activities described above are shown in Figure 3.1.

Figure 3.1 Exposure pathways for the human health risk assessment



The following ways that people are exposed as shown in the above figure are:

- **Surface Water**: Based on answers from the land use survey, there is a mix of people who drink lake water and bottled water within the study area.

Additionally, some people indicated that they swim at inland lakes. Thus, drinking water and swallowing water and skin contact while swimming were considered in the assessment. It should be noted that arsenic advice from the Chief Public Health Office is to not drink untreated water from lakes.

- **Soil**: People may come into contact with soil while being out on the land, for exampling while hunting or trapping or gathering activities. Children and toddlers may also be exposed while playing outside on the ground. Arsenic and antimony in the soil can transfer to skin by these activities, and soil on hands can end up in the mouth and be eaten.
- **Indoor Dust**: Dust from soil has similar concentrations as found in soil and can be tracked from outside into cabins or houses. Dust can be picked up by hands and transferred to the mouth or can pass through the skin into the body.
- **Sediment**: Some people reported that they wade in the inland lakes. People who are boating may also come into contact with sediments as they carry out boating or fishing activities. Sediments can stick on the skin resulting in arsenic and antimony getting into the body. Suspended sediments in the water can also be swallowed while swimming. Ingestion of suspended sediments in drinking water obtained from lakes was not evaluated since it was assumed that these sediments are generally removed from the water, either by deposition in a holding tank or by screens/filters in the line from the lake.
- **Fish**: People have reported fishing in the inland lakes and therefore the assessment considered consumption of fish flesh from the lakes, as well as fish eyes and the skin/fatty layer. Eating other fish organs was considered but the GMRP HHERA (CanNorth 2018) demonstrated that eating fish organs (liver) added very little to the arsenic and antimony exposure and therefore is not evaluated in this assessment.
- **Wild Plants (Berries and Mushrooms)**: Based on the responses from the questionnaire, some people collect and eat berries and mushrooms from different locations within the study area.
- **Game**: The land use survey indicated that people hunt and/or trap in areas considered in the assessment. The dietary survey for the GMRP HHERA (CanNorth 2018) indicated that people consume moose, grouse, ptarmigan, rabbit/hare, duck, and muskrat and thus it was assumed that these animals were consumed in the assessment. The GMRP HHERA (CanNorth 2018) demonstrated

that eating organs (liver, heart, gizzard) added very little to the arsenic and antimony exposure and therefore eating organs from game is not evaluated in this assessment.

- **Supermarket Food**: As part of the dietary survey completed for the GMRP HHERA (CanNorth 2018), many people indicated that a large portion of their diet was supermarket food. Thus, eating food bought from the supermarket was considered in the assessment.

Other pathways such as inhalation of air, eating vegetables and livestock and drinking groundwater were also considered but were not evaluated for the following reasons:

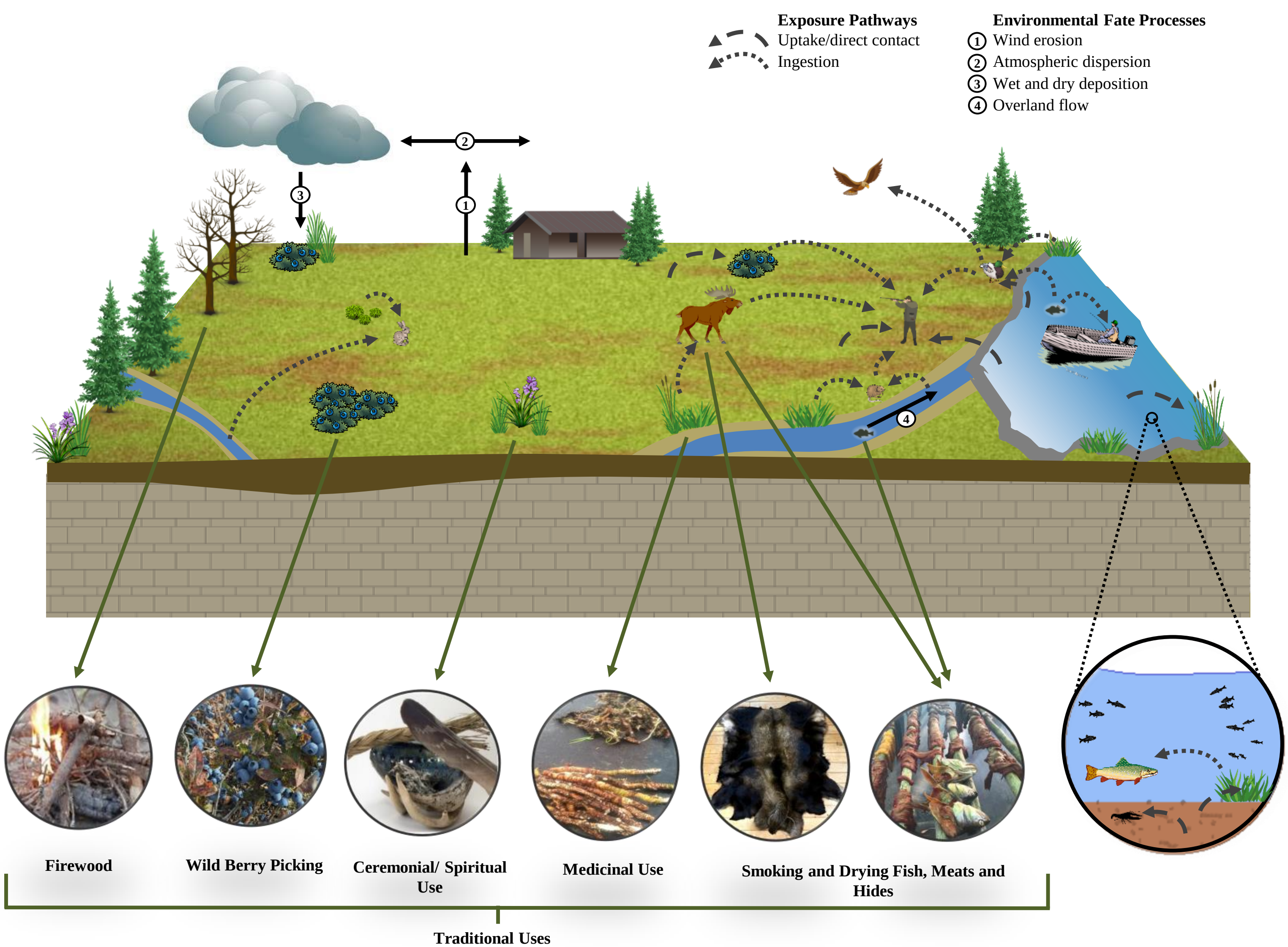
- **Air:** Arsenic and antimony may be present in the air and can be breathed in by people during recreational activities or when they are present at their cabins or houses in the study area. However, since activities have ceased at the Giant and Con Mine sites and the roasters have been demolished, the concentrations in air are very low. The GMRP HHERA (CanNorth 2018) found that breathing air was a negligible pathway and thus was not considered in this assessment. This pathway would also be negligible during remediation of the Giant Mine site as there would be procedures and mitigation in place to ensure that arsenic and antimony air concentrations are low.
- **Garden Produce**: Vegetable gardens are not present within the recreational areas being evaluated. There may be a few gardens around cabins at the inland lakes, but concentrations of antimony and arsenic in these gardens are expected to be small. The GMRP HHERA (CanNorth 2018) found that there is no increased health risk from consuming garden produce and thus this pathway was not considered. A follow up study on levels of arsenic in garden produce is currently in progress.
- **Wild Plants (Medicinal)**: Based on the responses from the questionnaire, people may also collect wild plants for medicinal purposes (e.g., rat root, birch bark, Labrador tea, etc.) from different locations within the study area. Based on the results of the GMRP HHERA (CanNorth 2018), exposure to antimony and arsenic from drinking of medicinal tea is a very small pathway and therefore drinking medicinal teas or eating medicinal plants was not considered further.

- **Livestock**: There are no known livestock farms in the study area and thus this pathway was not evaluated.
- **Groundwater**: There are no groundwater wells in the study area and people indicated either drinking bottled water or water from the inland lakes therefore groundwater was not considered further.

3.3 Conceptual Site Model

The CSM for the HHRA is presented in Figure 3.2. A CSM generally provides a picture to show the different pathways that are being evaluated in the risk assessment as well as the ways that the COPC move from the soil, sediment, and water and are taken up by plants, fish, and other animals. The picture in Figure 3.2 captures many of the pathways that are being considered in the HHRA but does not include every pathway. For example, it shows a large animal, such as a moose, but does not show all small animals, such as grouse or ptarmigan. The animals presented are selected to represent all game. The CSM presented here represents the assumptions for the evaluation of people at inland lakes with houses/cabins, which also includes recreational pathways. Traditional activities are also presented in the CSM.

Figure 3.2 Conceptual site model for the human health risk assessment



4.0 EXPOSURE ASSESSMENT

The exposure assessment involves the estimation of the intakes of antimony and arsenic by people using the recreational areas, TLU area, or living on inland lakes with houses or cabins. The total intake for antimony or arsenic represents the sum of the intakes calculated for each of the exposure pathways, including soil, surface water, sediment, fish, berries, mushrooms, and game. The approach used in the exposure assessment tends to use assumptions that overestimate exposures.

4.1 Receptor Characterization

Several different characteristics of individuals influence their exposure. These characteristics include their body weight, how much water they drink, how much food they eat, and how long they spend outdoors, to name a few. These characteristics are different depending on the age of the individual. For example, toddlers tend to eat more soil and dust since they crawl and play on the ground and then put their hands in their mouths. Since they do not weigh very much, a toddler also tends to be the most highly exposed life stage in HHRA on a body weight basis.

The intake rates for the fish, berries, mushrooms, and game were obtained from the dietary survey conducted as part of the GMRP HHERA (CanNorth 2018), while the intake rates for soil, drinking water, and water and sediment while swimming were obtained from regulatory agencies such as Health Canada and the United States Environmental Protection Agency (U.S. EPA). These intakes are the same as what was used in the GMRP HHERA (CanNorth 2018). The receptor characteristics are summarized in the following sections for the Elder (70 plus years of age), adult (20 to 69 years of age), teen (12 to 19 years of age), child (5 to 11 years of age), and toddler (0.5 to 4 years of age), while more details are provided in Appendix F.

4.1.1 Food Consumption

People may be exposed to arsenic and antimony through eating both supermarket foods and country foods. A dietary survey was conducted as part of the GMRP HHERA (CanNorth 2018) and based on this, three different diets with unique consumption rates were identified:

1. A predominantly supermarket food diet where only a small amount of country food is eaten.
2. A mixed supermarket/country food diet where a higher amount of country food is eaten. This diet is representative of the majority of respondents from the survey who consumed country food.
3. A diet where people live entirely off the land (i.e., subsistence country food diet with no supermarket food). The subsistent diet, which provides higher exposures in some cases, is only representative of a small number of respondents from the dietary survey as most people supplement their country food with food from the supermarket.

A summary of the dietary survey results from the GMRP HHERA (CanNorth 2018) is provided in Appendix F.

The people who only had occasional exposures in recreational areas A through D were assumed to have a predominantly supermarket food diet. Two dietary scenarios were considered for people exposed year-round in cabins/houses on inland lakes, including a predominantly supermarket food diet and a mixed supermarket/country food diet for those who may obtain more food from the land. The use of the mixed diet encompasses people from the YKDFN that may use the inland lake areas on a year-round basis. For the TLU area, the mixed supermarket food/country food diet and the subsistence country food diets were evaluated.

4.1.1.1 Country Food Consumption Rates

For this HHRA, the information on country food consumption rates from the dietary survey for the GMRP HHERA (CanNorth 2018) was considered to be appropriate to use for the amount of fish, berries, mushrooms, and game that people eat as it was obtained from community members. The amount that people eat of the various country food items from the dietary survey was related to adults and Elders. Consumption rates for other life stages were estimated by assuming that the diets of a teen, child, and toddler are 91%, 75%, and 50%, respectively, of that of an adult. The percentage value for teens is based on data from Richardson (1997) for First Nations people, and the percentage values for the child and toddler are based on data from a Canada-wide survey (Health Canada 1994). The subsistence country food diet was only considered for adults as it was clear from the dietary survey that only adults had a diet consisting largely of country foods; this is the same approach that was used in the GMRP HHERA (CanNorth 2018). The specific amounts of food that people eat that were used in the assessment are summarized in Table 4.1. It is noted that in the dietary survey, respondents with high country food intakes indicated that they did not eat mushrooms and this is reflected by the zero (0) in the table for the subsistence diet. Additionally, only adults were evaluated for eating mushrooms collected in the study area based on the survey results.

Table 4.1 Summary of country food ingestion rates for human receptors

Country Food Item	Elder/Adult	Teen[a]	Child[a]	Toddler[a]
Predominantly Supermarket Food Diet (g/d)				
Moose	2.8	2.5	2.1	1.4
Fish	49	45	37	24
Rabbit	0.2	0.2	0.2	0.1
Ptarmigan/Spruce Grouse	1.4	1.3	1.0	0.7
Ducks (includes Goose)	1.9	1.7	1.3	0.9
Muskrat	0.5	0.4	0.3	0.2
Berries	2.5	2.2	1.8	1.2
Mushrooms[b]	7.5	0	0	0
Mixed Supermarket/Country Food Diet (g/d)				
Moose	7.0	6.4	5.2	3.5
Fish	170	155	128	85
Rabbit	2.8	2.5	2.1	1.4
Ptarmigan/Spruce Grouse	2.8	2.5	2.1	1.4
Ducks (includes Goose)	4.2	3.8	3.1	2.1
Muskrat	1.8	1.7	1.4	1.0
Berries	2.5	2.2	1.8	1.2
Mushrooms[b]	7.5	0	0	0
Subsistence Country Food Diet (g/d)[c]				
Moose	21	*6.4*	*5.2*	*3.5*
Fish	255	*155*	*128*	*85*
Rabbit	18	*2.5*	*2.1*	*1.4*
Ptarmigan/Spruce Grouse	9.3	*2.5*	*2.1*	*1.4*
Ducks (includes Goose)	27	*3.8*	*3.1*	*2.1*
Muskrat	20	*1.7*	*1.4*	*1.0*
Berries	4.9	*2.2*	*1.8*	*1.2*
Mushrooms[b]	0	*0*	*0*	*0*

Note: Based on results of dietary survey completed as part of GMRP HHERA; averaged over 365 days.
[a] Values estimated assuming they represent 91% (teen), 75% (child), and 50% (toddler) of adult ingestion rates.
[b] Based on survey results, mushroom consumption was evaluated for adult receptor; mushroom ingestion rate obtained from Obst (2014) and is discussed in Appendix F. Respondents with high country food intakes indicated they did not eat mushrooms and thus mushrooms were not evaluated for a subsistence country food diet.
[c] Subsistence country food diet was only evaluated for adults; *set equal to mixed supermarket/country food diet for teen, child, and toddler for evaluation of lifetime incremental cancer risks to a composite receptor*.

4.1.1.2 Supermarket Food Intakes

In the assessment, it was assumed that people would eat some supermarket foods, except for those people with a subsistence country food diet (i.e., 100% country foods). Typical intakes of antimony and arsenic from Canadians eating supermarket foods are available in the literature and are presented in Table 4.2. There is some double-counting, since supermarket intakes include some foods obtained from local sources as country foods (e.g., berries, fish, etc.).

Table 4.2 Summary of general Canadian supermarket food dietary intakes

COPC	Intake (mg/kg-d)				Reference
	Elder/Adult	Teen	Child	Toddler	
Antimony	3.3×10^{-5}	5.0×10^{-5}	5.0×10^{-5}	7.7×10^{-5}	FSA (2009), with consideration of information presented in Health Canada (1997).
Arsenic	8.0×10^{-5}	1.0×10^{-4}	2.0×10^{-4}	3.0×10^{-4}	EC (1999), inorganic arsenic in food.

Note: FSA = United Kingdom Food Standards Agency, EC = Environment Canada.

4.1.2 Water Intake

The average amount of water drunk by an Elder/adult, teen, child, and toddler from Health Canada (2012a) are 1.5 L/d, 1 L/d, 0.8 L/d, and 0.6 L/d, respectively. This is equivalent to about 6 glasses, 4 glasses, 3 glasses, and 2½ glasses of water a day.

4.1.3 Soil Intake

Various studies related to camping and wilderness lifestyles were reviewed in the selection of the appropriate values for the assessment (Stanek and Calabrese 2000; Irvine et al. 2014; Doyle et al. 2012). Appendix F provides a more detailed discussion for the selection of how much soil people end up eating during outdoor activities.

For the assessment of year-round residents of inland lakes with cabins, soil ingestion rates from Health Canada (2012a) were used, with a value of 80 mg/d for the toddler and 20 mg/d for the Elder, adult, teen, and child.

For exposure during occasional recreational and TLU activities such as camping and hunting, higher soil ingestion rates were used. The soil ingestion rates that represent the highest values (upper percentile) in a population from the U.S. EPA (2017) Exposure Factors Handbook were selected. These values are 90 mg/d for the toddler and child and 50 mg/d for the teen and adult/Elder and are within the range of mean values derived in other studies for an adult practicing a wilderness lifestyle (Irvine et al. 2014; Doyle et al. 2012).

4.1.4 Indoor Dust Intake

People may eat some indoor dust when it is present on their hands and they then put them in their mouth. Wilson et al. (2013) provides average dust ingestion rates for the Elder/adult, teen, child, and toddler of 2.5 mg/d, 2.2 mg/d, 31 mg/d, and 41 mg/d, respectively. These values are supported by Health Canada in their recent guidance on exposure to indoor settled dust (Health Canada 2018b). Further discussion on the selection of indoor dust intake rates is provided in Appendix F.

4.1.5 Sediment Intake

The assessment considered the swallowing of suspended sediments while swimming in the inland lakes. The estimated sediment ingestion rates from the literature for use in human health risk assessments are limited. Wilson et al. (2015) provides a suspended sediment ingestion rate of 7.7 mg/hr for all age groups partaking in near-shore, in-water activities in shallow water (i.e., wading, walking, playing in water). This value was used in the assessment.

4.1.6 Swimming Water Intake

There is limited available information related to the amount of water someone can drink while swimming. The U.S. EPA (2019a) provides an estimate of the amount of water a person could drink while swimming, based on results from swimming pool experiments (Dufour et al. 2006). Dufour et al. (2006) considered that swimming behaviour of recreational pool swimmers may be similar to freshwater swimmers. Based on the U.S. EPA (2019a), the mean hourly rates for the Elder/adult, teen, and child of 28 mL/hr, 44 mL/hr, and 38 mL/hr, respectively, were used. The value for the child was also applied for the toddler. The Chicago School of Public Health (Dorevitch et al. 2011) carried out a study of water ingestion during recreational activities. This study indicated that the upper confidence estimate of water ingestion during swimming was 35 mL/hr, which is similar to the average of the ingestion rates provided by the U.S. EPA (2019a). Further details on the amount of water swallowed while swimming are provided in Appendix F.

4.1.7 Skin Contact

4.1.7.1 Soil

People can be exposed through soil sticking to the skin during different outdoor activities. Exposed skin surface areas for hands for the Elder/adult, teen, child, and toddler of 890 cm^2, 800 cm^2, 590 cm^2, and 430 cm^2, respectively, are provided by Health Canada (2012a). Exposed skin surface areas for arms and legs for the Elder/adult, teen, child, and toddler of 8,220 cm^2, 7,200 cm^2, 4,550 cm^2, and 2,580 cm^2, respectively, are also provided by Health Canada (2012a). The total body surface area is not considered, since clothes provide protection to other areas of the body. Estimates for soil loading to exposed skin (hands, arms, and legs) are provided by Health Canada (2012a); these values are $1x10^{-7}$ kg/cm^2-event for hands and $1x10^{-8}$ kg/cm^2-event for arms and legs.

4.1.7.2 Indoor Dust

People can also be exposed to dust on ledges and other areas in a cabin or house when dust sticks to the skin. Exposed skin surface areas for hands for the Elder/adult, teen, child, and toddler of 890 cm^2, 800 cm^2, 590 cm^2, and 430 cm^2, respectively, are provided by Health Canada (2012a, 2018b). Indoor dust exposure mainly occurs through hand contact since clothes provide protection to other areas of the body and hands are the most likely to be in contact with indoor dust. Dust loading to exposed skin (hands) are provided by Wilson & Meridian (2011); this value is $2x10^{-7}$ kg/cm^2-event for hands.

4.1.7.3 Sediment

Sediment can also stick to the skin while wading, and then antimony and arsenic can be transferred through the skin. Weighted sediment adherence factors for skin for all life stages were calculated based on Shoaf et al. (2005a) for adults and Shoaf et al. (2005b) for children. Full body (hands, arms, legs, feet) exposure was considered for toddlers (3,000 cm^2), while children were assumed to have feet and leg exposure (3,790 cm^2). Teens and adults/Elders are generally assumed to have sediment exposure to feet only (1,080 cm^2 and 1,200 cm^2, respectively). It should be noted that sediments that are underwater are likely to be washed off while wading in water whereas wet sediments at the shoreline may to stick to the skin.

4.1.7.4 Swimming Water

While swimming, skin is in contact with water and thus antimony and arsenic can be transferred. Exposed total body skin surface areas for the Elder/adult, teen, child, and toddler of 17,640 cm^2, 15,470 cm^2, 10,140 cm^2, and 6,130 cm^2, respectively, are provided by Health Canada (2012a).

4.1.8 Body Weight

The body weight (bw) of a receptor is needed to calculate a daily intake rate in mg/(kg bw/d. Body weights for the Elder/adult, teen, child, and toddler of 70.7 kg, 59.7 kg, 32.9 kg, and 16.5 kg, respectively are provided by Health Canada (2012a).

4.2 Exposure Scenarios

The exposure scenarios for the assessment were developed based on information gathered as part of the community engagement, land use questionnaires that were completed in May 2018, and ongoing discussions with the YKDFN. Based on the reported recreational and traditional land uses of the study area (see Section 2.2), different exposure scenarios were developed for occasional and year-round recreational and traditional land uses, including a base case and additional scenarios. The following combinations of receptors and exposure scenarios were identified:

1. People carrying out occasional recreational activities such as running, walking, picnicking, and hunting in areas A through D and the TLU.
2. People fishing and swimming in areas A through C and the TLU. These pathways were not evaluated for Area D, which is closest to the Giant Mine site, as there are no inland lakes within this area that are suitable for fishing or swimming.
3. People who have a house or cabin on an inland lake and spend time swimming, fishing, and hunting there.

These are summarized in Table 4.3 and discussed below.

4.2.1 Base Case

The base case scenarios considered exposures associated with drinking bottled water or municipal water, touching and eating soil, and eating berries and game. Eating fish from inland lakes with cabins/houses was only considered in the base case for people living on these lakes. This encompasses people who would come from the Yellowknife to fish on weekends or occasions. Indoor dust exposure in cabins/houses was also considered in the base case for people living on inland lakes.

A person with a predominantly supermarket food diet was evaluated for the base case for recreational activities in areas A, B, C, and D as well as year-round residents at the inland lakes (Vee, Landing, Ryan, Walsh, Banting, Prosperous, Madeline, Pontoon, Prelude, and River). Year-round residents were also evaluated assuming they ate a mix of supermarket and country foods. Members of the YKDFN who hunt, fish, and gather in the TLU area were evaluated assuming that they eat a mix of supermarket and country food, as well as live entirely off the land (i.e., subsistence country food diet).

The exposure pathways evaluated for the base case scenarios are summarized in Table 4.3.

4.2.2 Additional Scenarios

Several additional scenarios were evaluated based on the responses to the survey questionnaires (Appendix B) and included activities such as fishing, swimming, and eating mushrooms. These scenarios result in the addition of various exposure pathways onto the base case scenarios presented above. The completed survey questionnaires reported low use of Area D (area closest to the Giant Mine site), therefore only the base case was evaluated for this area.

The Chief Public Health Office arsenic advice is to not drink untreated water from lakes. However, responses to the survey questionnaire (Appendix B) indicated that some people do drink water from the lakes and thus a scenario was included to evaluate this exposure pathway. As seen from Section 2.4.2, concentrations are available for many of the small, unnamed lakes in the study area and a number of these small lakes have much higher concentrations than the larger lakes. For example, arsenic concentrations in water in Duck, Mason, and Hay lakes in the TLU are below drinking water guidelines but there are smaller lakes in the TLU with arsenic concentrations above the guideline (see 2.4.2.1). Year-round exposure at inland lakes was considered on a daily basis (residents) or periodically (occasional cabin-goers) for lakes where the arsenic concentrations are above the drinking water guideline. Thus only Landing Lake and Ryan Lake are evaluated since arsenic concentrations in these lakes exceed the drinking water guidelines. It was assumed that people using the houseboat at Vee Lake would not drink water from the lake.

There were also a wide range of responses to the questionnaire regarding swimming in lakes, from ‘never’ to ‘daily’. Therefore, additional scenarios were considered to evaluate exposure to surface water and sediment while swimming in the inland lakes. It was assumed that people would swim in the recreational and TLU areas. For year-round residents of lakes with cabins, swimming was only evaluated in Landing Lake and Ryan Lake since the arsenic concentrations were above the drinking water guideline and thus represents a potential incremental arsenic exposure risk. Swimming in Vee Lake was not evaluated as people mainly use this lake to access other lakes.

Eating fish was considered as an additional scenario for areas A, B, C, and the TLU. For the TLU area, discussions with members who use the land indicated that fish are generally obtained from Duck Lake or Mason Lake. There is higher reported use of Duck Lake as opposed to Mason Lake. Thus, eating fish was evaluated separately for Duck and Mason lakes.

Eating mushrooms was also reported by some people. For occasional recreational use areas, this pathway was evaluated only for Area C since most of the data are for mushrooms that were collected from within this area (Figure 2.5). People with cabins/houses on Landing and Ryan lakes were also assumed to eat mushrooms, since exposures are considered to be the highest at these two locations and encompass the exposures from other year-round inland lakes.

The exposure pathways evaluated for the additional scenarios are summarized in Table 4.3.

Table 4.3 Scenarios evaluated in the assessment

Recreational Area	Scenario	Soil Ingestion and Contact[a]	Hunting	Berries	Drinking Lake Water	Swimming[b]	Fishing	Mushrooms	Diet[c]
AREA A									
Occasional	Base Case	**Y**	**Y**	**Y**	N	N	N	N	Predominantly supermarket food
	Fishing	**Y**	**Y**	**Y**	N	N	**Y**	N	
	Drinking Lake Water	**Y**	**Y**	**Y**	**Y**	N	N	N	
	Swimming	**Y**	**Y**	**Y**	N	**Y**	N	N	
	All	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	N	
Year-round	None								
AREA B									
Occasional	Base Case	**Y**	**Y**	**Y**	N	N	N	N	Predominantly supermarket food
	Fishing	**Y**	**Y**	**Y**	N	N	**Y**	N	
	Drinking Lake Water	**Y**	**Y**	**Y**	**Y**	N	**Y**	N	
	Swimming	**Y**	**Y**	**Y**	N	**Y**	**Y**	N	
	All	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	N	
Year-round (Vee, Landing, and Ryan lakes)	Base Case	**Y**	**Y**	**Y**	N	N	**Y**	N	1. Predominantly supermarket food 2. Mixed supermarket/ country food
Year-round (Landing and Ryan lakes[d])	Drinking Lake Water – Daily	**Y**	**Y**	**Y**	**Y**	N	**Y**	N	Mixed supermarket/country food
	Drinking Lake Water – Periodically	**Y**	**Y**	**Y**	**Y**	N	**Y**	N	
	Swimming	**Y**	**Y**	**Y**	N	**Y**	**Y**	N	
	Eating Mushrooms	**Y**	**Y**	**Y**	N	N	**Y**	**Y**	
	All	**Y**	**Y**	**Y**	**Y**[e]	**Y**	**Y**	**Y**	
AREA C									
Occasional	Base Case	**Y**	**Y**	**Y**	N	N	N	N	Predominantly supermarket food
	Fishing	**Y**	**Y**	**Y**	N	N	**Y**	N	
	Drinking Lake Water	**Y**	**Y**	**Y**	**Y**	N	N	N	
	Swimming	**Y**	**Y**	**Y**	N	**Y**	N	N	
	Eating Mushrooms	**Y**	**Y**	**Y**	N	N	N	**Y**	
	All	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	

Year-round	None

Table 4.3 Scenarios evaluated in the assessment (Continued)

Recreational Area	Scenario	Soil Ingestion and Contact[a]	Hunting	Berries	Drinking Lake Water	Swimming[b]	Fishing	Mushrooms	Diet[c]
Area D									
Occasional	Base Case	**Y**	**Y**	**Y**	N	N	N	N	Predominantly supermarket food
Year-round	None								
Other Lakes									
Year-round (Walsh, Banting, Prosperous, Madeline, Pontoon, Prelude, and River lakes)	Base Case[f]	**Y**	**Y**	**Y**	N	N	**Y**	N	1. Predominantly supermarket food 2. Mixed supermarket/ country food
TLU									
Traditional	Base Case	**Y**	**Y**	**Y**	N	N	N	N	1. Mixed supermarket/country food 2. Subsistence country food
	Fishing	**Y**	**Y**	**Y**	N	N	**Y**[e]	N	
	Drinking Lake Water	**Y**	**Y**	**Y**	**Y**	N	**Y**	N	
	Swimming	**Y**	**Y**	**Y**	N	**Y**	**Y**	N	
	All	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**[g]	N	

Note:
[a] Hand to mouth soil intake and skin contact with dust was also evaluated for year-round exposure in cabins/houses on Vee, Landing, Ryan, Walsh, Banting, Prosperous, Madeline, Pontoon, Prelude, and River lakes.
[b] Includes evaluation of skin contact with and swallowing surface water and sediments while swimming.
[c] See Section 4.1.1 for description of diets.
[d] It was assumed that people would not drink lake water year-round or swim in Vee Lake since it only has a houseboat on it and the lake is used mainly as a way to access other lakes further north.
[e] Under the 'All' scenario, drinking lake water was evaluated periodically.
[f] Additional scenarios were not evaluated for these lakes since the arsenic concentrations in surface water are below the drinking water quality guideline (DWQG).
[g] Fishing was evaluated separately for Mason and Duck lakes.

4.3 Exposure Frequency and Duration

The exposure assessment considers how often and for how long people are exposed by the different pathways considered in the HHRA. Exposure frequency refers to how often a person is exposed, while exposure duration refers to how long over a year that the behaviour occurs. Information learned from the various engagement opportunities discussed in Section 1.5 was used to develop these scenarios.

The assessment considered exposure to food (country and supermarket) and indoor dust (for year-round exposure in cabins/houses) for 7 days per week, 52 weeks per year, or 100% of the time. Even though some country foods such as berries are not available year-round, it was assumed people may pick the berries and preserve them to eat all year. This is considered to be a conservative estimate.

During the various engagement opportunities, people indicated that Great Slave Lake is where people primarily obtained their fish. The assessment therefore considered that people would only catch and eat only a portion of their fish from the inland lakes as follows[3]:

- Occasional use (recreational areas A through C) and traditional (TLU)
    - It was assumed that people frequenting these areas would only catch one tenth of their total fish over a year from inland lakes. Based on an assumed average total fish weight of 1 kg (based on average fish northern pike and lake whitefish caught in Yellowknife Bay) and the fish intake rates shown in Table 4.1, this represents the equivalent of approximately 2 fish total over the course of a year for an adult with a predominantly supermarket food diet, 6 fish for an adult with a mixed supermarket/country food diet, and 10 fish for an adult with a subsistence country food diet within the TLU area.
- Year-round use (lakes with cabins/houses)
    - Larger lakes (Prelude, Prosperous): Approximately half of total fish eaten in a year (equivalent to approximately 10 fish over the course of a year

[3] Equivalent number of fish based on a fish of approximately 1 kg and the fish ingestion rates in Section 4.1.1.1.

for an adult with a predominantly supermarket food diet and 30 fish for an adult with a mixed supermarket/country food diet).

- Medium lakes (Walsh): Approximately one quarter of total fish eaten in a year (equivalent to approximately 5 fish over the course of a year for an adult with a predominantly supermarket food diet and 15 fish for an adult with a mixed supermarket/country food diet).
- Smaller lakes (Banting, Landing, Madeline, Pontoon, River, Ryan, and Vee): Approximately one tenth of total fish consumed in a year (equivalent to approximately 2 fish over the course of a year for an adult with a predominantly supermarket food diet and 6 fish for an adult with a mixed supermarket/country food diet).

It has been assumed that in the occasional recreational and the TLU scenarios people would generally carry their drinking water with them. However, as some respondents of the questionnaire indicated that they drank water from inland lakes, a scenario was evaluated where a person would get approximately 20% of their daily water (the equivalent of a cup of water for an adult) from an inland lake every time they are in the area (i.e., 2 days a week). For year-round exposure, two scenarios were considered. The first was a resident who obtains all of their drinking water directly from the lake. The second considered an occasional/seasonal user going to the cabin for a weekend and who drinks lake water 2 days per week, 16 weeks per year (during open water season only).

For outdoor soils, it was assumed that people may come in direct contact with soils only when the ground is not covered in snow (May to September, or 16 weeks). Based on survey results, people were evaluated for occasional recreational or TLU activities 2 days per week of these 16 weeks. For a year-round resident of a cabin/house, it was assumed that soil contact may occur every day during 16 week period. Exposures to the skin were assumed to occur at a frequency of one event per day of exposure.

To evaluate exposure from swimming, it was assumed that the lakes would be warm enough for swimming only in July, August, and the first half of September (approximately 10 weeks per year). People present in the occasional recreational and TLU areas were assumed to swim infrequently (0.5 hours per day, 1 day per week) during these 10 weeks, while a person living in a cabin/house was assumed to swim more frequently during this time (2 hours per day, 7 days per week).

4.4 Bioavailability/Bioaccessibility Assessment

Relative bioavailability refers to comparative bioavailabilities of different forms of a substance or for different exposure media containing the substance (i.e., bioavailability of a metal from soil relative to its bioavailability from water), referred to as a Relative Absorption Factor (RAF). For skin contact, there are factors that account for the amount of a chemical that can be absorbed through the skin. Dermal RAF values for skin contact are available from literature and are provided in Table 4.4 for arsenic and antimony.

Table 4.4 Dermal Relative Absorption Factors

COPC	Dermal RAF	Reference
Arsenic	0.03	Health Canada (2010)
Antimony	0.1	Ontario Ministry of the Environment and Climate Change (OMOE 2011)

For evaluating exposure from arsenic ingestion, the oral bioaccessibility is considered. This is the fraction of the arsenic that is soluble in a gastrointestinal environment and is available for absorption (into the central blood compartment). This is the measure of arsenic availability that is considered for the risk assessment.

Arsenic is present in many different chemical forms (e.g., arsenopyrite, arsenic trioxide, etc.) and some of these forms can be absorbed through the gastrointestinal tract, while others cannot. The bioaccessibility values used in this assessment are summarized in Table 4.5 and are discussed in Appendix G. The bioaccessibility of arsenic in water and berries was assumed to be 100% in the absence of other information, as was the bioaccessibility of antimony in all media and mercury in fish for the same reason.

Table 4.5 Summary of arsenic bioaccessibility assumptions for oral exposure

Medium	Bioaccessibility Assumption	Rationale	Data Reference
Surface Water	100%	No data available.	–
Soil/Dust	36%	Based on the average of five samples from off-site mine areas (Fred Henne Campground) and similar to undisturbed soils on the Giant Mine. Considered to be representative of undisturbed soil in the study area.	See Appendix G (Golder 2016a)
Sediment	45%	Based on the average of five samples from Long Lake which is an inland lake in the study area. Assumed to be	See Appendix G (Golder 2016a)

Medium	Bioaccessibility Assumption	Rationale	Data Reference
		representative of all inland lakes.	
Fish	69%	Based on the average of lake whitefish and northern pike from Yellowknife Bay. Assumed to be representative of fish in inland lakes.	See Appendix G (Stantec 2014b)
Berries	100%	No data available.	–
Mushrooms	70%	Based on the average of 10 samples from literature for Yellowknife area. This was the same assumption used in the GMRP HHERA (CanNorth 2018).	See Appendix G (Koch et al. 2013)
Game	50%	Based on the average of hare flesh from uncontaminated areas from literature for Yellowknife area. Value for hare assumed for all other game. This was the same assumption used in the GMRP HHERA (CanNorth 2018).	See Appendix G (Koch et al. 2013)

Note: 100% bioaccessibility assumed for antimony in all media and mercury in fish due to lack of other information.

4.4.1 Arsenic Speciation

Arsenic is found in different forms in the environment. Speciation is the process of determining the proportions of actual chemical forms in a sample since the chemical form can affect the relative toxicity of the chemical. For example, in fish, there are many forms of arsenic both in an inorganic and organic form. Many forms of inorganic arsenic are considered to be toxic (see Section 5.1); however, arsenobetaine (an organic form of arsenic) found in fish is considered to be non-toxic. The incorporation of speciation information helps to increase the accuracy of, and confidence in, the health risk predictions. For this assessment, site-specific arsenic speciation data (i.e., percentage of total arsenic in a sample that is arsenobetaine) were available for fish. There is also information on speciation on mushrooms from the area based on a literature paper (Koch et al. 2013). The data and resulting estimated concentrations of inorganic, toxic arsenic in fish and mushrooms are discussed in Appendix G.

4.5 Exposure Point Concentrations

Exposure point concentrations (EPCs) are estimations of the concentration of arsenic or antimony in the environment to which a person may be exposed, and are generally a conservative estimate of the average concentration in the environment. The EPCs were calculated using the measured concentrations in the environmental media from the various sampling programs from the GNWT and other agencies, as reviewed in Section 2.4 and detailed in Appendix E. The EPCs used in the assessment are summarized in the following section, while Appendix G provides more details.

4.5.1 Country Food Exposure Point Concentrations

For country foods, the average values were selected as the EPCs since the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization ([WHO; FAO and WHO 2008]) indicate that the average concentration is appropriate when determining dietary exposures and that the use of maximum concentrations in food substantially overestimates the dietary exposure. This was the same approach used in the GMRP HHERA (CanNorth 2018).

4.5.1.1 Fish Flesh

For recreational use lakes in Areas A through C, EPCs for lake whitefish and northern pike were developed separately for each area as there were sufficient data (more than 10 samples) for each species to do so (see Section 2.4.2.3). Fish EPCs were not developed for Area D since, as discussed in Section 4.2, eating fish from lakes in this area does not occur. Data for fish from Kam Lake in Area A were not used in the development of the EPCs since advice from the Chief Public Health Office is that people do not fish from this lake due to the high arsenic concentration in surface water. As discussed in Section 2.4.2.3, even though limited data show the arsenic concentrations in the water of Kam Lake are high, the arsenic concentrations in northern pike and lake whitefish flesh are lower than in fish from other nearby lakes (i.e., Grace, Long, and Lower Martin lakes).

For the TLU area, lake whitefish data are available for Mason and Duck lakes. For Mason Lake, data for northern pike, burbot, and trout were combined since there were only a few samples and concentrations were similar (see Section 2.4.2.3). Only lake whitefish were caught in Duck Lake. A few samples of eyes and the skin/fatty layer were also available for lake whitefish and trout from Mason Lake. Since the concentrations generally did not vary greatly with tissue type in Mason Lake (see Section 2.4.2.3) and information on how much people eat of these tissue types were not available from the dietary survey collected as part of the GMRP HHERA, these data were pooled with the flesh data. However, to account for the fact that the eyes and skin/fatty layer make up only a small fraction of the total fish, the concentrations were weighted assuming eyes comprise 1% of the total fish body weight and the skin/fatty layer comprises 20%. The remaining 79% was assumed to be flesh.

For antimony, fish data from occasional recreational use lakes are only available for Lower Martin Lake in Area B and therefore the data from Lower Martin Lake were used as a surrogate for areas A and C. The uncertainty of this assumption is discussed in Section 6.3.

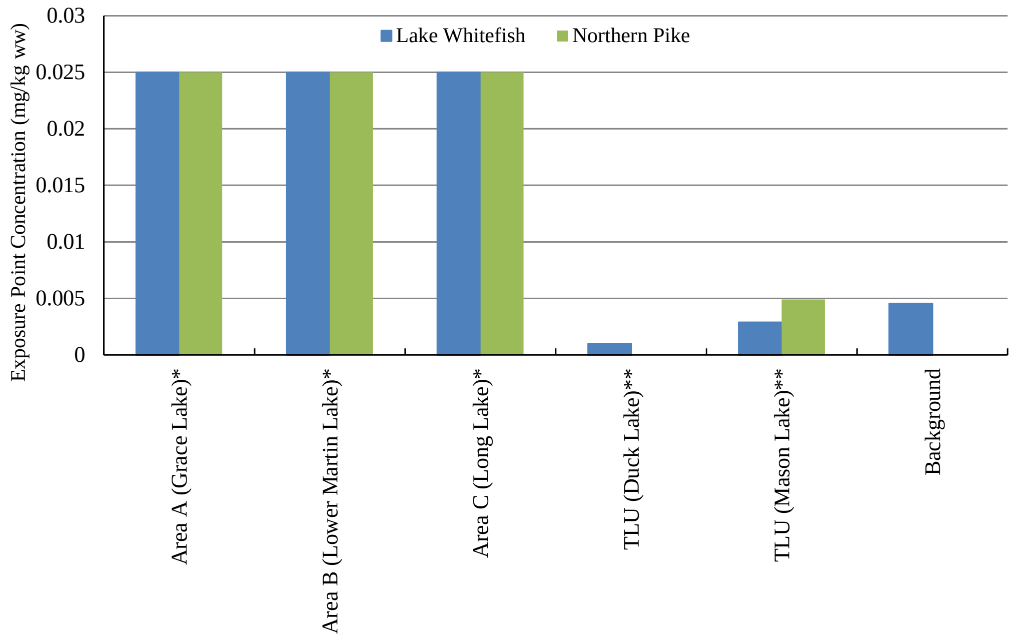
For evaluation of year-round recreational use lakes (i.e., lakes with cabins/houses), data are generally only available for one fish species per lake (see Section 2.4.2.3) and thus the data for lake whitefish, northern pike, and trout were pooled to develop a single fish flesh EPC for each lake. No fish flesh data are available for Vee Lake, and thus the EPC for fish in Landing Lake was used as a surrogate. This was considered appropriate since Landing Lake is nearby, is also within Area B, and the surface water and sediment concentrations are similar in the two lakes (see sections 2.4.2.1 and 2.4.2.2, respectively).

Samples of lake whitefish and northern pike from Chitty Lake, Small Lake, and Cameron Falls were used to develop the background fish flesh concentrations. For the occasional recreational and TLU exposure scenarios, a separate background concentration for lake whitefish and northern pike were developed. For the year-round exposure lakes the background concentrations of lake whitefish and northern pike were combined since the fish caught in these lakes were pooled.

The resulting EPCs and background concentrations are shown in Figure 4.1 (antimony) and Figure 4.2 (arsenic) in lakes in the occasional recreational and TLU areas, and in Figure 4.3 (antimony) and Figure 4.4 (arsenic) in lakes with year-round residents. The arsenic EPCs presented in the figures represent the amount of toxic inorganic arsenic in the fish as they have been adjusted for the amount of non-toxic arsenobetaine measured in the samples from speciation analysis. Details on the speciation and derivation of the fish EPCs are provided in Appendix G.

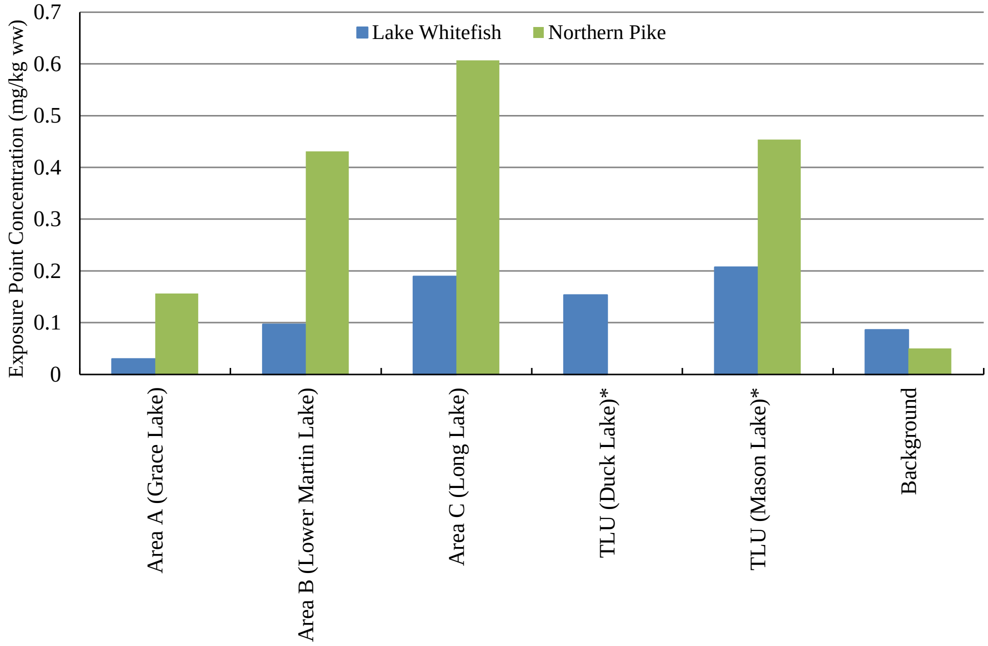
The evaluation of mercury involved the comparison of mercury concentrations in fish to the Health Canada (2018a) ML for mercury in the edible portion of fish of 0.5 mg/kg ww. From Section 2.4.2.3, mercury concentrations were above the ML only in northern pike flesh from Lower Martin and Mason lakes and thus a risk calculation to look at exposure to mercury from eating pike from these lakes is presented in this report. The mercury EPCs for northern pike flesh are 0.66 mg/kg ww for Lower Martin Lake (average of 18 samples) and 0.76 mg/kg ww for Mason Lake (single sample). As discussed in Section 2.4.2.3, the elevated concentration of mercury in the single northern pike sample from Mason Lake may be attributed to the age of the fish, as it was noted to be large.

Figure 4.1 Antimony exposure point concentrations for fish flesh in occasional recreational and traditional use areas



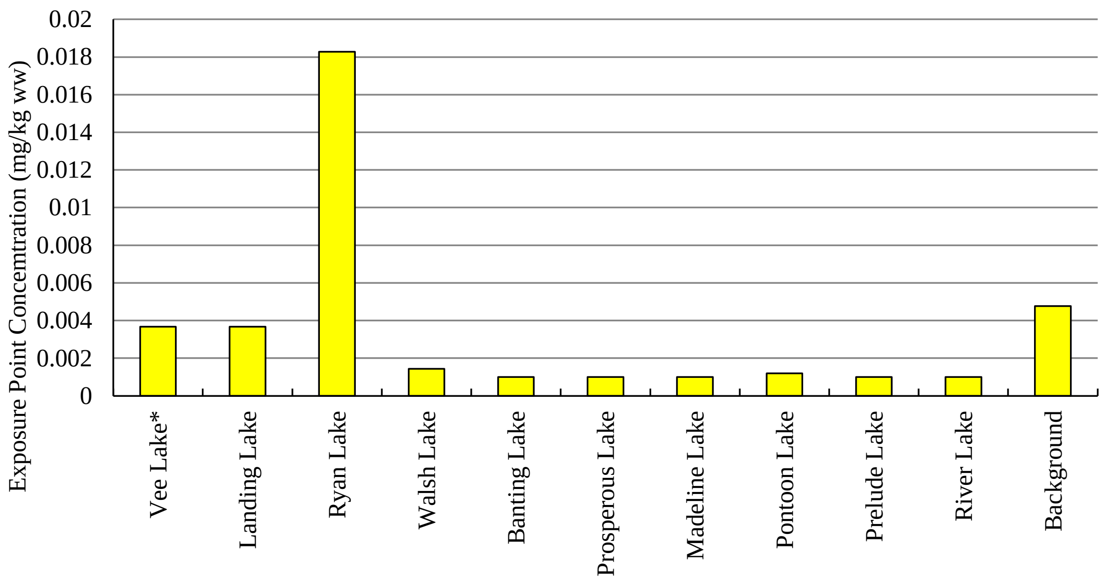
Note: Background from Small Lake, Chitty Lake, and Camercon Falls.
*Area B EPCs are detection limits and are used as surrogates for areas A and C (no antimony data).
**Duck and Mason lake EPCs are a weighted average of data for eyes, skin/fatty layer and flesh; Mason Lake northern pike EPC is trout, burbot, and pike

Figure 4.2 Inorganic arsenic exposure point concentrations for fish flesh in occasional recreational and traditional use areas



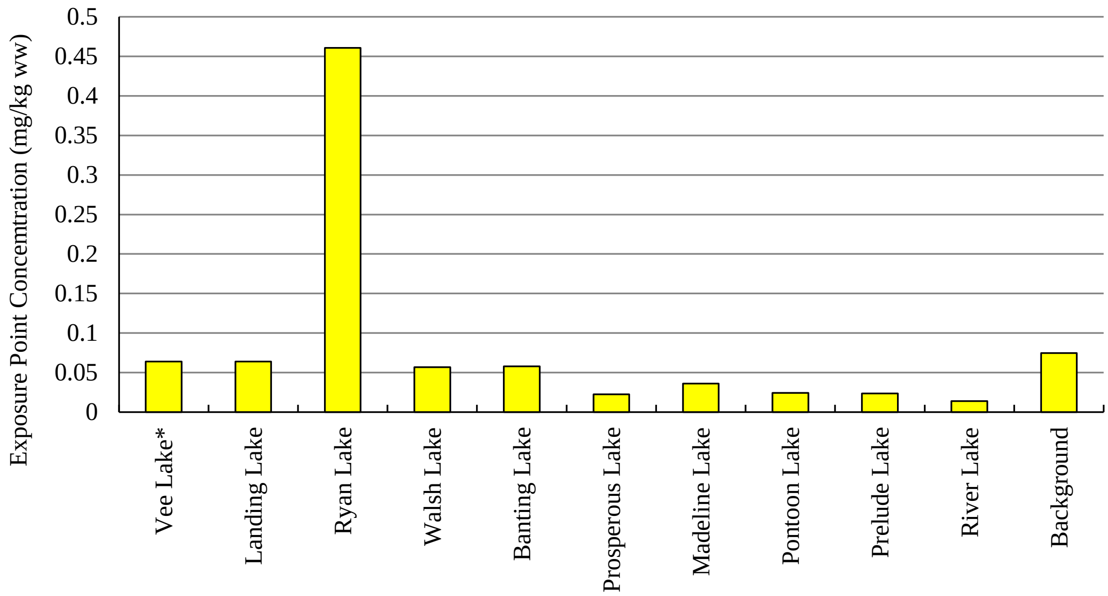
Note: Arsenic concentrations are inorganic (total arsenic modified by speciation data); Background from Small Lake, Chitty Lake, and Camercon Falls.
*Duck and Mason lake EPCs are a weighted average of data for eyes, skin/fatty layer and flesh; Mason Lake northern pike EPC is trout, burbot, and pike

Figure 4.3 Antimony exposure point concentrations for fish flesh in year-round use areas



Note: Lake whitefish, northern pike, and trout. Background from Small Lake, Chitty Lake, and Cameron Falls
*No data for Vee Lake; Landing Lake used as a surrogate due to similar surface water and sediment concentrations

Figure 4.4 Inorganic arsenic exposure point concentrations for fish flesh in year-round use areas



Note: Arsenic concentrations are inorganic (total arsenic modified by speciation data); Lake whitefish, northern pike, and trout. Background from Small Lake, Chitty Lake, and Cameron Falls
*No data for Vee Lake; Landing Lake used as a surrogate due to similar surface water and sediment concentrations

4.5.1.2 Berries, Mushrooms, and Game

The data for berries, mushrooms and game were obtained from the voluntary country food sampling program that was carried out in support of the GMRP HHERA (CanNorth 2018). Data for berries, mushrooms, and game were considered across the entire study area as the concentrations are similar from all areas collected. Average concentrations were used as the EPCs. Samples of berries, mushrooms, and game obtained from greater than 25 km of the Giant and Con Mine sites (greater than 50 km for moose) were used to develop the background concentrations that were used in the assessment.

The resulting EPCs and background concentrations are summarized in Table 4.6. The arsenic EPCs for mushrooms was adjusted by an average percentage arsenobetaine value of 33%, which is the average of 8 samples from a study by Koch et al. (2013). This value was also used in the GMRP HHERA (CanNorth 2018).

Table 4.6 Summary of exposure point concentrations in berries, mushrooms, and game

Country Food	Study Area	Concentration (mg/kg ww)		Comment
		Antimony	Arsenic	

Country Food	Study Area	Concentration (mg/kg ww)		Comment
Berries	Exposure	0.004	0.08	Average of 31 samples from within 25 km radius
	Background	0.001	0.02	Average of 2 samples
Mushrooms	Exposure	0.06	0.5[a]	Average of 24 samples from within 25 km radius (excluding samples from *Tricholomataceae* family of mushrooms)
	Background	0.02	0.1[a]	Average of 70 samples (excluding samples from *Tricholomataceae* family of mushrooms)
Rabbit Flesh	Exposure	0.01	0.07	Average of 3 rabbit samples (2 from Area D and 1 from Prelude Lake)
	Background	0.004	0.008	Average of 4 rabbit samples.
Muskrat Flesh	Exposure	0.005	0.16	Average of 9 samples (5 from Yellowknife Bay, 3 from Hay lake, and 1 from Duck Lake)
	Background	0.004	0.03	Average of 2 samples (Hidden Lake)
Grouse/Ptarmigan Flesh	Exposure	0.02	0.2	Average of 6 samples (1 spruce grouse from Area D, 1 ptarmigan from Area A, 3 ptarmigan from just within Giant Mine Site near Area B, and 1 ptarmigan from Prelude Lake)
	Background	0.004	0.005	Average of 6 samples (3 grouse and 3 ptarmigan)
Duck/Goose Flesh	Exposure	0.002	0.05	Average of 4 samples (1 scaup and 1 mallard from Area B, and 2 black duck from Area D)
	Background	0.002	0.03	Average of 2 samples (1 mallard and 1 Canada goose)
Moose Flesh	Exposure	0.002	0.05	Average of 4 moose samples (1 from Area D, 1 from outside Area D, and 2 from just east of Prelude Lake)
	Background	0.001	0.01	Average of 3 moose samples

Note: EPCs for exposure areas based on samples obtained from within 25 km radius (within 50 km for moose); background considered to be samples obtained from outside of 25 km radius (greater than 50 km for moose).
[a] Arsenic EPCs for mushrooms are inorganic (total modified by percentage arsenobetaine value of 33%).

4.5.2 Surface Water

For the base case scenarios in which the drinking water source is assumed to be bottled water or municipal water, the EPCs that were used were those developed as part of the 2018 GMRP HHERA (CanNorth 2018). The EPCs for arsenic and antimony were 0.002 mg/L and 0.0002 mg/L, respectively, based on data for treated water from the City of Yellowknife.

For the scenarios in which drinking untreated lake water and/or swimming in the lakes were evaluated, the EPCs were developed using the data reviewed in Section 2.4.2.1. The 95% Upper Confidence Level of the Mean (95% UCLM) concentrations were selected as the EPCs for inland lakes within recreational use (i.e., areas A, B, and C) and TLU areas and were based on data from the larger lakes (e.g., Lower Martin Lake [Area B], Duck Lake [TLU], and Mason Lake [TLU]) as well as the smaller, unnamed lakes within each area. The smaller unnamed lakes generally have higher concentrations than the larger lakes. No EPCs for surface water were developed for Area D or Vee Lake since the survey indicated that people do not drink water from lakes in these areas.

Average concentrations were selected for lakes where people may drink water year-round (i.e., lakes with cabins and houses). The average concentration was considered to be representative of year-long exposures.

The resulting surface water EPCs that were used in the assessment are detailed in Appendix G and summarized in Figure 4.5 for antimony and Figure 4.6 for arsenic. Figure 4.5 demonstrates that all the EPCs for antimony are below the DWQG of 0.006 mg/L. The assessment of people drinking water containing arsenic considered the incremental risks of drinking water with arsenic concentrations above the DWQG of 0.01 mg/L. Figure 4.6 demonstrates that arsenic concentrations in the water in Banting, Walsh, Madeline, Pontoon, Prelude, Prosperous, and River lakes are all below the DWQG of 0.01 mg/L. Thus the assessment considers the risks for drinking water above the DWQG from lakes within areas A through C as well as Landing and Ryan lakes. The arsenic concentrations in Hay, Duck, and Mason lakes are below the DWQG, however, the arsenic EPC in surface water in the TLU area is slightly above the DWQG due to higher concentrations in smaller lakes in this area. Similarly, the higher EPCs for arsenic and antimony in areas B and C are the result of higher concentrations in the smaller, unnamed lakes in these areas.

Figure 4.5 Antimony exposure point concentrations for surface water

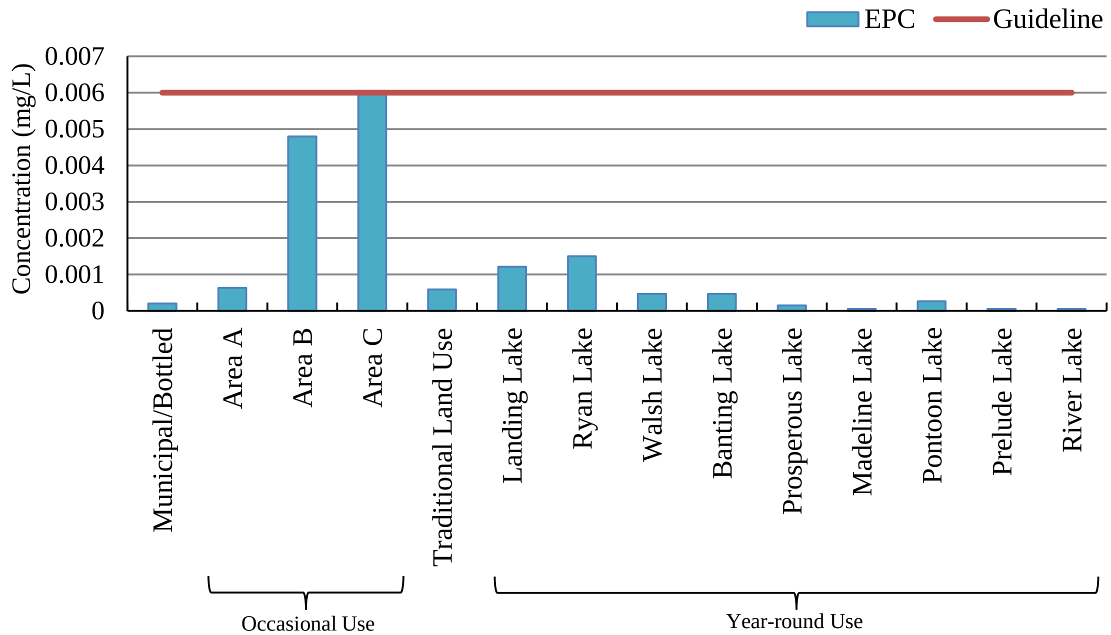
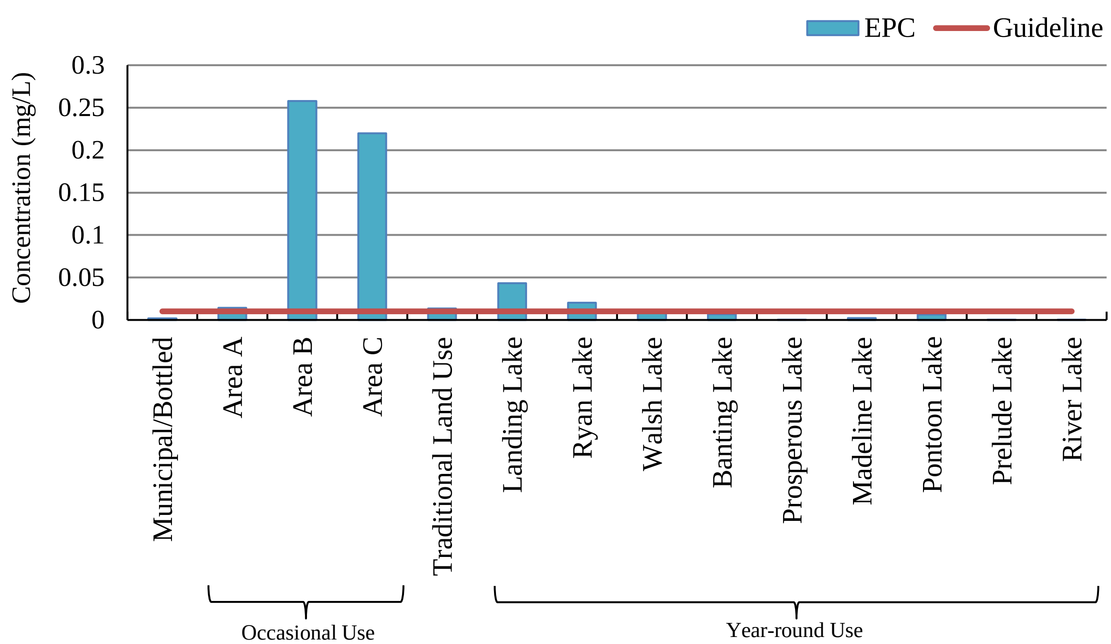


Figure 4.6 Arsenic exposure point concentrations for surface water



4.5.3 Sediment

The EPCs for shallow sediments were developed using the data reviewed in Section 2.4.2.2. A number of the sediment samples in the recreational areas come from smaller unnamed lakes where people are unlikely to be present. In addition some of the samples from the larger lakes come from one location in a lake. Therefore to evaluate a scenario where someone would be wading in sediments in the shallow part of the lake, the average concentrations were selected to represent exposures.

No EPCs for sediment were developed for Area D or Vee Lake as people do not swim in these areas. Sediment background EPCs were developed using data from inland lakes greater than 25 km from the Giant Mine site.

The resulting EPCs and background concentrations that were used in the assessment are detailed in Appendix G and summarized in Figure 4.7 for antimony and Figure 4.8 for arsenic. From Figure 4.7 it can be seen that sediment antimony concentrations in Banting, Prelude, Prosperous, and River lakes are similar to background. For arsenic (Figure 4.8), sediment concentrations in Banting, Madeline, Prelude, Prosperous, and River lakes are similar to background. The sediment concentrations in areas A to C reflect the higher concentrations in sediments in the smaller, unnamed lakes in these areas. Within the TLU area, the sediment EPCs also reflect the concentrations in the smaller, unnamed lakes, which are higher than in the larger, more regularly used lakes in the area like Mason and Hay lakes (see Section 2.4.2.2).

Figure 4.7 Antimony exposure point concentrations for shallow sediments

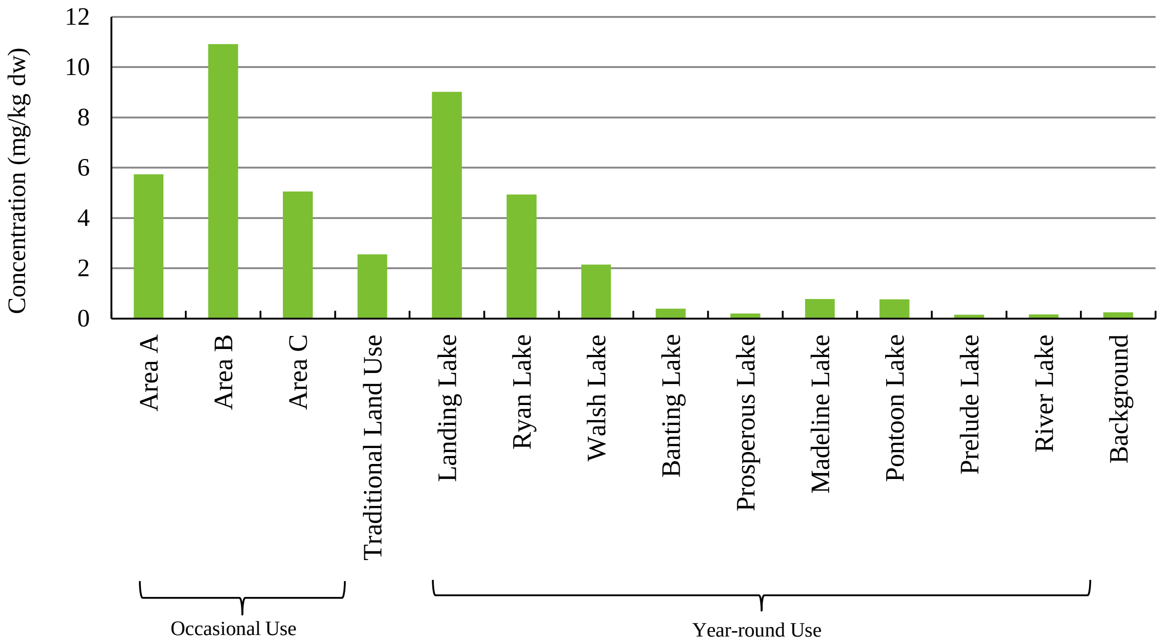
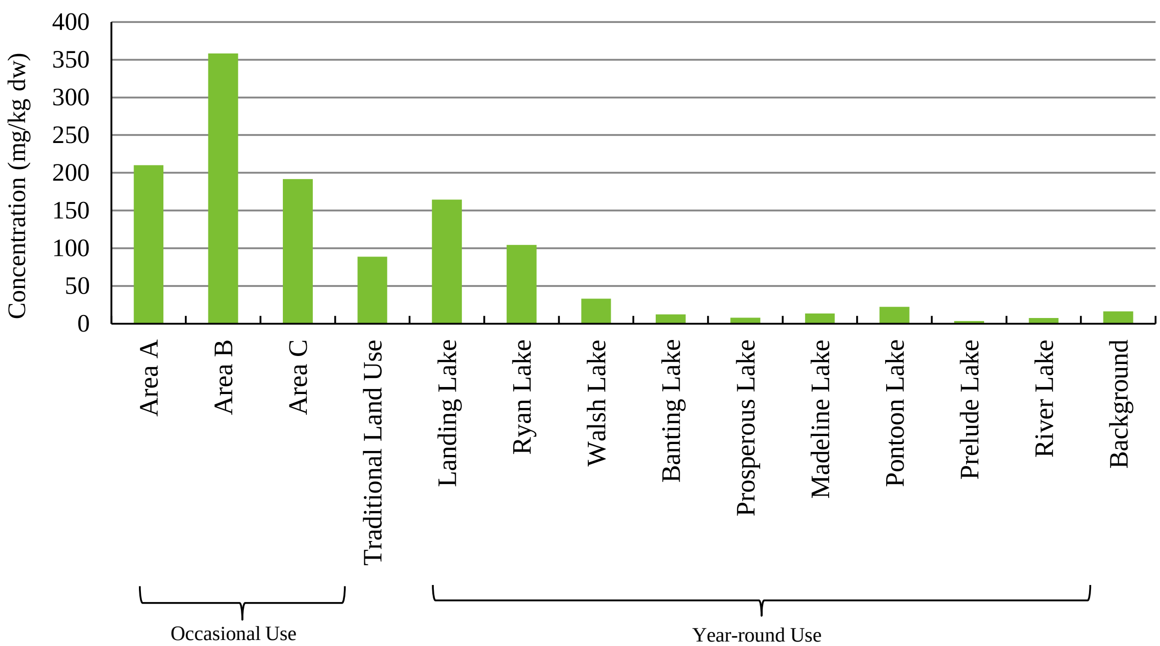


Figure 4.8 Arsenic exposure point concentrations for shallow sediments



4.5.4 Soil

The EPCs for shallow soils (top 10 cm) were the 95% UCLM concentrations of the data reviewed in Section 2.4.1.1. To develop the soil EPCs around inland lakes used year-round, the concentrations of arsenic in surficial soil samples from around the lakes were reviewed in further detail to determine if there were any noticeable differences in soil concentrations based on location or soil type (i.e., forest canopy versus outcrop). The results are detailed in Appendix G and indicated that arsenic soil concentrations were similar around the following groups of lakes:

- Vee, Landing, and Ryan lakes
- Banting and Walsh lakes
- Madeline, Pontoon, Prelude, Prosperous, and River lakes

Therefore, the soil data were combined to develop three representative EPCs to be used for evaluation of year-round exposure depending on the lake.

As discussed in Section 2.4.1.1, two background concentrations for arsenic have been developed for within a 25 km radius of the Giant Mine site (Stantec 2020):

1. 114 mg/kg for YGB and within the Yellowknife municipal boundary
    - This was applied when evaluating incremental arsenic exposure in areas C and D, and Vee, Landing, Ryan, Walsh, and Banting lakes
2. 41 mg/kg for non-YGB and outside of the Yellowknife municipal boundary
    - This was applied when evaluating incremental arsenic exposure in areas A and B, the TLU area, and Prosperous, Madeline, Pontoon, Prelude, and River lakes

As detailed in Appendix D, the background concentrations for antimony are the same that were considered in the GMRP HHERA(CanNorth 2018).

As seen in the figures, the antimony and arsenic concentrations in soil generally decrease with distance from the Giant and Con Mine sites. For example soil concentrations in Area D, which is closest to the Giant Mine, have the highest concentrations. Similarly, arsenic concentrations in soil in Area C, which is close to the Con Mine site, are the second highest arsenic concentrations in the study area. Arsenic concentrations in and Prosperous, Madeline, Pontoon, Prelude, and River lakes are close to background and these lakes are further away from the legacy mining areas.

Figure 4.9 Antimony exposure point concentrations for soil

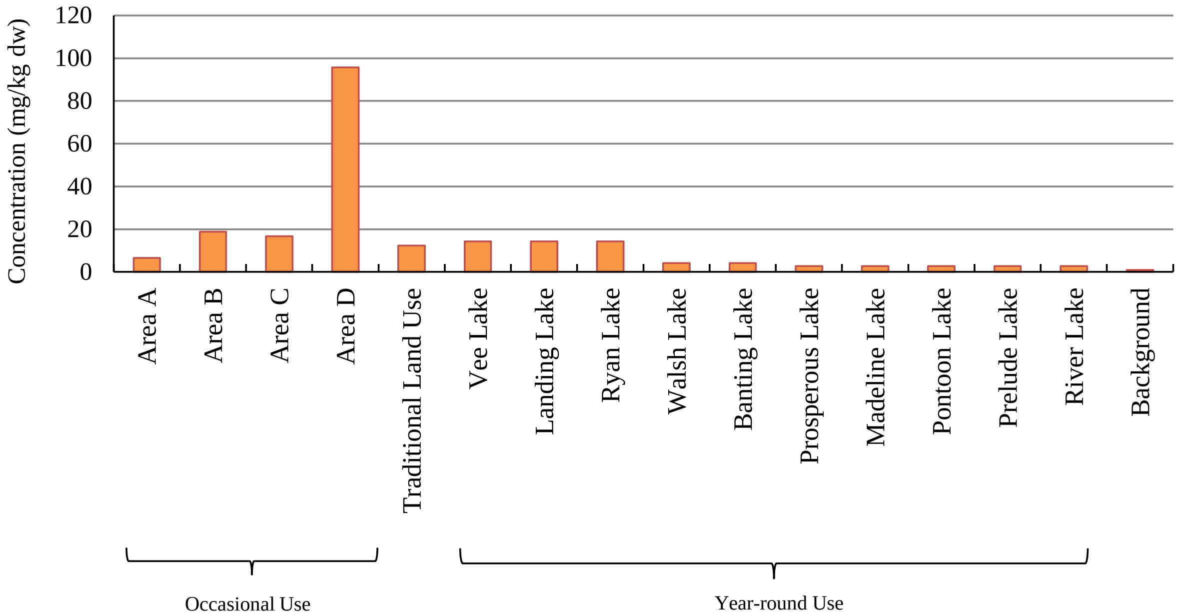
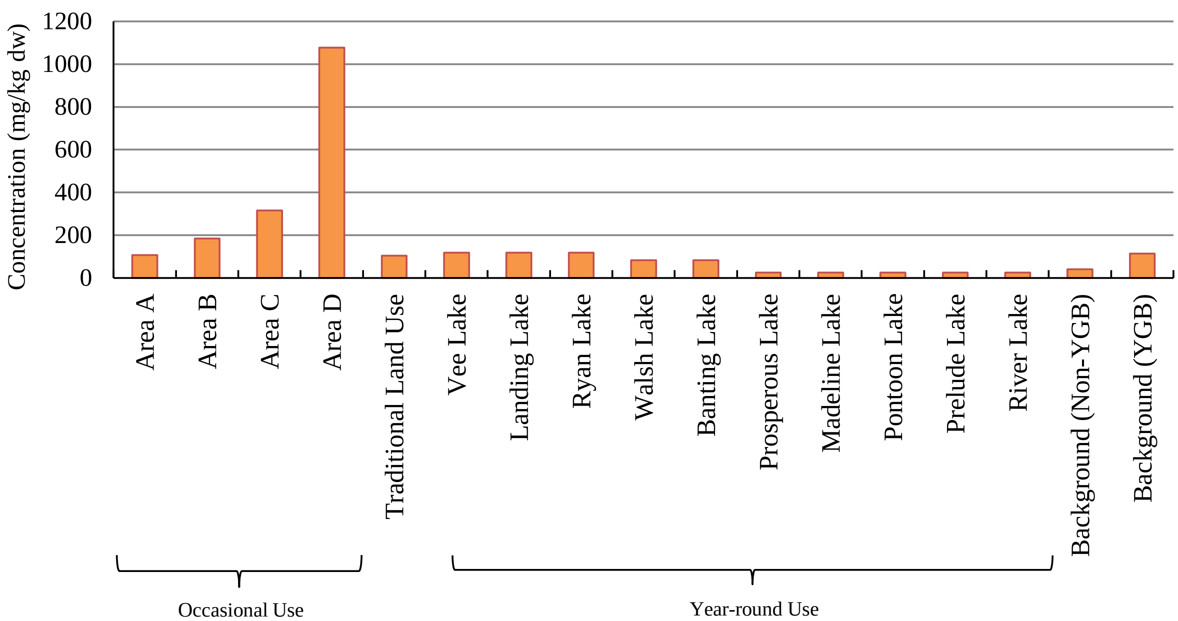


Figure 4.10 Arsenic exposure point concentrations for soil



4.5.5 Indoor Dust

No indoor dust measurements are available; therefore, assumptions were made to estimate indoor dust concentrations for people who live in houses/cabins throughout the year at the inland lakes. There are a number of published studies that discuss how indoor dust concentrations can be obtained from outdoor soil concentrations (see Appendix G). A value of 70% (i.e., 0.7 g soil/g dust) from the U.S. EPA (1998) is used in this assessment, which is also the value that was used in the GMRP HHERA (CanNorth 2018). Thus, indoor dust EPCs for arsenic and antimony were set equal to 70% of the soil EPCs.

4.6 Exposure Estimation

The exposure assessment uses all of the available information collected about people and the EPCs of antimony and arsenic in water, soil, sediments, indoor dust, supermarket foods, and country foods to estimate the total exposures (intakes) of antimony and arsenic, to people (toddlers, children, teens, and adults). It also uses the available information on mercury in fish flesh to look at exposure from eating northern pike from Lower Martin Lake and Mason Lake since only northern pike samples in these two lakes exceeded the ML from Health Canada for mercury.

Exposures from water, soil, sediments, indoor dust, supermarket foods, and country foods for each route of exposure (eating, breathing, skin contact) were calculated using equations provided by Health Canada (2012a). These equations are provided in Appendix G. The HHRA considers long-term exposures for residents who live in cabins/houses on inland lakes as well as occasional exposures for people participating in recreational or traditional activities in areas A to D and the TLU area; background exposures were taken into account in the exposure estimates. For evaluation of risks of non-cancer effects from exposures to antimony and arsenic, averaging periods were considered to be similar to the exposure periods for an activity. For example, the exposure for someone swimming was considered for ten weeks duration and averaged over ten weeks and not a year. For cancer effects associated with exposure to arsenic (see Section 5.1), exposures were averaged over an entire year as is the risk assessment practice.

4.7 Summary of Exposure Assessment

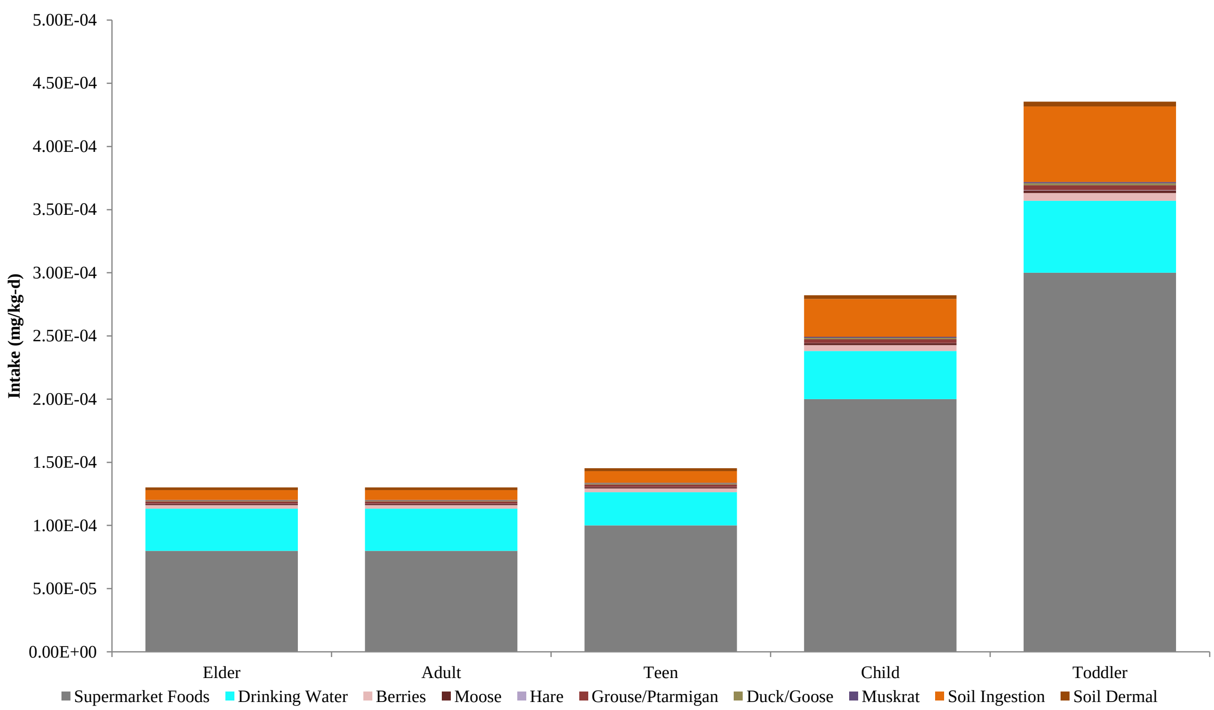
The estimates (intakes) based on the above assumptions are discussed in the following sections. Background arsenic intakes are provided in Appendix G.

4.7.1 Occasional Recreational Use and Traditional Land Use

Figure 4.11 presents a summary of the estimated intakes for total arsenic for a recreational user in Area A for the base case scenario with a predominantly supermarket food diet. As described in Section 4.2.1, the base case considered exposures associated with drinking bottled water or municipal water, touching and eating soil, and eating berries and game.

This figure illustrates that the toddler is the most exposed life stage, and that the majority of the exposure is from eating supermarket foods. Since the toddler is the most exposed life stage, all of the results in Figure 4.12 (total arsenic), Figure 4.13 (incremental arsenic), and Figure 4.14 (antimony) are presented for a toddler to demonstrate the worst case exposure. Estimated intakes for all life stages and scenarios are provided in Appendix G.

Figure 4.11 Estimated intakes for base case for occasional recreational users in Area A – total arsenic



Drinking water is municipally sourced or bottled water (not untreated lake water).

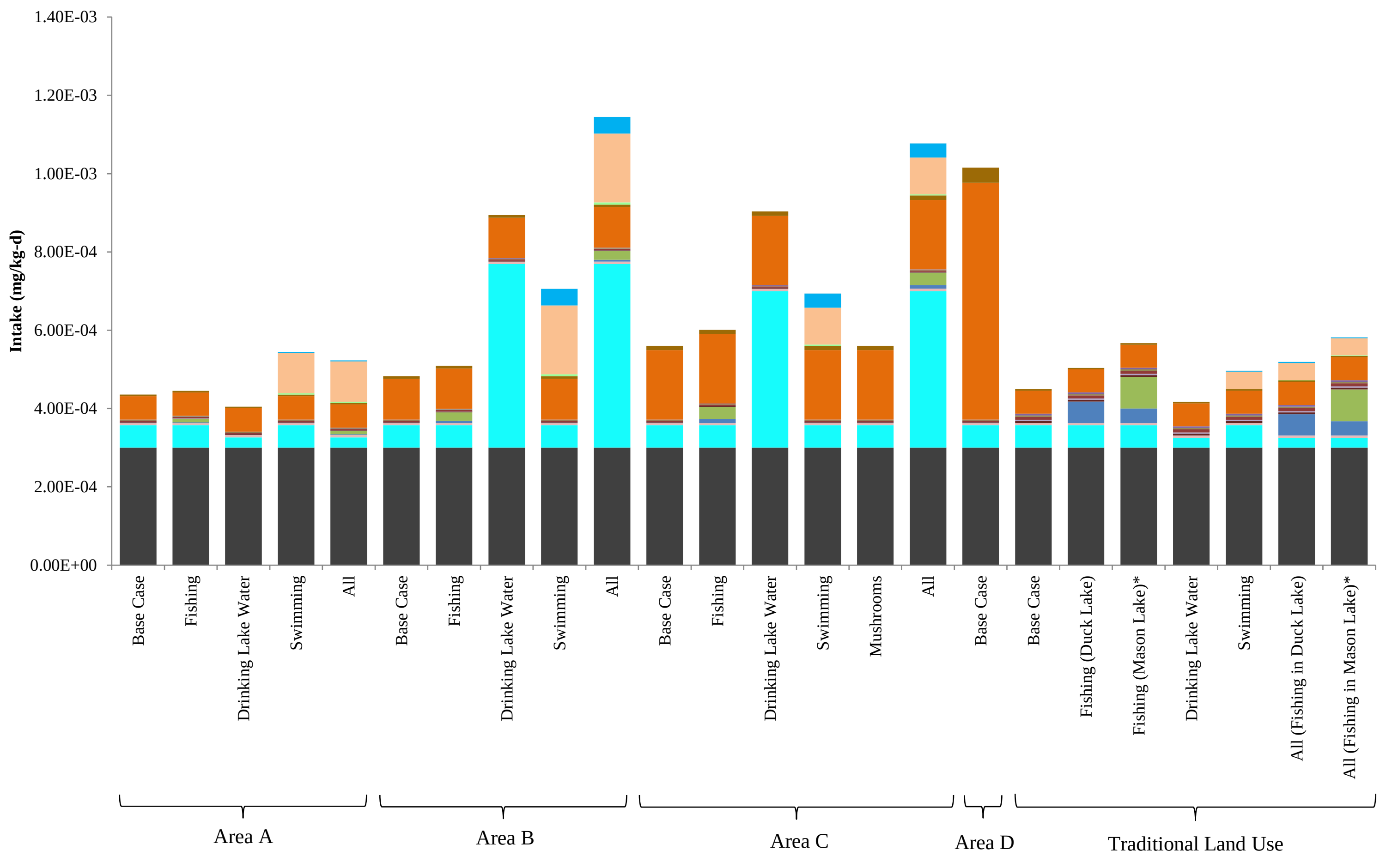
Figure 4.12 shows that most of the exposure is from supermarket foods, with the exception of areas B and C where drinking untreated lake water represents the highest exposure. This is a reflection of the higher arsenic concentrations in the smaller, unnamed lakes in the areas and not the larger lakes. Eating soil is the highest exposure pathway in Area D where the arsenic concentration in soil is 1,078 mg/kg as a result of its proximity to the Giant Mine site. In all other areas, after supermarket foods, the main sources of exposure are eating soil, skin contact with sediment while swimming/wading, and drinking lake water periodically from inland lakes. Within the TLU area, eating northern pike/burbot/trout represents the highest exposure after supermarket foods. Eating soil is the next highest exposure pathway and for anyone who swims in the lakes sediment exposure to the skin represents an arsenic exposure similar to eating northern pike. The average concentrations of arsenic in lake water within the larger lakes that are more widely used (i.e., Hay, Duck, and Mason lakes) in the TLU are all below the drinking water guideline; however the drinking water exposures shown in the figure are based on exposures associated with water from the smaller lakes in this area.

There is some double-counting for the total arsenic intakes presented in Figure 4.12, since intakes from supermarket foods were not reduced to account for the foods obtained as country foods.

Because the cancer effect for arsenic exposure is evaluated on an incremental basis (i.e., total arsenic – background arsenic), Figure 4.13 is provided to illustrate the relevant pathways of exposure for incremental arsenic exposure. Background arsenic intakes are provided in Appendix G. Figure 4.13 shows that food pathways contribute marginally to the overall incremental intake of arsenic since a number of the country foods (such as lake whitefish and muskrat) are very near to or at background arsenic concentrations. With the subtraction of background, drinking untreated lake water from small lakes in areas B and C represents the major pathway of exposure, while eating soil dominates the intake in Area D. In the TLU area, eating northern pike/burbot/trout from Mason Lake is the major exposure pathway.

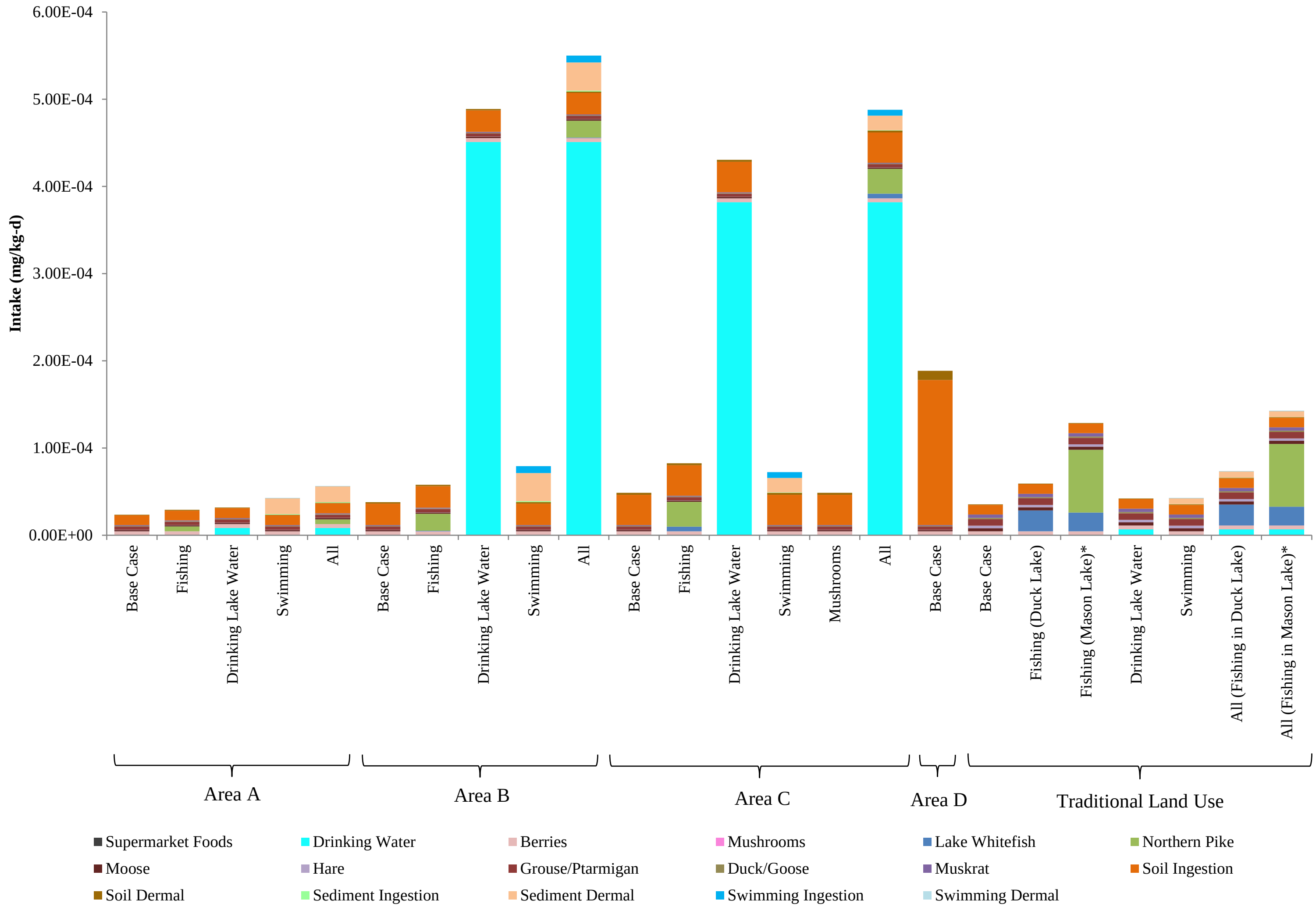
Figure 4.14 shows the exposure pathways for antimony and indicates that, after supermarket foods, eating soil is the next largest exposure to antimony for toddlers, with the highest soil exposure in Area D which is closest to the Giant Mine site. Skin contact with sediment while wading and swimming in the smaller lakes in these areas represent exposures similar to the soil pathway. Again, there is some double-counting for the antimony intakes presented in Figure 4.14, since intakes from supermarket foods were not reduced to account for the foods obtained as country foods.

Figure 4.12 Estimated intakes for a toddler for occasional recreational and traditional use – total arsenic



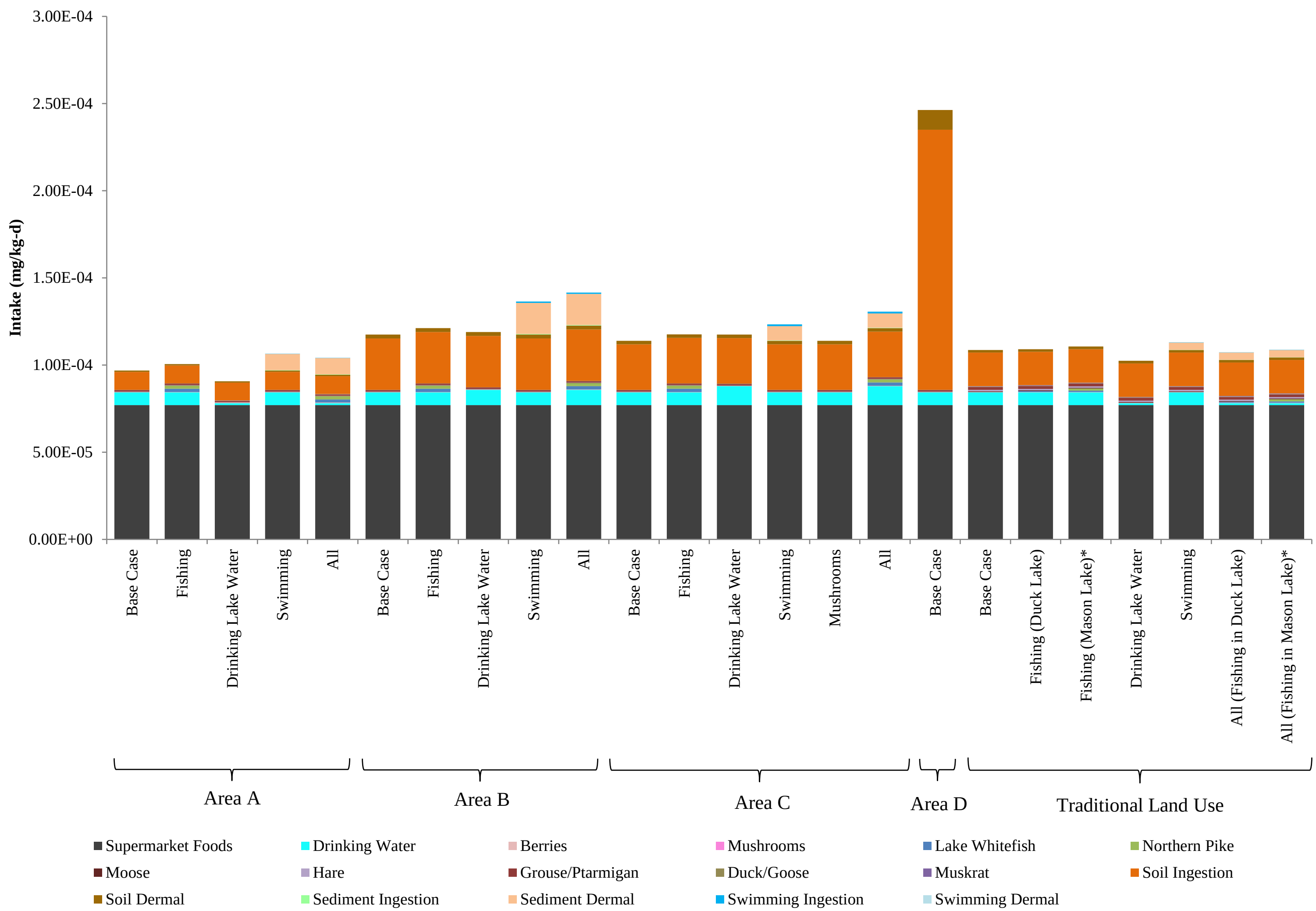
Eating mushrooms was only evaluated for the adult and thus the intakes for the Base Case and Mushrooms scenario are the same for the toddler; intakes are for a predominantly supermarket food diet for areas A through D,and a mixed supermarket/country food diet for the Traditional Land Use (TLU) area;northern pike in Mason Lake is pike/burbot/trout; drinking water is municipally sourced or bottled water for all scenarios except 'Drinking Lake Water".
* Northern pike in Mason Lake is pike, burbot, and trout.

Figure 4.13 Estimated intakes for a toddler for occasional recreational and traditional use – incremental arsenic



Eating mushrooms was only evaluated for the adult and thus the intakes for the Base Case and Mushrooms scenario are the same for the toddler; intakes are for a predominantly supermarket food diet for areas A through D,and a mixed supermarket/country food diet for the Traditional Land Use (TLU) area;northern pike in Mason Lake is pike/burbot/trout; drinking water is municipally sourced or bottled water for all scenarios except 'Drinking Lake Water".
* Northern pike in Mason Lake is pike, burbot, and trout.

Figure 4.14 Estimated intakes for a toddler for occasional recreational and traditional use – antimony

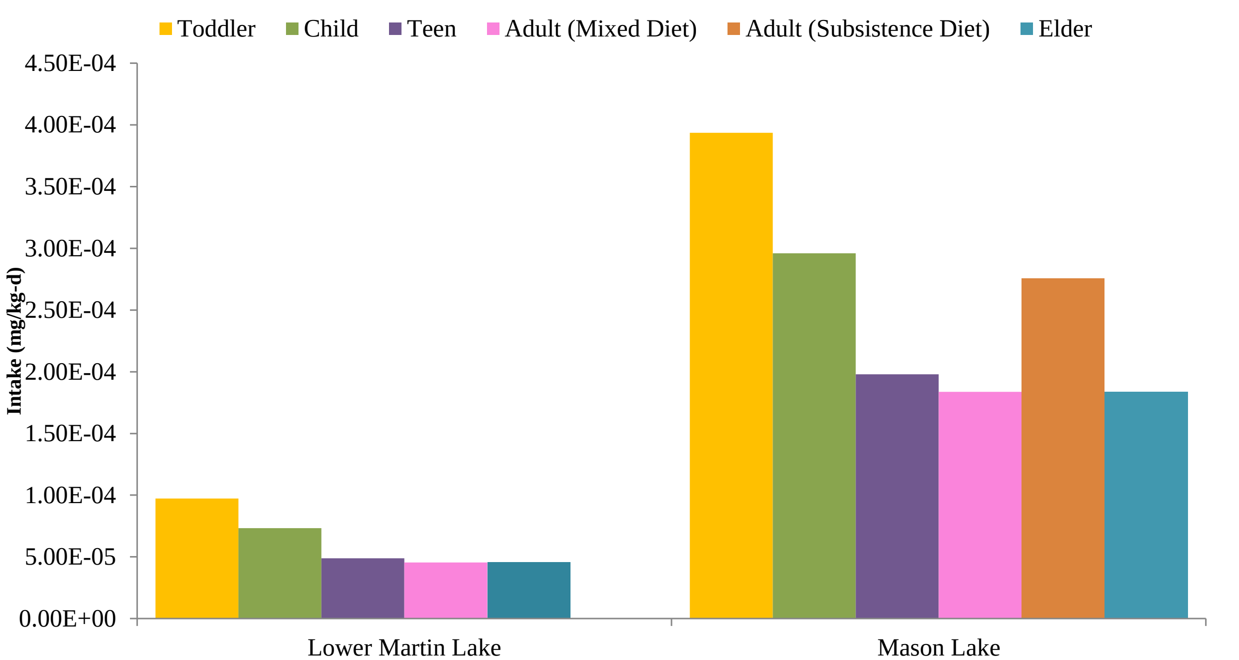


Eating mushrooms was only evaluated for the adult and thus the intakes for the Base Case and Mushrooms scenario are the same for the toddler; intakes are for a predominantly supermarket food diet for areas A through D,and a mixed supermarket/country food diet for the Traditional Land Use (TLU) area;northern pike in Mason Lake is pike/burbot/trout; drinking water is municipally sourced or bottled water for all scenarios except 'Drinking Lake Water".
* Northern pike in Mason Lake is pike, burbot, and trout.

Intakes of mercury for the adult and toddler eating northern pike from Lower Martin Lake and Mason Lake are shown in Figure 4.15. These are the only two lakes where the fish flesh concentrations of northern pike were above the Health Canada (2018a) Maximum Level (ML) for mercury in the edible portion of fish of 0.5 mg/kg ww.

The different diet assumptions for these two lakes are presented on the figure. People fishing in Lower Martin Lake are assumed to have a diet that is predominantly supermarket food where as in the TLU area (Mason Lake), people are assumed to either live entirely off the land or to have a mixed diet of country foods and supermarket foods. For mercury exposure, the toddler who eats northern pike is the most exposed receptor. The intakes for Mason Lake are based on a single, large northern pike sample with an elevated mercury concentration that may be attributed to the age of the fish. All other fish caught in Mason Lake had mercury concentrations below the ML.

Figure 4.15 Estimated intakes of mercury from eating northern pike from Lower Martin Lake and Mason Lake

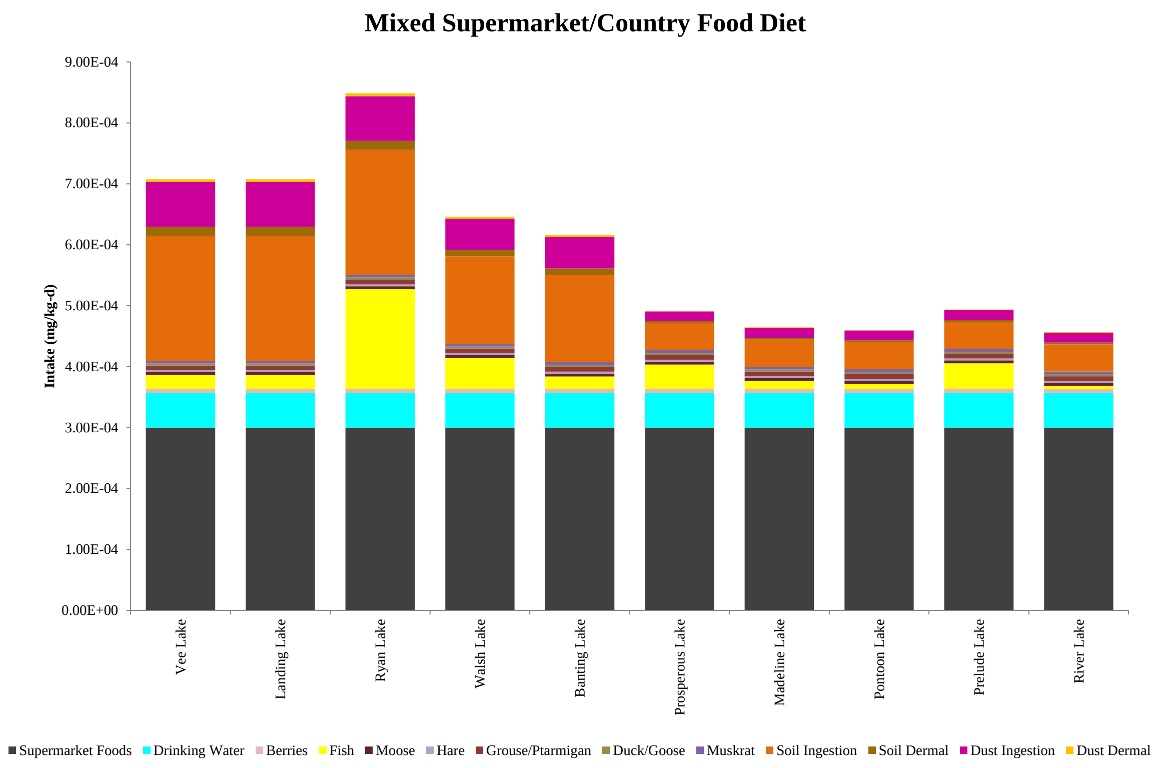


Intakes are for a predominantly supermarket food diet for Lower Martin Lake; a subsistence country food diet was only evaluated for the adult; intakes for Mason Lake are based on concentrations measured in 1 northern pike sample.

4.7.2 Year-round Use

For year-round exposure where houses/cabins are present, the results are presented for a toddler (most exposed receptor) with a mixed supermarket/country food diet. The results for total arsenic exposure, presented in Figure 4.16, show the dominant exposure pathway is eating supermarket foods, followed by eating soil or drinking municipal water (depending on lake). Eating fish is a fairly small exposure pathway, with the exception of Ryan Lake where it represents the third highest pathway. This is the result of the three northern pike flesh samples, with an average concentration over seven times higher than the single trout flesh concentration (see Section 2.4.2.3). The results show that lakes closest to the Giant Mine site (i.e., Vee, Landing, and Ryan lakes within Area B) have the highest total arsenic exposures, and exposures generally decrease with increasing distance from the legacy mining areas.

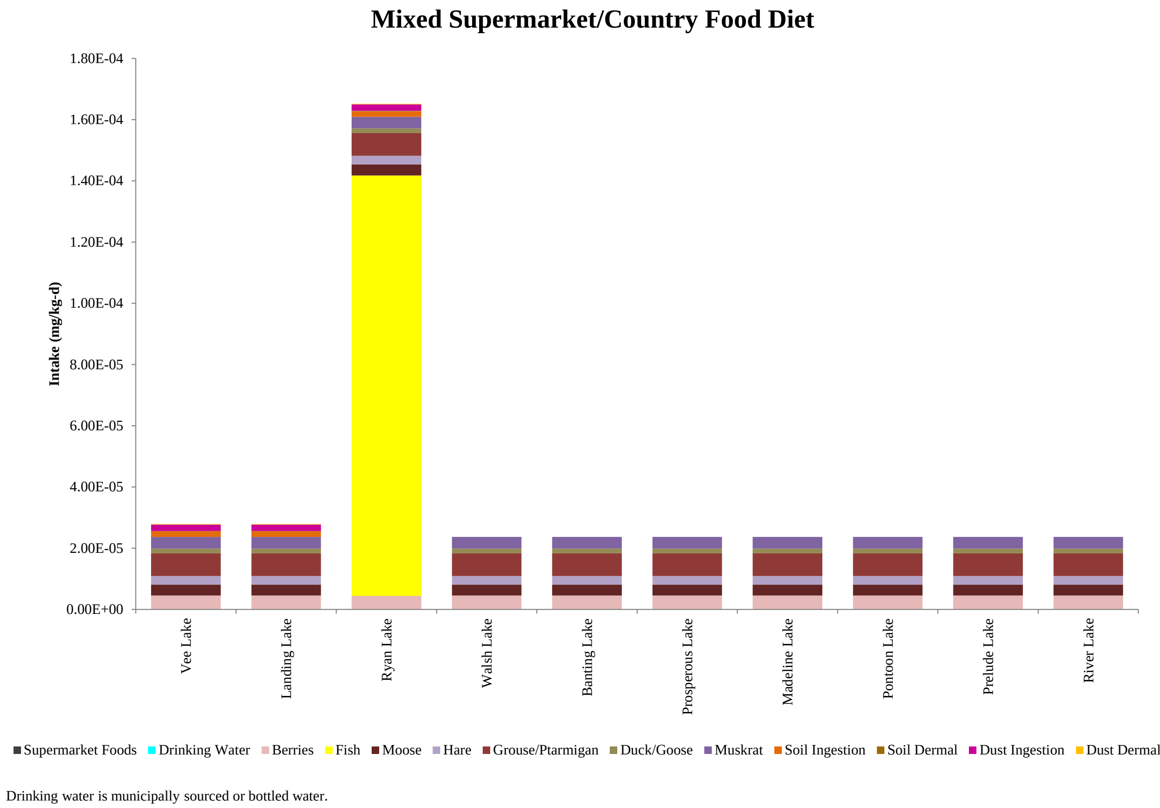
Figure 4.16 Estimated intakes for base case for a toddler exposed year-round at an inland lake with a cabin – total arsenic



Drinking water is municipally sourced or bottled water.

Figure 4.17 shows the incremental arsenic exposures for the various lakes. As seen from the figure, Ryan Lake has the highest exposure due to eating fish (northern pike), with Vee and Landing lakes having the next highest exposures due to soil/dust exposure. The incremental arsenic exposures for all the other locations are due to eating country food which is the same across the study area. Based on this, the following discussion focuses on Landing and Ryan lakes where exposures are the highest in the area. Exposures at all the other lakes will be lower than these two lakes and are provided in Appendix G.

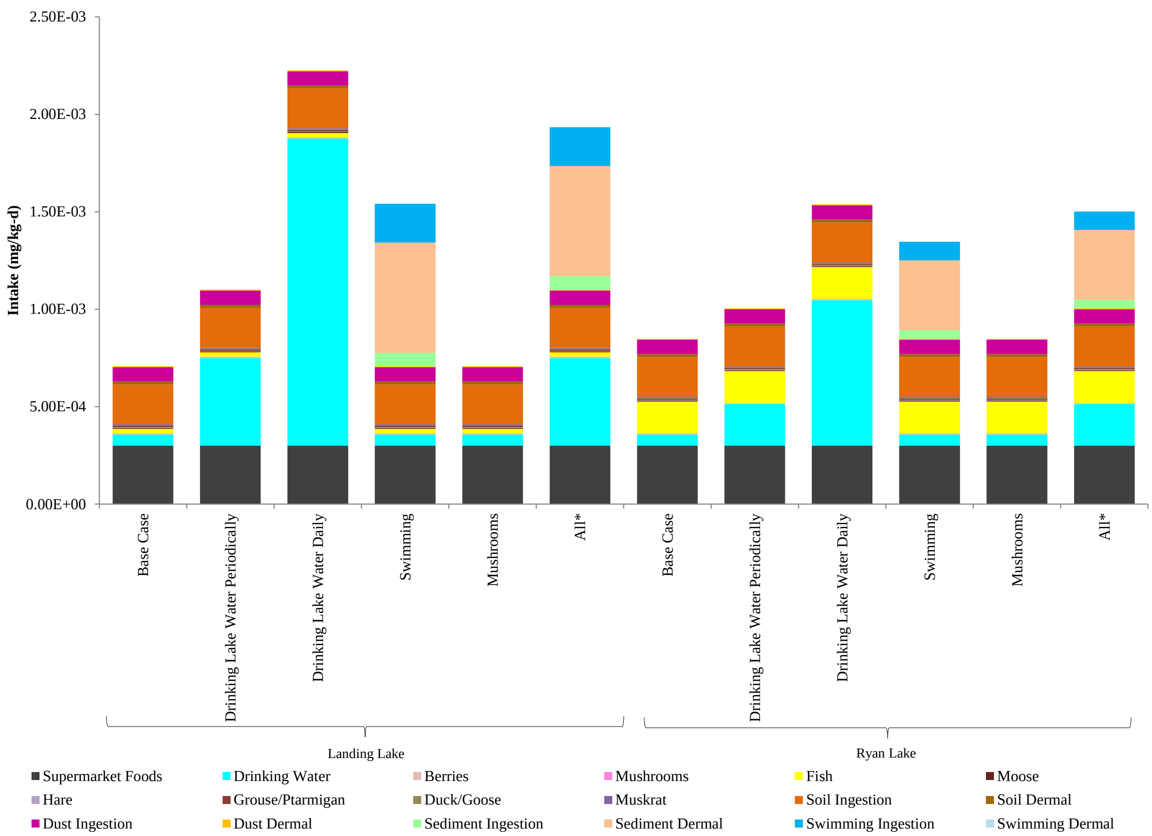
Figure 4.17 Estimated intakes for base case for a toddler exposed year-round at an inland lake with a cabin – incremental arsenic



Drinking water is municipally sourced or bottled water.

Figure 4.18 shows the estimated intakes of total arsenic for exposures at Landing and Ryan lakes for the base case and additional scenarios discussed in Section 4.2. These scenarios involve drinking water from the lakes, swimming and wading, and eating mushrooms from the area. The figure shows that drinking water from these lakes represents the highest exposure pathway followed by wading in the sediments. Again, there is some double-counting for the total arsenic intakes presented in Figure 4.18, since intakes from supermarket foods were not reduced to account for the foods obtained as country foods.

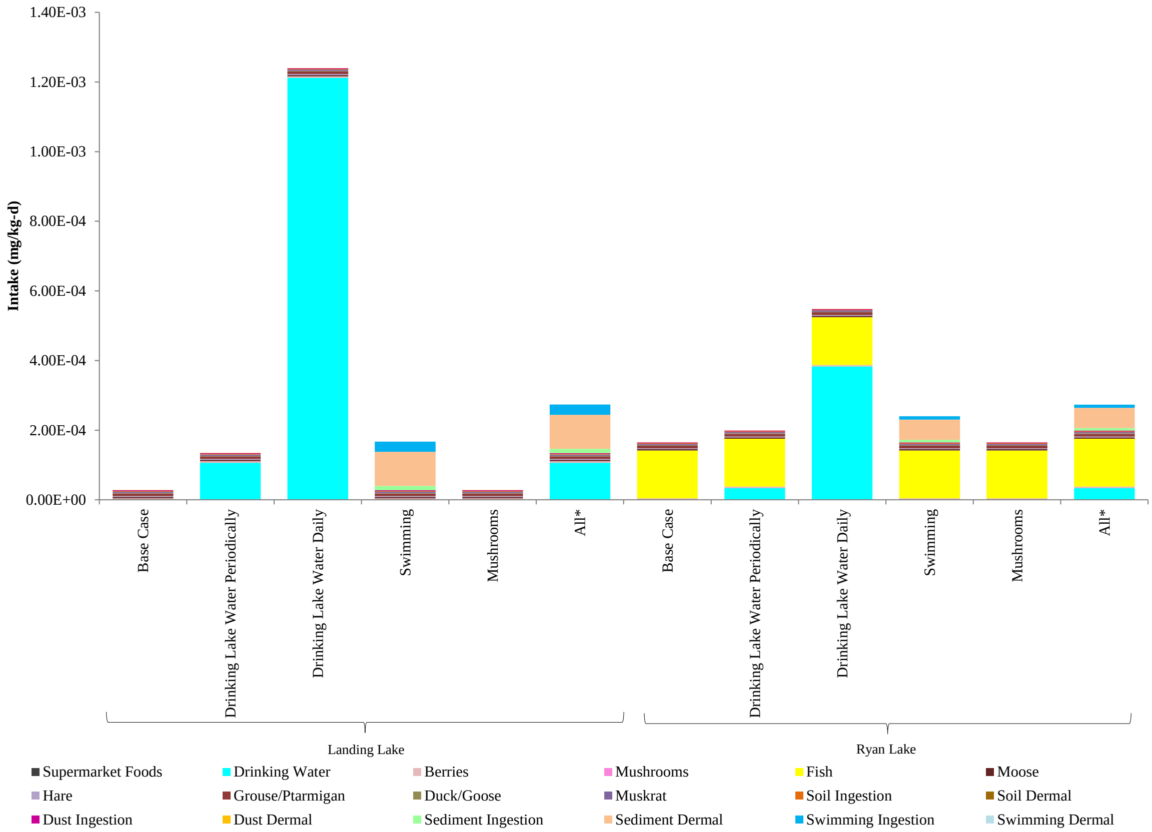
Figure 4.18 Estimated intakes for a toddler exposed year-round on Landing Lake or Ryan Lake – total arsenic



Drinking water is municipally sourced or bottled water for all scenarios except 'Drinking Lake Water Daily and Periodically"; eating mushrooms was only evaluated for the adult and thus the intakes for the Base Case and mushroom scenarios are the same for the toddler; intakes are for a supermarket food diet supplemented with country food. *All includes drinking lake water periodically, swimming, and eating mushrooms.

Figure 4.19 shows the relevant pathways of exposure for incremental (i.e., total – background) arsenic exposure. Drinking lake water daily from Landing or Ryan lakes dominates the intakes of incremental arsenic by the toddler receptor. Eating fish (northern pike) from Ryan Lake also contributes to the incremental arsenic intakes. This is as a result of the elevated concentrations of arsenic in the flesh of three northern pike samples. Otherwise, eating country food contributes marginally to arsenic exposure at lakes within the year-round recreational areas.

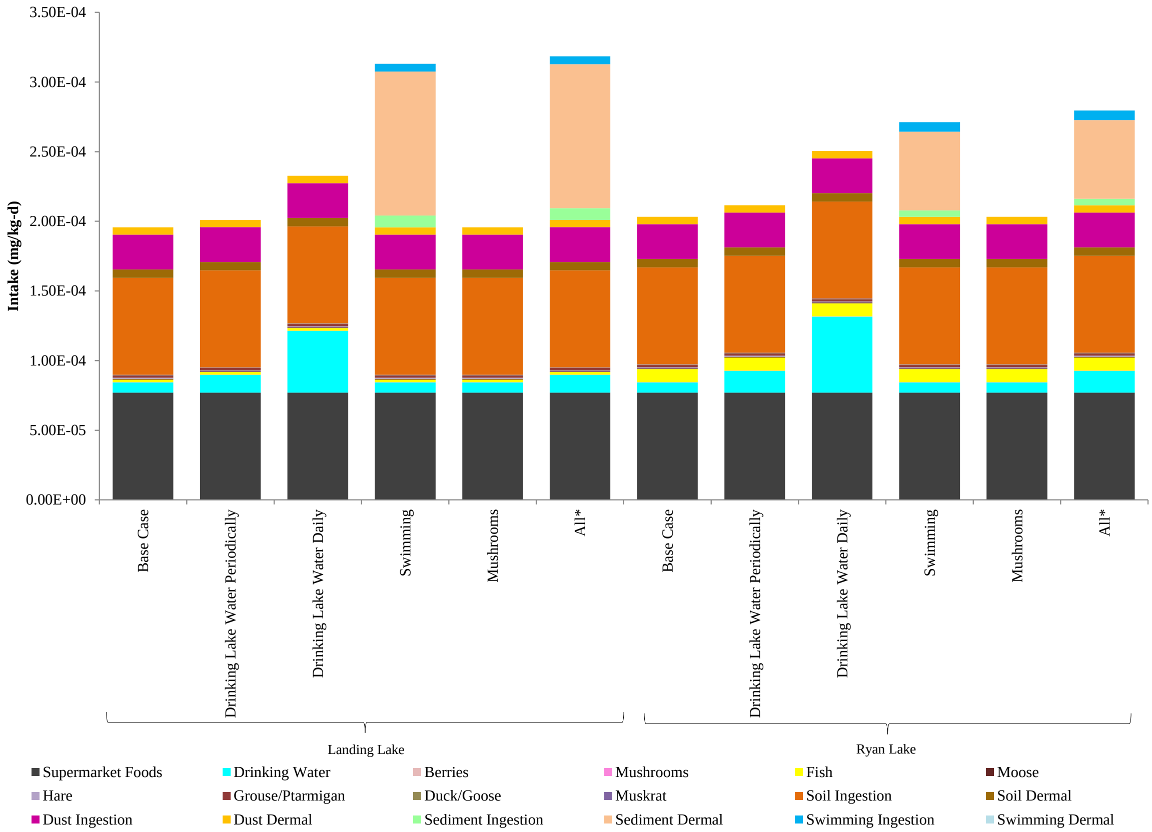
Figure 4.19 Estimated intakes for a toddler exposed year-round on Landing Lake or Ryan Lake – incremental arsenic



Drinking water is municipally sourced or bottled water for all scenarios except 'Drinking Lake Water Daily and Periodically''; eating mushrooms was only evaluated for the adult and thus the intakes for the Base Case and mushroom scenarios are the same for the toddler; intakes are for a supermarket food diet supplemented with country food. *All includes drinking lake water periodically, swimming, and eating mushrooms.

Figure 4.20 shows the intakes from antimony exposure at these lakes. The figure shows that after supermarket foods, eating soil and skin contact with sediment while wading represent the next largest exposure pathways to antimony for toddlers. Again, there is some double-counting for the antimony intakes since intakes from supermarket foods were not reduced to account for the foods obtained as country foods.

Figure 4.20 Estimated intakes for a toddler exposed year-round on Landing Lake or Ryan Lake – antimony



Drinking water is municipally sourced or bottled water for all scenarios except 'Drinking Lake Water Daily and Periodically"; eating mushrooms was only evaluated for the adult and thus the intakes for the Base Case and mushroom scenarios are the same for the toddler; intakes are for a supermarket food diet supplemented with country food. *All includes drinking lake water periodically, swimming, and eating mushrooms.

5.0 TOXICITY ASSESSMENT

Toxicity refers to the ability of a chemical to cause temporary or permanent adverse effects in the body. Toxicity depends on several factors such as the form of the chemical, the amount of exposure, and the duration of the exposure.

For some chemicals that do not cause cancer (in this case antimony and mercury), there is a permissible (safe) level or threshold dose, called an oral reference dose, below which adverse health effects are not expected to occur. These permissible levels are set by regulatory agencies such as Health Canada and the U.S. EPA based on scientific studies from laboratory animal tests or on human epidemiological studies or workplace exposure investigations. These studies are reviewed by a number of experienced scientists in a wide range of scientific disciplines in order to determine the maximum dose that a human can be exposed to without having an adverse health effect. Permissible doses are usually reported as the amount of chemical per unit body weight per unit time that a person may be exposed to every day of their entire life that will not cause adverse health effects. It should be noted that exposure above a permissible level does not mean that an effect will occur, but instead means that there is an increased risk of an adverse effect occurring.

Arsenic is known to cause cancer but also has a non-cancer endpoint. For chemicals that cause cancer, the total exposure over an entire lifespan (from birth to death) is calculated using a lifetime receptor, which represents a combination of all life stages (infant, toddler, child, adolescent, and adult). This is because before a cancer occurs, a person needs to be exposed for a very long time to arsenic before an adverse effect is observed. The exposure calculated for the lifetime receptor is known as the lifetime average daily dose. The cancer-causing power of a carcinogen is represented by its cancer slope factor. These are values set by regulatory agencies such as Health Canada and the U.S. EPA based on specially designed cancer studies in humans or laboratory animals. Cancer slope factors are used in combination with the average lifetime exposure estimates for carcinogens to estimate cancer risks.

Toxicity Reference Values (TRVs), including oral reference doses and cancer slope factors, are intended to protect the most sensitive individuals (e.g., the elderly, pregnant women, children, etc.) as well as people with compromised health such as asthmatics.

Table 5.1 provides a summary of the TRVs selected for use in the assessment for oral exposure. The TRVs for the carcinogenic effects of arsenic and non-carcinogenic effects of mercury were obtained from Health Canada (2010) and the TRVs for the non-carcinogenic effects of arsenic and antimony were obtained from the U.S. EPA Integrated Risk Information System (IRIS) database (U.S. EPA 2019b). The TRVs, health effects (toxicological endpoints), and reference sources for each TRV are provided in the table. TRVs for the dermal exposure pathway are not generally available. Therefore, dermal exposures are generally added to the ingestion exposures once adjustments are made to account for differences in absorption (see Appendix H and Table 4.4).

The TRVs presented in Table 5.1 are for chronic (long-term) exposure. Although some exposure pathways in the HHRA are being evaluated for short-term (i.e., running, hiking, swimming and camping) exposure, such as those related to soil which are evaluated assuming contact 2 days per week for a total of 16 weeks a year, TRVs for short-term exposure were not used since other pathways such as food ingestion were assumed to occur year-round. Thus the use of the chronic exposure TRVs are appropriate and in the case of the occasional recreational exposure scenarios are more conservative.

The following sections provide a brief discussion of the toxicity of antimony, arsenic, and mercury. A more detailed discussion of the toxicity is provided in Appendix H.

Table 5.1 Summary of toxicity reference values used in the assessment

COPC	Oral Toxicity Reference Value				Endpoint
	Carcinogenic (Slope Factor)		Non-Carcinogenic (Reference Dose)		
	$(mg/(kg\text{-}d))^{-1}$		(mg/(kg-d))		
Antimony	N/A		4.0×10^{-4}	U.S. EPA (2019b)	Longevity, blood glucose and cholesterol
Arsenic	1.8	Health Canada (2010)	3.0×10^{-4}	U.S. EPA (2019b)	Internal cancers (carcinogenic) Skin effects (non-cancer)
Mercury (organic)	N/A		2.0×10^{-4} (toddler, child) 4.7×10^{-4} (teen, adult)	Health Canada (2010)	Neuro-toxicity and neurodevelopmental toxicity

N/A: Not applicable; there are no TRVs for dermal exposures; dermal exposures are added to oral exposures after adjustments made for absorption.

5.1 Arsenic

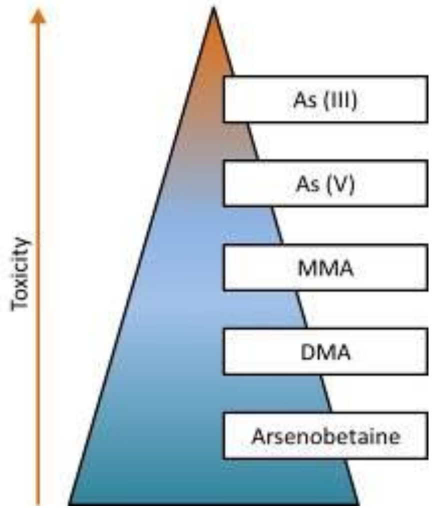
Arsenic is considered to have both cancer and non-cancer endpoints. The Agency for Toxic Substances and Disease Registry (ATSDR 2017) provides a detailed discussion of the various toxicity endpoints for arsenic. The focus of this discussion and the discussion in Appendix H is on the endpoints used by regulatory agencies for TRVs.

Trivalent arsenic (As^{3+}) is generally more toxic than pentavalent arsenic (As^{5+}). The problem with arsenic toxicity is the formation of by-products of oxidation of arsenate, such as arsenite, methylarsonic acid [MMA], and dimethylarsinic acid [DMA] that do not allow for a clear dose-response curve. While the methylation of arsenate helps in the removal of arsenic from the body, it has been shown to increase the levels of these three toxicants.

Research has shown that all four forms of arsenic (As^{3+}, As^{5+}, DMA, MMA) have adverse effects at the cell metabolism level by damaging cell DNA or by reacting with critical sulfhydryl containing enzymes; however, it is unclear how to correlate data obtained from animal studies to actual human effects (Hughes et al. 2011). Organic arsenic compounds such as arsenobetaine are found in fish and shellfish and are considered not to be toxic.

Figure 5.1 shows a schematic of the relative toxicities of the arsenic species. Due to the fact that there are no definitive dose response curves for the various arsenic species As^{3+}, As^{5+}, DMA, MMA, they have all been assumed to have the same toxicity as As^{3+}. Arsenobetaine has been assumed to be non-toxic.

Figure 5.1 Schematic of the relative toxicities of arsenic species



Arsenic is considered to cause cancer in the lung, bladder, and skin as discussed in Appendix H. An oral slope factor of 1.8 (mg/kg d)$^{-1}$ derived by Health Canada (2010) is used in this assessment. The IRIS database (U.S. EPA 2019b) provides an oral slope factor of 1.5 (mg/kg d)$^{-1}$ (see Appendix H). The effect of using this oral slope factor is discussed in the Uncertainty section (see Section 6.3).

Although the focus for arsenic exposure is on lifetime incremental cancer risks, consideration must also be given to the non-carcinogenic effects resulting from occasional exposure to arsenic by a recreational user. There is an acute (7 to 14 day exposure) oral reference dose available from the Agency for Toxic Substances and Disease Registry (ATSDR 2007); however, as discussed above, chronic TRVs were considered more appropriate for this assessment and thus the chronic oral reference dose of 3.0x10^{4} mg/kg-d for hyperpigmentation (skin discolouration) from the IRIS database (U.S. EPA 2019b) was used in this assessment for recreational users.

More details on the selection of these values are provided in Appendix H.

5.2 Antimony

Antimony is not considered to cause cancer. Toxicity occurs either from exposure in the workplace or during therapy. Workplace exposure may cause irritation in the respiratory system, lung disease, antimony spots on the skin, and problems with digestion. The critical effects for exposure to antimony include effects on longevity, blood glucose, and cholesterol levels.

Health Canada (2010) has no published TRVs for antimony. The IRIS database (U.S. EPA 2019b) provides an oral reference dose of 0.0004 mg/kg-d, which is based on a study in rats. This value includes a safety factor of 1,000. This value was used in the assessment. More details on antimony toxicity and the selection of this TRV are provided in Appendix H. There are more recent evaluations of the toxicity of antimony by the WHO and other international regulatory agencies. Based on their evaluations, an oral reference dose of 0.006 mg/kg-d has been derived (see Appendix H). The effect of using this antimony TRV is discussed in the Uncertainty section (see Section 6.2.3).

5.3 Mercury

Mercury occurs naturally in the environment, exists in several forms, and is not known to cause cancer. When mercury combines with carbon, the compounds formed are called "organic" mercury compounds or organomercurials. The most common organic mercury compound is methylmercury. Methylmercury is produced primarily by microorganisms (bacteria and fungi) in the environment, rather than by human activity. Methylmercury is of particular concern because it can build up in certain edible freshwater and saltwater fish and marine mammals to levels that are many times greater than levels in the surrounding water.

The primary exposure route of organic mercury is through the ingestion of contaminated fish and this is what is being considered in the assessment.

Health Canada (2011) provides an oral reference dose of 4.7×10^{-4} mg/kg-d for methylmercury for the general adult population based on epidemiological studies. This value was applied to the adult and teen in this assessment. A more conservative value of 2×10^{-4} mg/kg-d was derived for children under 12 years old and women of child-bearing age, which was applied for the toddlers and children in this assessment.

5.4 Evaluation of Potential Toxic Interactions

There are very few methods for combining exposures to multiple COPC at a regulatory level. The simple approach to multiple chemical exposures involves examination of the individual toxicities and adding the exposures if the end points are for the same target cell or tissue. For example if a two chemicals had effects on the kidney, those exposures would be added together. As seen from Table 5.1, antimony exposures are associated with changes in cholesterol in the blood and arsenic either is related either to a skin effect or cancer. Therefore these two COPC act on very different parts of the body and thus, there is a very low possibility of toxic interactions.

6.0 RISK CHARACTERIZATION

The risk characterization integrates the exposure assessment and the toxicity assessment to determine the risks. The following sections provides a summary of the results; more detailed results are provided in Appendix I. Appendix J provides the sample calculations.

6.1 Non-carcinogenic Risks

Antimony has been determined to not cause cancer. Although the main effect of exposure to arsenic is cancer, there is also a non-cancer endpoint for arsenic exposure and this was used to evaluate occasional exposures in recreational areas.

For mercury, an evaluation was completed for people (all life stages) eating northern pike from Lower Martin Lake and Mason Lake, which were the only lakes with where the mercury concentrations in northern pike flesh were above the ML.

The risk for antimony, arsenic, and mercury is determined by comparing the calculated exposure estimates to the permissible dose or safe level (i.e., the TRV). When the calculated exposure is below this safe level, adverse health effects are not expected. In this case, risks may be considered to be insignificant or negligible. If the calculated exposure estimate exceeds the safe level, then the risk of an adverse health effect cannot be ruled out and further investigation is required.

The toddler is typically the most exposed receptor due to lower body weight and generally higher relative exposures to soil and sediment. Therefore, results for the toddler as well as results for an adult are presented. Complete results for all life stages, including a breakdown by exposure pathway, are provided in Appendix I.

6.1.1 Occasional Recreational Use and Traditional Land Use

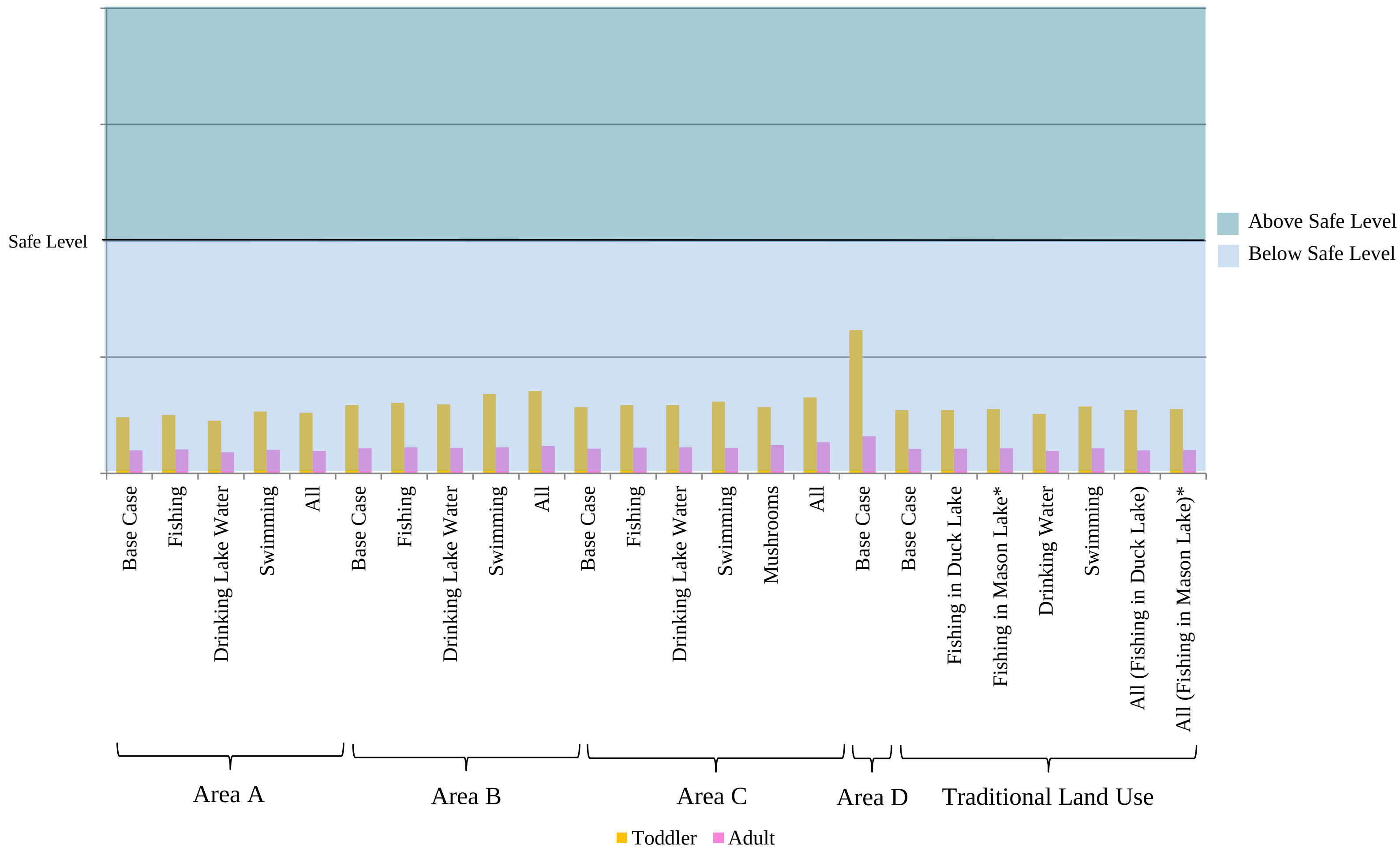
The non-carcinogenic risk evaluation for the occasional recreational and TLU areas evaluated exposure of people to antimony and arsenic in soil, surface water, sediment, berries, mushrooms, game, and fish. In addition, the results from eating northern pike with elevated mercury concentrations in Lower Martin Lake and Mason Lake are presented.

6.1.1.1 Antimony

Figure 6.1 provides a summary of the estimated exposures to antimony calculated for people spending time within recreational areas A through D and the TLU area for the base case and additional scenarios discussed in Section 4.2. The mushroom scenario was only considered for recreational Area C as most of the mushroom samples were collected in this area; however, the exposure from eating mushrooms is considered to be the same for any of the recreational areas evaluated. The results for combining all these pathways (all) are also presented. It is noted that there is some double-counting for the antimony exposures presented in the figure since intakes from supermarket foods were not reduced to account for intakes for the foods obtained as country foods.

Figure 6.1 shows that all the exposures to antimony from occasional recreational and traditional activities are below the safe level and, therefore, the risk from exposures to antimony for people using these areas for activities such as hiking, swimming, fishing, hunting, and mushroom and berry collection is considered to be negligible. A person may also drink water from inland lakes with no significant risk from antimony exposure. The figure also demonstrates that, as expected, toddlers are more exposed than adults. People in Area D are more exposed than in other areas because of the higher soil concentration, but the exposures are still well below the safe level.

Figure 6.1 Estimated potential risks for occasional recreational and traditional use areas – antimony



Intakes are for a predominantly supermarket food diet for areas A through D,and a mixed supermarket/country food diet for the Traditional Land Use area; base case includes soil ingestion, soil dermal contact, and game and berry consumption; eating mushrooms was only evaluated for the adult and thus the exposures for the Base Case and Mushrooms scenario are the same for the toddler; drinking water is municipally sourced or bottled (not untreated lake water) for all scenarios except for "Drinking Lake Water".
* Northern pike in Mason Lake is northern pike, burbot, and trout.

6.1.1.2 Arsenic

As discussed above, the assessment considered exposure to arsenic of people within the recreational and TLU areas for short but repeated periods of time. As the results are similar to the results associated with the cancer end-points for arsenic they are presented in Appendix I and the conclusions are discussed in the cancer effects associated with arsenic exposure (see Section 6.2.1).

6.1.1.3 Mercury

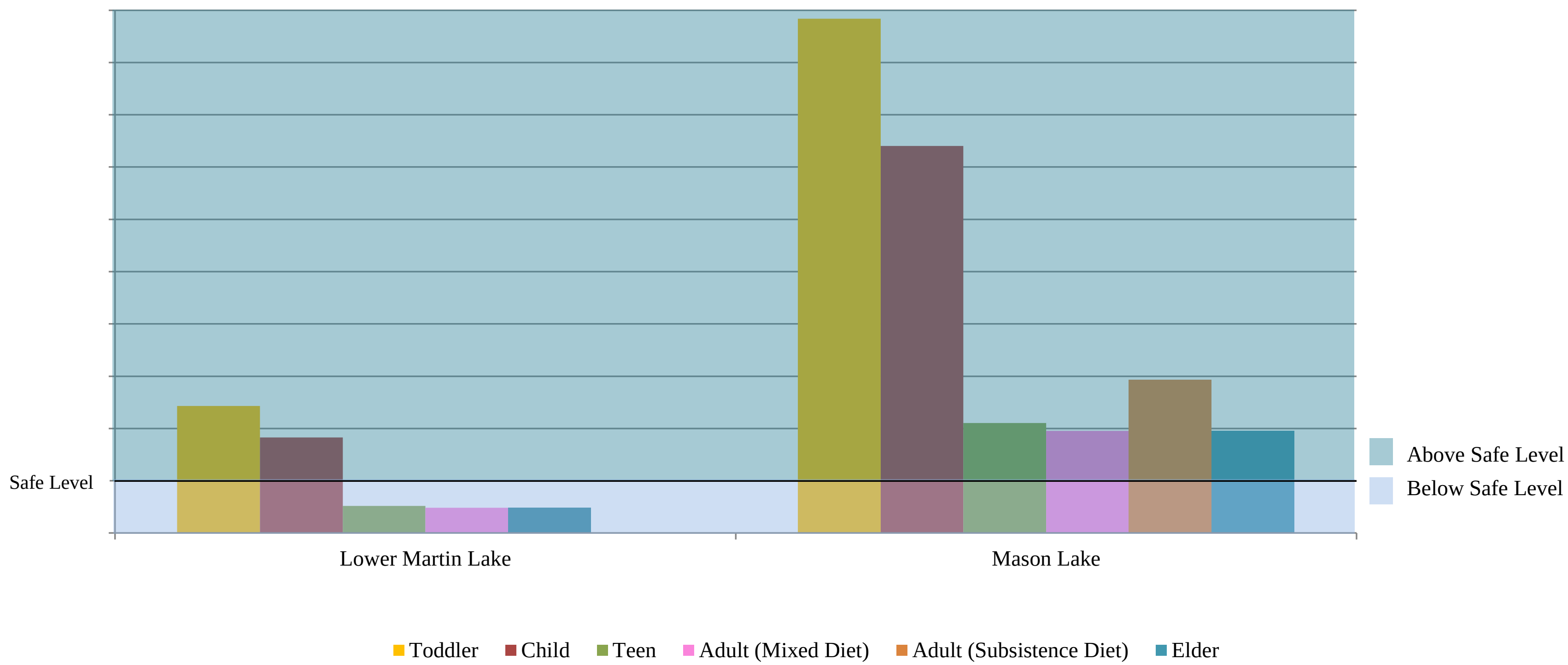
Average mercury concentrations in fish flesh from inland lakes in the study area are below the Health Canada (2018a) ML for mercury in the edible portion of fish of 0.5 mg/kg ww, with the exception of northern pike flesh from Lower Martin Lake and Mason Lake. Thus, Figure 6.2 presents a summary of the estimated exposures to mercury for people getting 10% of their annual fish intake from northern pike flesh from Lower Martin and Mason lakes. This represents a conservative estimate of intake. The calculations were completed assuming the following:

- People eating northern pike flesh from Lower Martin Lake based on a predominantly supermarket food diet (equivalent to approximately 2 fish total (1 kg each) over the course of a year for an adult and 1 fish total for a toddler).
- People eating northern pike flesh from Mason Lake based on a mixed supermarket/country food diet (equivalent to approximately 6 fish total over the course of a year for an adult and 3 fish for a toddler).
- Adults eating northern pike flesh from Mason Lake based on a subsistence country food diet (equivalent to approximately 10 fish total over the course of a year).

From the figure, it can be seen that there are no risks for teens, adults, or Elders eating the equivalent of 2 northern pike per year from Lower Martin Lake. If a toddler or child eat approximately 1 pike total (about 1 kg in size) over the year from Lower Martin Lake, there are some risks from exposure to mercury. Thus, it may be prudent to restrict the amount of northern pike from Lower Martin Lake that people eat.

There are also some risks to people of all ages who eat between 3 and 10 northern pike (1 kg each) over the year from Mason Lake. However, this estimate is based on mercury concentrations measured in a single sample of northern pike flesh from Mason Lake which may be attributed to the age of the fish as it was noted to be large. All other fish in Mason Lake had mercury concentrations below the ML and do not represent a concern.

Figure 6.2 Estimated potential risks from exposure to mercury in northern pike from Lower Martin and Mason lakes



Values are for a predominantly supermarket food diet for Lower Martin Lake; a subsistence country food diet was only evaluated for the adult. Mason Lake results are based on concentrations of mercury in 1 northern pike sample.

6.1.2 Year-round Use

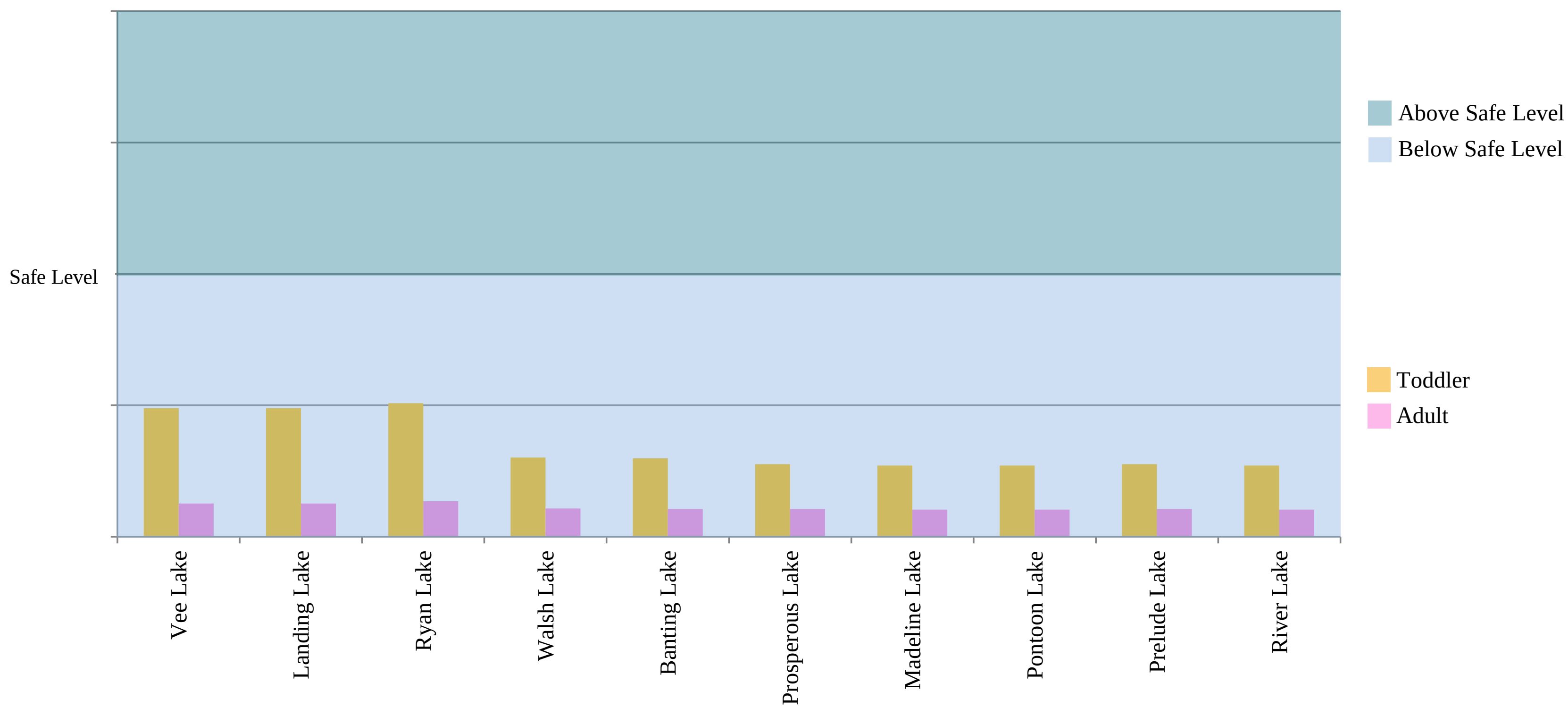
Year-round exposure of people living on inland lakes evaluated exposure to antimony in soil, surface water, sediment, berries, mushrooms, game, and fish. Mercury concentrations in fish flesh from lakes used year-round by residents were below the Health Canada (2018a) ML for mercury in the edible portion of fish and therefore are not a health concern. Chronic exposure to arsenic is evaluated through its effects to cause cancer.

6.1.2.1 Antimony

Figure 6.3 provides a summary of the estimated exposures to antimony calculated for people living year-round on inland lakes with a mixed supermarket/country food diet, while Figure 6.4 provides the results for people with a predominantly supermarket diet. A base case was evaluated which captured exposures from contact with soil (hand to mouth intake, skin contact), eating berries and preserving them to be eaten later, and eating fish, game, and food from the supermarket. It was also assumed that people drank bottled water or were municipally serviced for the base case. There is some double-counting for the antimony exposures presented in the figure since intakes from supermarket foods were not reduced to account for intakes for the foods obtained as country foods.

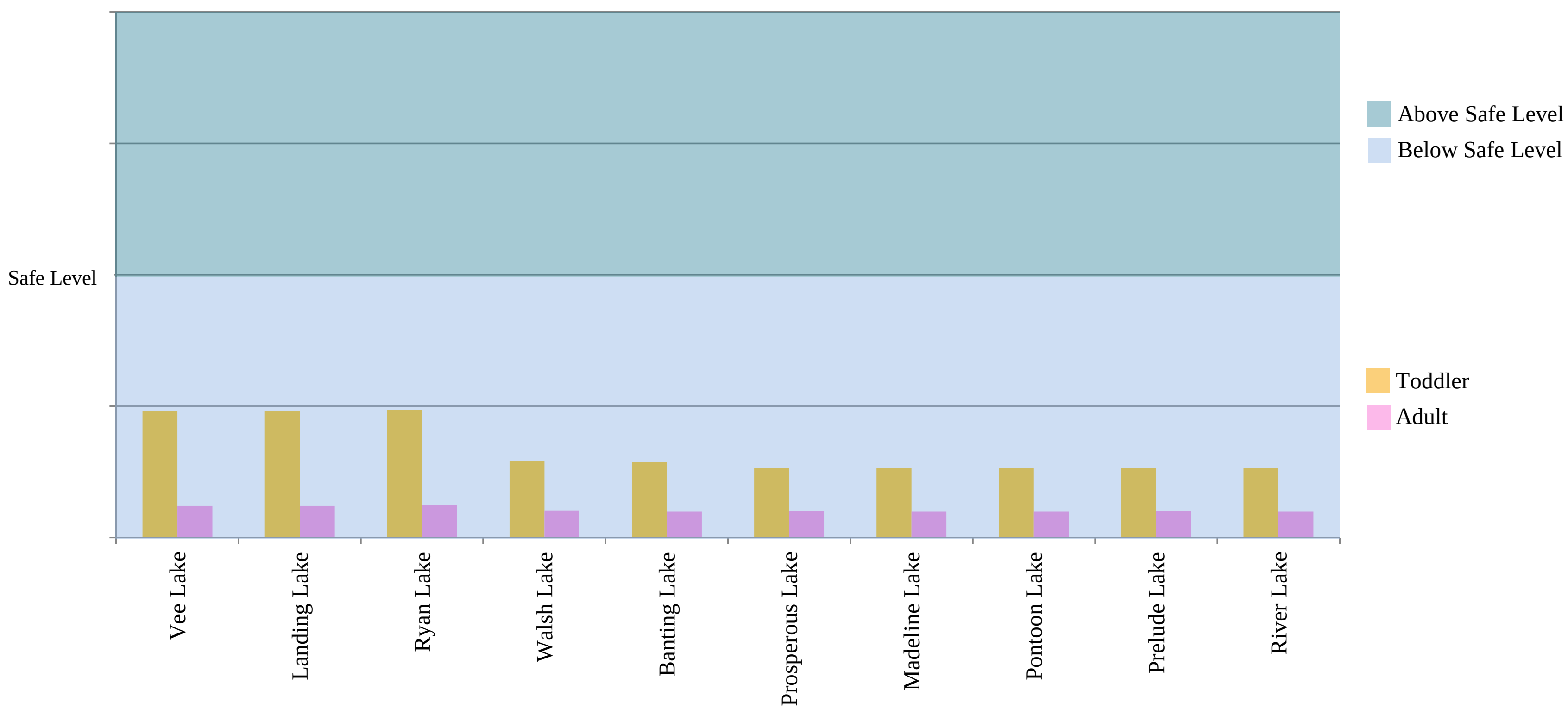
The figures show that the exposures are essentially identical between the two different diets, and that all the results are below the safe level. Therefore, the risk from exposures to antimony from playing outdoors, eating game and berries, and being exposed to indoor dust is considered to be negligible. The antimony concentrations in the inland lakes with cabins/houses are all below the drinking water guideline of 0.006 mg/L and therefore drinking water from the lake and swallowing water while swimming is considered represent a negligible exposure pathway for antimony.

Figure 6.3 Estimated potential risks from year-round recreational use – antimony



Note: Results are for a person with a mixed supermarket/country food diet.

Figure 6.4 Estimated potential risks from year-round recreational use – antimony



Note: Results are for a person with a predominantly supermarket food diet.

6.2 Incremental Carcinogenic Risks

Arsenic is known to cause cancer. The evaluation of potential cancer risks from exposure to arsenic is completed on an incremental basis (i.e., incremental risk = total risk – background risk). In many cases, it is difficult to separate incremental risk from total risk. Total cancer risk is calculated by adding all exposures including background exposures.

Any level of exposure to a cancer-causing chemical such as arsenic is associated with some level of risk. Thus, an acceptable level of risk must be set for these chemicals. Acceptable risks are provided by regulators in the form of incremental lifetime cancer risks, which are set at risk levels considered to be negligible. Health Canada's negligible incremental lifetime cancer risk level is one-in-one hundred thousand people (1 in 100,000).

For cancer-causing chemicals, the incremental lifetime cancer risk is estimated by multiplying the average daily dose over a lifetime, which includes all life stages combined (lifetime receptor) by the cancer slope factor (TRV). In order to provide a context for the incremental risks associated with arsenic exposure in this study, a framework, which has been used by recognized experts in the field of risk communication (Calman 1996; Paling 2003), was adopted. The different levels of risk are described below (Calman 1996):

- High: These risks may be fairly regular events and would occur at a rate greater than 1 in 100. They may also be described as frequent, serious, or significant.
- Moderate: This term relates to a risk of between 1 in 1,000 and 1 in 100. This would apply to a wide range of medical procedures (e.g., whole CT scans, nuclear stress tests) and environmental events.
- Low: This relates to a predicted increased risk of between 1 in 10,000 and 1 in 1,000. Again, many risks of clinical procedures (e.g., barium enemas, partial CT scans) and environmental hazards fit into this broad category. Other words that might be used include reasonable, tolerable, and small.
- Very Low: This describes a risk between 1 in 100,000 and 1 in 10,000; many health care interventions (e.g., dental x-rays, chest x-rays, mammograms) have adverse effects that are in this range.

- Negligible: Health Canada describes this as an adverse event occurring in less than 1 per 100,000 people. While still important to identify and monitor, such a risk would be of little concern for normal living. Another word that could be used to describe this risk level is insignificant. Health Canada considers that remedial activities should be implemented to reduce risks to a negligible risk level.

Potential risks are evaluated on a lifetime basis, which is done through the use of a lifetime receptor. As described in Section 4.1.7, various durations of exposure for each life stage were considered in order to estimate a lifetime risk to a receptor. A lifetime receptor was calculated assuming 4 years as a toddler, 6 years as a child, 8 years as a teen, 52 years as an adult, and 10 years as an Elder, for a total of 80 years of exposure. The results presented below for arsenic are estimated incremental lifetime cancer risks for a lifetime receptor.

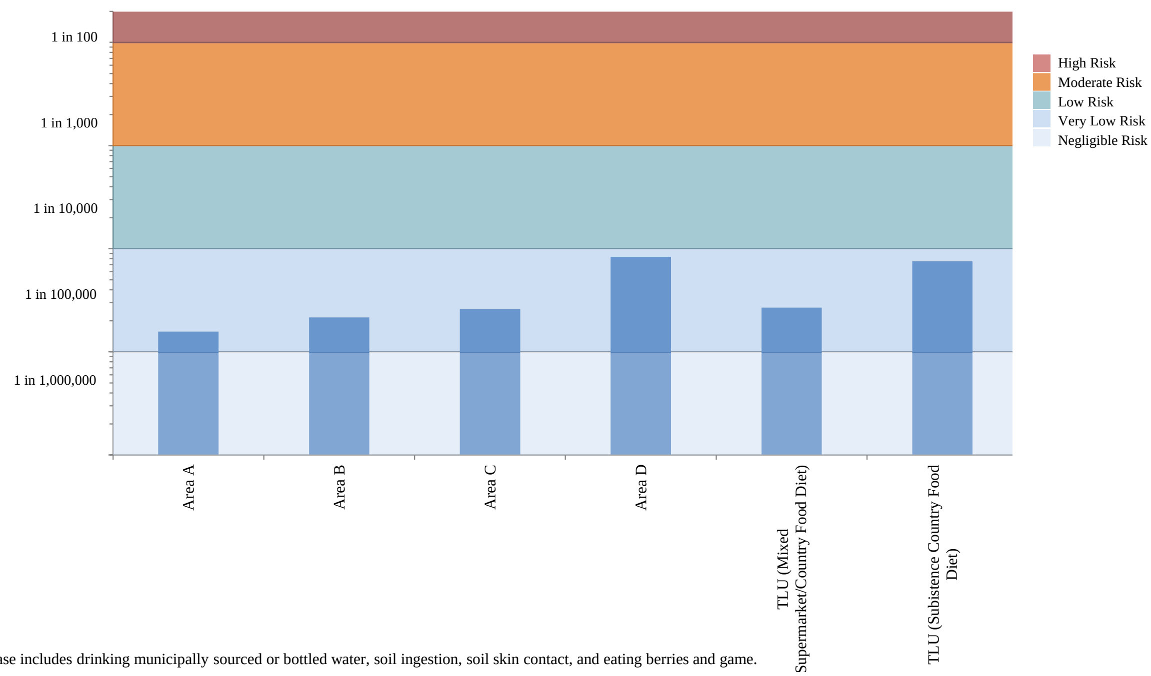
To determine the incremental risks, the background exposure was subtracted from the total exposures to determine the incremental exposure, and then the risk was calculated. For drinking water, the risk for arsenic exposure was based on evaluation of risks above the Health Canada drinking water guideline of 10 µg/L. Background concentrations for sediment, fish, berries, mushrooms, and game were based on samples obtained from greater than the 25 km radius (greater than 50 km for moose). Appendix D provides the description and values for the background concentrations. The EPCs and background concentrations used in the calculations are summarized in Section 4.5 and detailed in Appendix G. Detailed results, including a breakdown by exposure pathway, are provided in Appendix I; sample calculations are provided in Appendix J.

6.2.1 Occasional Recreational Use and Traditional Land Use

Figure 6.5 provides a summary of the estimated incremental lifetime cancer risks for arsenic calculated for the base case scenarios for occasional recreational and traditional activities in areas A through D and the TLU area. The YKDFN reported that they used the TLU for traditional activities but it was not indicated that anyone lived in this area. These activities involve exposure from contact with soil (hand to mouth intake, skin contact), eating berries while carrying out activities and taking them home and preserving them to be eaten later, and eating game and food from the supermarket. For the base case scenario, people were assumed to drink municipally serviced or bottled water as advice from the Chief Public Health Office is for people to not drink untreated water from lakes.

From the figure it can be seen that the incremental lifetime cancer risks from arsenic are in the very low range, even for a person with a subsistence country food diet. Risks are highest in Area D which is the closest to the Giant Mine as a result of contact with soil (arsenic soil EPC in Area D of 1,078 mg/kg, versus a range in other areas from105 mg/kg in Area A and the TLU area to 316 mg/kg in Area C). However, the risks are still in the very low range. The figure demonstrates that people using the study area for a range of activities including traditional harvesting will have a very low risk.

Figure 6.5 Estimated incremental lifetime cancer risk from arsenic – base case occasional recreational use and traditional land use



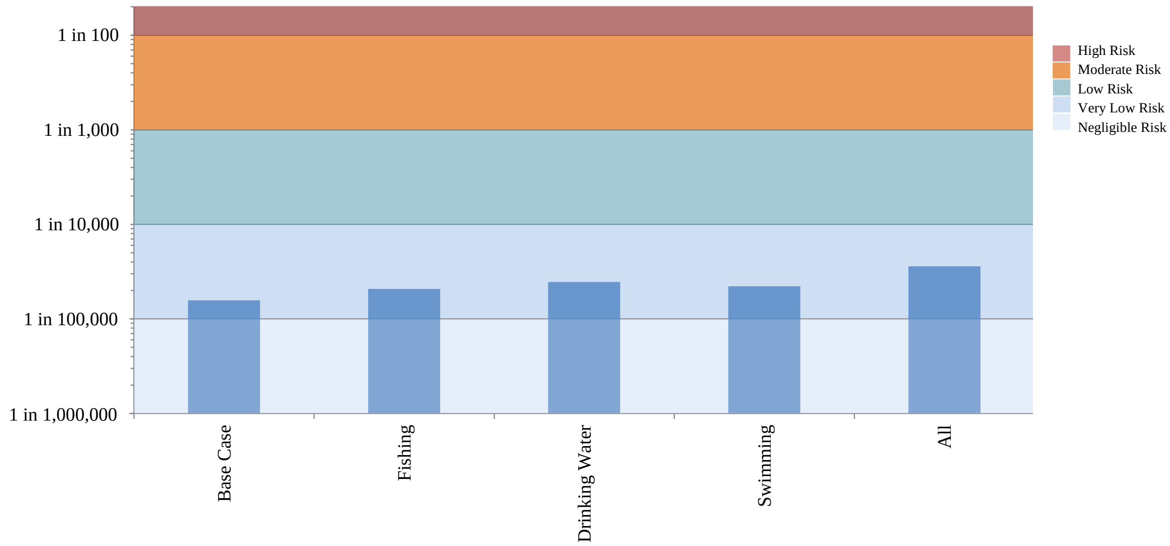
Base case includes drinking municipally sourced or bottled water, soil ingestion, soil skin contact, and eating berries and game.

The results of the survey indicated that people participate in other activities not covered in the base case while in the recreational areas. Therefore, additional activities were added to the base case to capture these exposures. These activities included drinking untreated water from inland lakes in the study area, fishing, swimming, and eating mushrooms. The mushroom scenario was only considered for Area C as most of the mushroom samples were collected in this area; however, the exposure from eating mushrooms is considered to be the same for any of the areas. Additional scenarios were not considered for Area D which is closest to the Giant Mine site since people who filled out the survey only reported running or hiking in that area, which is covered in the base case. The results of the additional analyses are presented in Figure 6.6 for Area A, Figure 6.7 for areas B and C (Base Case Area D is included for context), and Figure 6.8 for the TLU area.

Area A is the westernmost part of the study area. The arsenic concentrations in the surface water in the inland lakes in this area range from 3 µg/L to 50 µg/L and the surface water EPC for arsenic used in Area A is 15 µg/L. It is noted that advice from the Chief Public Health Office is to not drink untreated lake water from any lake, but occasional exposure to water with arsenic concentrations between 10 µg/L to 51.9 µg/L does not pose a significant risk for arsenic-related health effects and these lakes are considered safe for swimming and fishing.

For Area A (Figure 6.6), the additional exposure from fishing, drinking water, or swimming increases the estimated incremental lifetime cancer risk only slightly. Even if a person were to do all of these activities, the incremental lifetime cancer risk would still be in the very low range. It should be noted that these very low risks are similar to going to the dentist and having x-rays or having a chest x-ray. The results shown in Figure 6.6 support the advice from the Chief Public Health Office that lakes in this area are safe for swimming and fishing.

Figure 6.6 Estimated incremental lifetime cancer risk from arsenic from different pathways of exposure for Area A



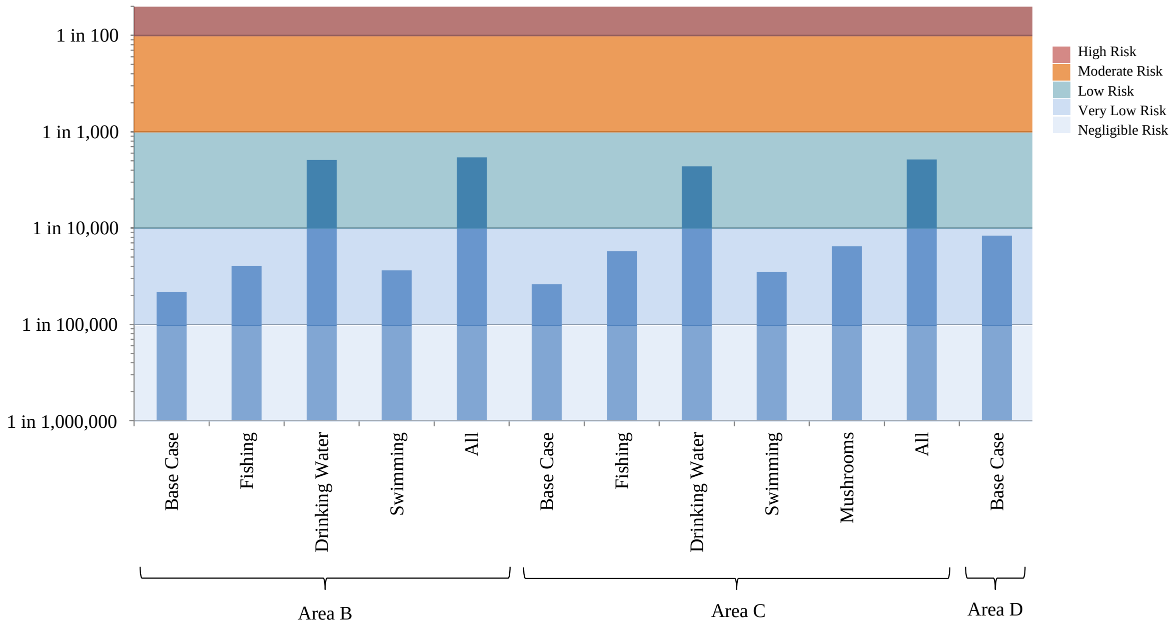
Base case includes drinking municipally sourced or bottled water, soil ingestion, soil skin contact, and eating berries and game based on a predominantly supermarket food diet. Exposure point concentration for surface water in inland lakes within this area is 15 µg/L; NWT Chief Public Health Office advice is to not drink untreated water from lakes, but occasional exposure at this concentration does not pose a significant risk. Lakes are considered safe for swimming and fishing.

In Area B (north of the former Giant Mine site), the arsenic water concentrations range from 7 µg/L for larger lakes to 1,000 µg/L for small, unnamed lakes and ponds. The surface water EPC, based on all available data in this area, was 228 µg/L. The Chief Public Health Office arsenic advice is to avoid fishing, swimming, and eating berries, mushrooms, and other edible plants around lakes with an arsenic concentration between 100 µg/L and 499.9 µg/L; thus, these activities should be avoided in and around the smaller, unnamed lakes in Area B where the arsenic concentrations are within and above this range. However, since people noted that they did some of these activities in Area B, they were evaluated in the assessment. Figure 6.7 shows that in Area B, fishing and swimming increase the arsenic cancer risk but the risks are still in the very low range. Drinking water 2 days a week for 16 weeks of the year increases the risk from the very low risk range into the low risk range. Combining all the exposure pathways also results in risks in the low risk range. Risks in the low category are similar to having a CT scan.

Area C is close to the City of Yellowknife and the Con Mine site. The arsenic water concentrations in this area range from 16 µg/L to 490 µg/L, with the lower concentrations again being representative of the larger lakes such as Long Lake and the higher concentrations being representative of smaller, unnamed lakes in the area. The surface water EPC used for the calculations is 220 µg/L, based on all available data regardless of size of lake. Figure 6.7 shows that the results are similar to those for Area B, in that fishing and swimming increases the arsenic cancer risk but the risks are still in the very low range. Eating mushrooms from Area C also results in the risks increasing, but they remain in the very low risk range. Drinking untreated water from smaller, unnamed lakes with elevated arsenic concentrations should be avoided, which is consistent with arsenic advice from the Chief Public Health Office. As seen from the figure, drinking water from lakes in this area results in the risks increasing into the low risk range. Combining all the exposure pathways also results in risks in the low risk range.

The results for these areas B and C show that fishing and swimming in these lakes result in cancer risks in the very low risk range. However, there are other documented reasons, such as algal blooms, for avoiding fishing and swimming in some of the lakes such as Jackfish Lake. Drinking lake water increases the arsenic cancer risks, and is consistent with the advice from the Chief Public Health Office. The consumption of mushrooms increases the cancer risk only slightly. The GNWT HSS, however, advises against eating mushrooms from within 10 km of the Giant Mine site.

Figure 6.7 Estimated incremental lifetime cancer risk from arsenic from different pathways of exposure for areas B, C, and D

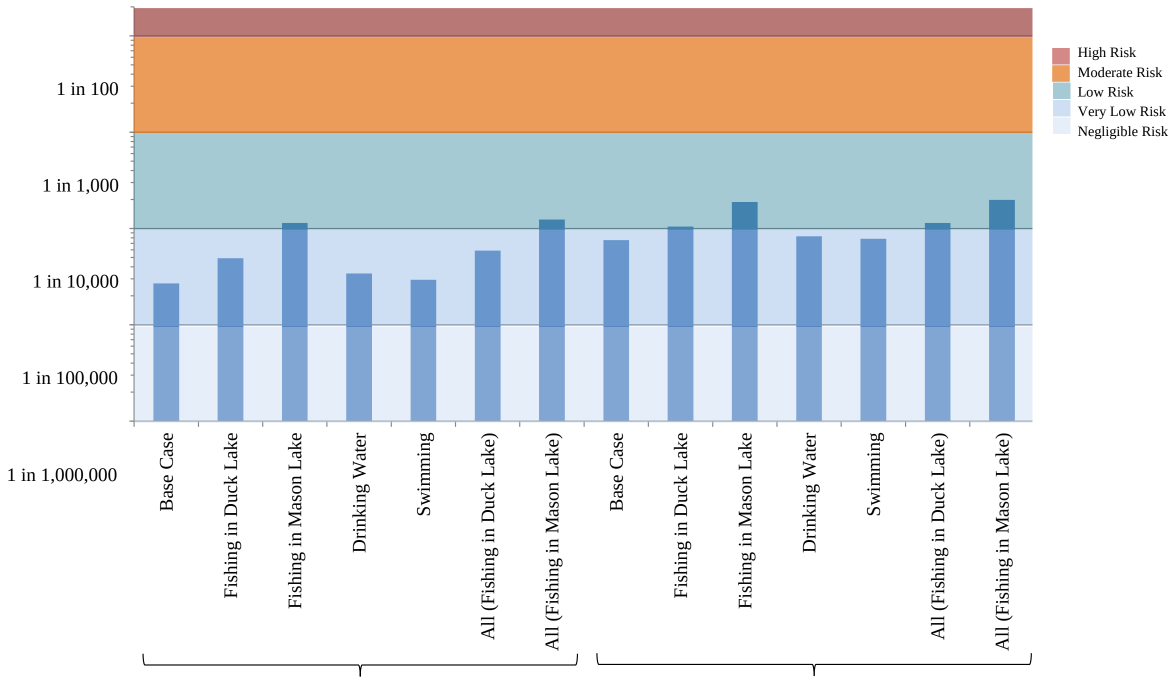


Base case includes drinking municipally sourced or bottled water, soil ingestion, soil skin contact, and eating berries and game based on a predominantly supermarket food diet. Exposure point concentrations for surface water in inland lakes within these areas are 258 µg/L (Area B) and 220 µg/L (Area C). Area D (EPC of 189 µg/L) was not evaluated for additional activities. NWT Chief Public Health Office advice is to not drink untreated water from lakes, and to avoid fishing, swimming, and eating berries, mushrooms, and other edible plants from around lakes with concentrations above 100 µg/L.

For the TLU area (Figure 6.8), the additional exposure from swimming in lakes increases the estimated incremental lifetime cancer risk marginally, but he risks for developing cancer from exposure to arsenic are still in the very low risk range and similar to going to the dentist and having x-rays or a chest x-ray. Eating fish from Duck Lake and drinking water from small lakes and ponds in the area also increases the incremental lifetime cancer risk slightly. Arsenic concentrations in Hay, Mason, and Duck lakes range from 2 µg/L to 10 µg/L which are below the arsenic drinking water guideline. In smaller lakes and ponds in this area the arsenic concentrations are as high as 51 µg/L, resulting in a surface water EPC for arsenic of 18 µg/L used in the assessment. Eating fish (primarily northern pike/burbot/trout) from Mason Lake increases the risks into the low risk range, but these risks are comparable to a partial CT scan.

The results of this assessment demonstrate that the YKDFN can continue carrying out traditional activities within the TLU area. Water from Hay, Mason, and Duck lakes is below the drinking water guideline for arsenic and therefore is safe to drink as long as it is boiled or treated.

Figure 6.8 Estimated incremental lifetime cancer risk from arsenic from different pathways of exposure for the Traditional Land Use area



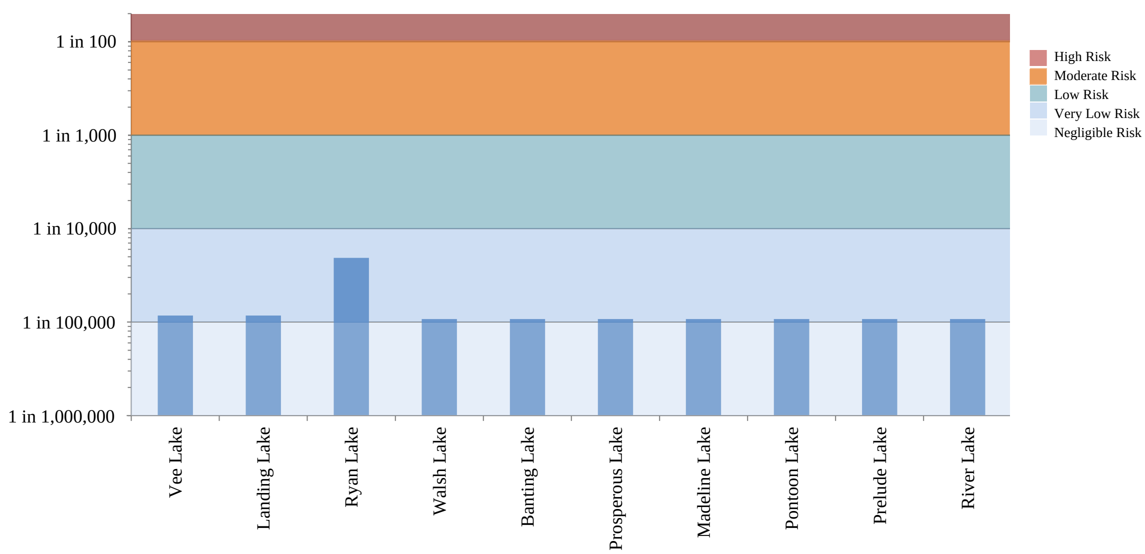
Base case includes drinking municipally sourced or bottled water, soil ingestion, soil skin contact, and eating berries and game. Exposure point concentration for surface water in inland lakes within this area is 14 µg/L, but concentrations in Hay, Duck, and Mason lakes are below the DWQG of 10 µg/L; NWT Chief Public Health Office advice is to not drink untreated water from lakes, but occasional exposure at this concentration does not pose a significant risk. Lakes are considered safe for swimming and fishing. Exposure from fish is primarily from northern pike/burbot/trout.

6.2.2 Year-round Use

The arsenic cancer risk evaluation for year-round exposure to people living on inland lakes evaluated exposure to arsenic in soil, surface water, sediment, berries, mushrooms, game, and fish. A base case was evaluated which captured exposures from contact with soil (hand to mouth intake, skin contact), eating berries and preserving them to be eaten later, and eating fish, game, and food from the supermarket. It was also assumed that people drank bottled water or were municipally serviced for the base case.

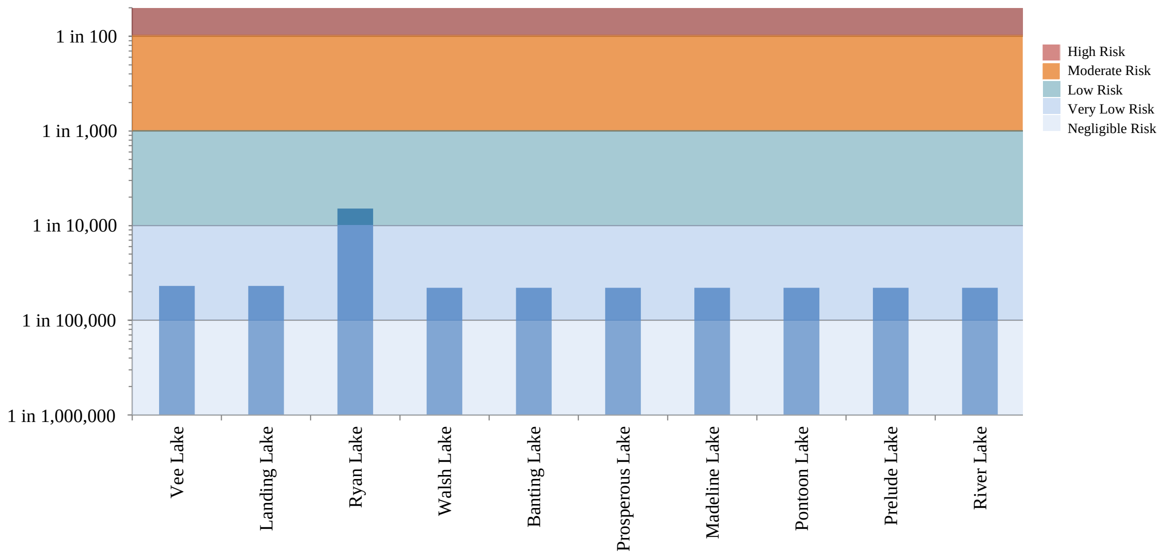
Figure 6.9 provides a summary of the estimated incremental lifetime cancer risks for arsenic for the base case calculated for a person living year-round on an inland lake with a predominantly supermarket food diet, while the results for a person with a mixed supermarket/country food diet are provided in Figure 6.10. The incremental lifetime cancer risks for people living in a cabin year-round on an inland lake in the base case scenario for the predominantly supermarket food diet are slightly above the negligible risk range (bottom end of the very low range) and for the mixed supermarket and country food diet are in the very low range which is similar to going to the dentist and having x-rays or having a chest x-ray. The risks are highest in Ryan Lake as a result of eating northern pike with elevated arsenic concentrations measured in the flesh, although are still in the low risk range and are equivalent to getting a CT scan. The arsenic concentrations in northern pike in Ryan Lake are higher than in other lakes with similar water and sediment concentrations.

Figure 6.9 Estimated incremental lifetime cancer risk from arsenic – base case year-round exposure, predominantly supermarket food diet



Base case includes drinking municipally sourced or bottled water, soil and dust ingestion, soil and dust skin contact, and eating berries, game, and fish.

Figure 6.10 Estimated incremental lifetime cancer risk from arsenic – base case year-round exposure, mixed supermarket/country food diet



Base case includes drinking municipally sourced or bottled water, soil and dust ingestion, soil and dust skin contact, and eating berries, game, and fish.

As the survey indicated that people carried out different activities on these lakes, exposures from drinking lake water and swimming were evaluated as separate scenarios for all inland lakes with cabins, except for Vee Lake since there is only a houseboat present for viewing northern lights. All the arsenic concentrations in water are below the Health Canada drinking water guideline of 10 µg/L with the exception of Landing and Ryan lakes. Thus the additional scenarios were evaluated on these two lakes as the additional incremental lifetime cancer risks for all the other lakes from these scenarios are zero and the results do not change. For Landing and Ryan lakes it was also assumed that people would eat mushrooms.

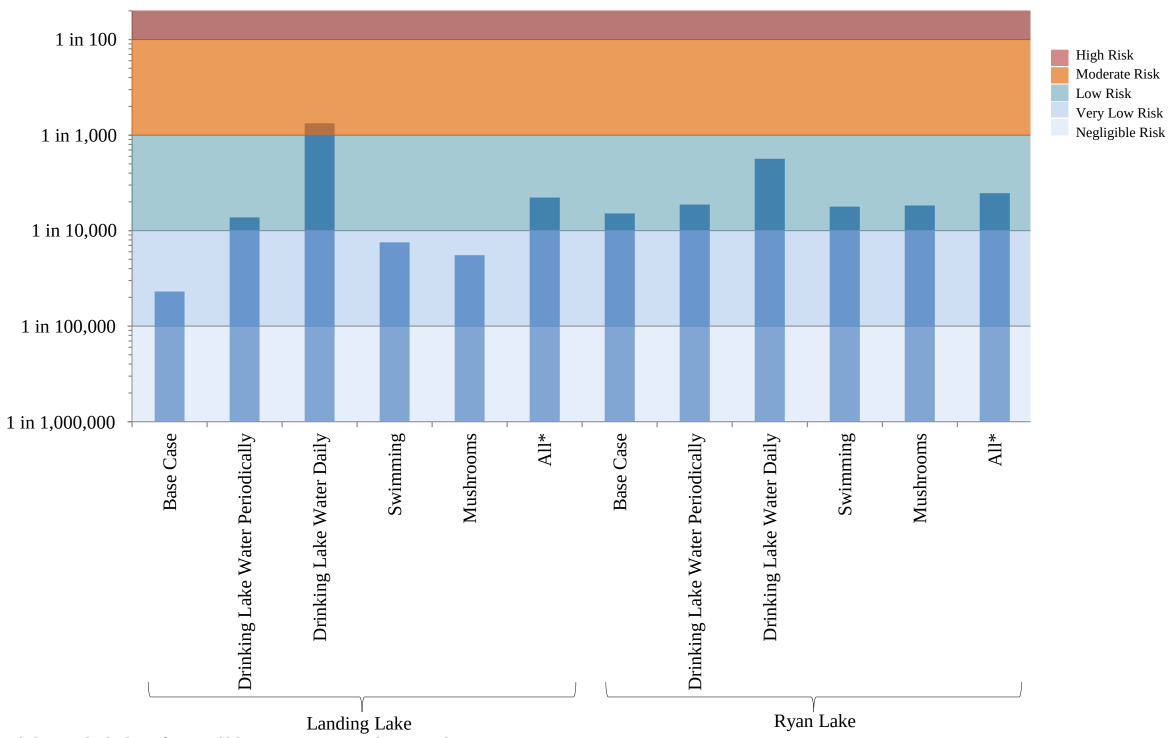
The additional scenarios were evaluated for a mixed supermarket/country food diet which results in higher arsenic exposures above background. The results for the additional scenarios for Landing and Ryan lakes are summarized in Figure 6.11 and shows that swimming increases the risks slightly from the base case but the results are still within the same risk level as for the base case (very low for Landing Lake and low for Ryan Lake).

The figure shows that using the lake water as the sole drinking water source results in an increase in risk from the very low risk range to the moderate risk range for Landing

Lake (based on arsenic EPC of 43 µg/L). Periodic drinking of water from Landing Lake (i.e., 2 days a week during open water season) results in risks increasing from the very low range to the low range. For Ryan Lake, based on a lower arsenic EPC of 21 µg/L, the risk from drinking lake water daily or periodically increases but remains in the low risk range. These results suggest that it is not prudent to drink water on a daily basis, particularly from Landing Lake.

Eating mushrooms results in an increased risk, but the risks remain in the very low range for Landing Lake and low range for Ryan Lake. If a person were to periodically drink lake water, swim in the lake, and eat mushrooms, there would be a low risk for developing cancer from exposure to arsenic via these pathways (all in Figure 6.11).

Figure 6.11 Estimated incremental lifetime cancer risk from year-round exposure to arsenic from additional pathways of exposure for a mixed supermarket/country food diet – Landing and Ryan Lakes



*All includes periodic drinking of untreated lake water, swimming, and eating mushrooms.

6.2.3 Implications of Arsenic Risks from Living in Yellowknife Area

To provide context to arsenic exposure associated with living in the Yellowknife area and engaging in different activities, a summary of the range of risks associated with arsenic exposure is provided in Figure 6.12.

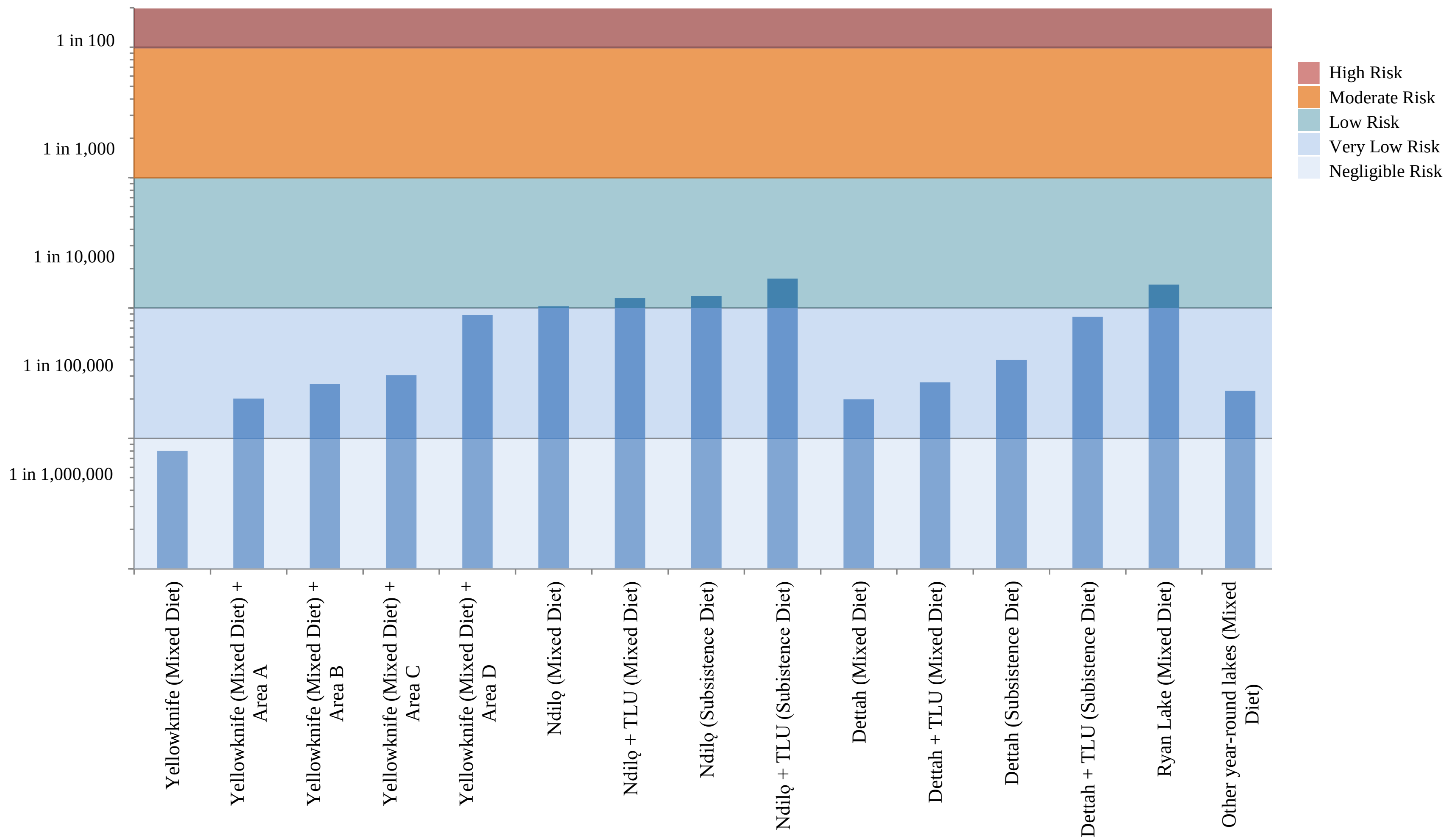
The results provided in the figure for recreational areas A to D consider a person living in the City of Yellowknife with a mixed supermarket/country food diet who gets some food off the land while visiting these areas. This covers hunters and gatherers who live in Yellowknife as well as members of the NSMA. The incremental risk associated with living in the City of Yellowknife but not frequenting areas A to D, also shown in the figure, was obtained from the GMRP HHERA (CanNorth 2018) and considers exposure to air, soil, and dust. The results show that risks increase from the negligible risk level to the low risk level when occasional recreational activities such as hiking, running, swimming and camping are carried out in areas A to D.

For the TLU area, the results are presented for people living in Ndilǫ or Dettah and carrying out traditional activities within this area. Both subsistence diets and people who eat some supermarket food (mixed diet) are presented. The incremental risks associated with living in Ndilǫ and Dettah but not frequenting the TLU area, also shown in the figure, were obtained from the GMRP HHERA (CanNorth 2018) and considers exposure to air, soil, and dust. The results show that there is some increase in risk from activities within the TLU; however, the change in risk is not significant. For Dettah, the risks from all the scenarios are within the low risk range. For Ndilǫ, the risks range from the upper end of the very low risk range into the lower end of the low risk range.

Results are also presented for people who live year-round on inland lakes and get some food of the land. For all inland lakes with the exception of Ryan Lake, the results are within the very low risk range. For Ryan Lake, the risks are within the low risk level due to eating of approximately 6 northern pike from the lake which have elevated arsenic concentrations. If someone only ate 3 northern pike in a year then the risk would drop to the very low risk level.

Overall, the figure demonstrates that most of the risks from living in the Yellowknife area and being exposed to arsenic are within the very low risk range. People living entirely off the land have risks within the low risk level, as does a person who eats the equivalent of approximately six northern pike a year from Ryan Lake.

Figure 6.12 Overall summary of incremental risks to residents



Note: Mixed diet is mixed supermarket/country food diet, while subsistence diet is subsistence country food diet. Other lakes include Prosperous, Pontoon, Prelude, Madeline, Banting, Landing, Walsh, and Vee Lakes. Yellowknife, Ndilǫ, and Dettah base case results are from the GMRP HHERA (CanNorth 2018).

6.3 Uncertainty

There are several areas of uncertainty in conducting a risk assessment due to the fact that assumptions have to be made throughout the assessment either due to data gaps, environmental fate complexities, generalizations of characteristics related to diet, and other human characteristics. An accounting of the uncertainty is provided to be able to place a level of confidence in the results. The magnitude and type of uncertainty are important in determining the significance of results. In recognition of these uncertainties, conservative assumptions were used throughout the assessment to ensure that the potential for exposure and risks would not be underestimated. The major assumptions are outlined below.

The arsenic and antimony concentrations used in the assessment were based on measured data, when available, from the aquatic and terrestrial environments from a variety of sampling programs. The number of data points was limited for some media in some of the areas. For example there are no fish data for arsenic and antimony in Vee Lake or for antimony in areas A or C. When possible, fish concentrations associated with similar water concentrations were used; however, this was not always possible for antimony and thus some of the fish concentrations may have been underestimated or overestimated. This adds some uncertainty to the assessment. For antimony, this would not affect the results since the results show negligible risk and eating fish is a small pathway of exposure.

The use of reasonable maximum exposure concentrations, which were either upper estimate (95% UCLM) values or average values of measured data, result in conservative estimates of exposure. For sediments, average concentrations were used in the study area since the majority of the sediment data were associated with small, unnamed lakes and ponds and not the larger lakes where people would most likely spend some time. Sediments represent a small exposure pathway and the use of the average concentrations does not change the outcome of the assessment. Average concentrations were used for people drinking water from inland lakes with cabins/houses as the exposures were assumed to be year-round. Average concentrations of arsenic and antimony were used for the country foods based on the measured data from the voluntary sampling as recommended by the WHO.

There were no measurements for indoor dust and, thus, the assessment assumed based on literature studies that the indoor dust concentration was 70% of the outdoor soil concentration. Literature studies indicate that dust levels range from 30% to 80% of outdoor soil concentrations and, thus, the use of 70% is at an upper end of the studies. The GMRP HHERA (CanNorth 2018) demonstrated that this assumption does not change the results and therefore the results are considered valid.

Site-specific bioaccessibility data were not available for antimony in any of the media considered in the assessment, for mercury in fish, or for arsenic in surface water or berries. It was therefore assumed that they were 100% bioaccessible when no information was available. This would lead to an overestimate of exposure. For arsenic, assumptions were made for the bioaccessibility in soil, sediments, fish, mushrooms, and game based on measured data for the area. These bioavailability assumptions were determined to be reasonable and were the same as the values used in the GMRP HHERA (CanNorth 2018).

The human receptor characteristics are also a source of uncertainty. The use of single values for various characteristics to evaluate exposure may overestimate exposure. For example, it has been assumed that an adult weighs 70.7 kg, when in reality an adult is likely to weigh more, thereby reducing the daily intake on a body weight basis (Richardson and Stantec 2013).

In evaluating swimming exposure at inland lakes, the assessment used incidental water ingestion intakes provided by the U.S. EPA (2019a) for the adult, teen, and child and toddler of 28 mL/hr, 44 mL/hr, and 38 mL/hr, respectively. Health Canada (2012b) in their guidelines for *Canadian Recreational Water Quality* use a value of 250 mL/d for a child swallowing water while swimming and the WHO (2006) uses a value of 100 mL/d. The use of the values from the U.S. EPA were determined to be valid in the GMRP HHERA (CanNorth 2018).

The TRVs are obtained from authoritative sources (e.g., Health Canada, U.S. EPA); nonetheless, they are always associated with uncertainty due to the extrapolation of testing on lab species (e.g., rats, mice, etc.) to field conditions as well as a range of receptors. Additionally, toxicity information for antimony, arsenic, and mercury was used regardless of its form in the test procedure, even though this may not be the same form in the environment (i.e., an oxide form compared to a more soluble form). In the derivation of cancer TRVs for arsenic, the linear extrapolation of data in the low-dose region of the dose-response curve is assumed to be sufficiently conservative to account for uncertainties related to the TRV. The use of an upper bound for the toxicity values ensures that the risk to humans is not underestimated. Currently, it is not possible or practical to develop approaches to evaluate the validity of the TRV assumptions on the overall assessment. As improvements occur in toxicological/human health research and assessments, the uncertainties may be reduced.

The arsenic TRV of 1.8 $(mg/kg\text{-}d)^{-1}$ for oral exposure used in the HHRA was obtained from Health Canada (2010), based on liver, lung and bladder cancers. As indicated in Appendix H, the IRIS database (U.S. EPA 2019b) provides a TRV of 1.5 $(mg/kg\text{-}d)^{-1}$ based on skin cancer. The risks from exposure to arsenic would be lower than estimated in the HHRA if the TRV of 1.5 $(mg/kg\text{-}d)^{-1}$ were used in the assessment. Although the endpoints are different for the two TRVs, the results of the arsenic evaluation would remain more or less unchanged.

Although some exposure pathways in the HHRA were evaluated for occasional exposure, such as those related to soil which are evaluated assuming contact 2 days per week for a total of 16 weeks a year, TRVs for short-term exposure were not used since other pathways such as food ingestion were assumed to occur year-round. This provides an over-estimate of risk as chronic TRVs are generally more conservative than short-term TRVs.

The antimony TRV of 0.0004 mg/kg-d that was used in the risk assessment was obtained from the IRIS database (U.S. EPA 2019b). Other international authoritative sources have suggested an alternate TRV of 0.006 mg/kg-d. The risks from the exposure to antimony are low and will be lower still if the higher TRV is used. Thus, the potential risks from exposure to antimony may have been overestimated.

The cumulative effect of arsenic and antimony on risk was not evaluated in this assessment. When dealing with toxic chemicals, there is potential interaction with other chemicals that may be found at the same location. From a human health perspective, it has been established that synergism, potentiation, antagonism, or additivity of toxic effects may occurs in the environment. A quantitative assessment of these interactions is constrained as there is not an adequate base of toxicological evidence to quantify these interactions. A simple qualitative assessment looking at the non-carcinogenic endpoints for humans indicates that there are no similar endpoints and, thus, risks are not considered to be additive. Therefore, the effects of arsenic and antimony interactions are anticipated to be negligible.

Table 6.1 provides a summary of the uncertainties and tries to assign a value to the uncertainty. It must be noted that these are approximations; however, in general it is accepted in the risk assessment community that the conservative assumptions used in the assessment generally result in overestimates of the risks by a factor of two to eight. It can be seen from the table that, in general, the uncertainties used in the assessment lead to an overestimate of exposures. Based on Table 6.1, the conclusions of the assessment are considered valid and reliable for the intended purpose.

Table 6.1 Summary of uncertainties in the assessment

Uncertainty	Overestimate	Possible Underestimate or Neutral Effect	Comment
No antimony fish flesh data for lakes within Area C			Fish flesh antimony data for Area B (area northwest of the Giant Mine) were used for Area C. Antimony concentrations in surface water are approximately 1.5 times higher in Area C than in Area B. Thus, fish flesh concentrations may be underestimated by a factor of up to 2.
No antimony in fish flesh data for lakes within Area A			Fish flesh antimony data for Area B (area northwest of the Giant Mine) were used for Area A. Antimony concentrations in surface water in Area A are approximately 8 times lower than in Area B, and thus fish flesh concentrations may be overestimated by a factor up to 8.
No fish flesh data for Vee Lake			Fish flesh data from Landing Lake were used as a surrogate for Vee Lake. Although Vee Lake is closer than Landing Lake to the Giant Mine site, there are no permanent houses on Vee Lake and it is largely used to access other lakes. People do not tend to fish from Vee Lake, and thus the inclusion of fish ingestion from this lake is an overestimate of exposure.
Evaluation of mercury data from a single fish in Mason Lake			Only one sample of northern pike from Mason Lake is available, with an elevated concentration of mercury that may be attributed to the age of the fish (large size). This may not be representative of the mercury concentrations in

Uncertainty	Overestimate	Possible Underestimate or Neutral Effect	Comment
			the northern pike population in Mason Lake, and thus the risks from eating northern pike from this lake may be overestimated.
Use of reasonable maximum exposure concentrations to characterize exposures			The use of the 95% UCLM to represent exposures for soil and surface water may overestimate exposures by a factor of up to two.
Use of average concentrations in sediment samples			Average sediment concentrations were used in the assessment as the majority of data came from small, unnamed lakes and ponds in the study area with higher concentrations than the larger lakes. The sediment pathway is a small pathway so the use of the average does not change the results and is a neutral effect.

Table 6.1 Summary of uncertainties in the assessment (Continued)

Uncertainty	Overestimate	Possible Underestimate or Neutral Effect	Comment
Use of average concentrations in country food samples			The use of the average concentration in country foods is an appropriate value to be used; however, if the maximum concentration was used the exposure may be underestimated by a factor of two to three.
Consideration of drinking water from inland lakes			Overestimation of exposure as drinking untreated water from lakes with elevated arsenic concentrations should be avoided according to advice from the Chief Public Health Office.
No adjustment for eating supermarket food for country food diet scenarios			This results in an overestimate of exposure for antimony in particular. All risks from exposure to antimony are below the safe level therefore results will not be changed.
Assumption of 100% bioaccessibility for antimony			It is known that metals are not fully absorbed in the digestive system. This may overestimate exposure by a factor of two to ten. All risks from exposure to antimony are below the safe level therefore results will not be changed.
Use of single values for human receptor characteristics such as body weight of 70.7 kg			People are different and weigh different amounts and drink various amounts of water etc. This may result in an overestimate of exposure by a factor up to two.
Food consumption rates for humans based on data from dietary survey			Studies have shown that people indicate in dietary surveys that they eat more than they actually do. This may result in an overestimate of exposure by a factor up to two.
Use of chronic TRVs to evaluate occasional exposures to soils,			The use of the chronic TRVs which are more restrictive can result in the overestimation of the

Uncertainty	Overestimate	Possible Underestimate or Neutral Effect	Comment
sediments, and drinking water			risks by a factor of ten.
Safety factors used by agencies in developing toxicity values			Regulatory agencies use safety factors when they develop toxicity values to try to make sure that sensitive people such as toddlers and elderly are protected. This tends to overestimate risks by a factor of three to ten.
Synergism, potentiation, antagonism, additivity of toxic effects			Toxicity endpoints were not the same and therefore this may be a neutral effect.

7.0 SUMMARY AND CONCLUSIONS

An HHRA was completed to evaluate potential risks from legacy contamination associated with mining activities in Yellowknife for people participating in traditional and recreational activities in areas surrounding the Giant and Con Mine sites. This assessment is in response to concerns raised by members of the public regarding exposure to legacy arsenic contamination in areas surrounding the Giant and Con Mine sites and included exposure from water, soil and indoor dust, sediment, berries, game, fish, and supermarket food.

The risks for non-cancer health effects from exposure to antimony in the study area were examined and found to be negligible.

The key concern from a health perspective is arsenic. Arsenic is considered to cause cancer and, therefore, the risk assessment evaluated the incremental (above-background) risk from exposure to arsenic in soils, indoor dust, water, sediment, and country foods in the area.

Figure 7.1 shows that the risks calculated from occasional exposure to arsenic while participating in a range of recreational activities including traditional harvesting are mainly within the very low to low risk range. These risks are equivalent to having dental and chest x-rays or a partial CT scan on an annual basis.

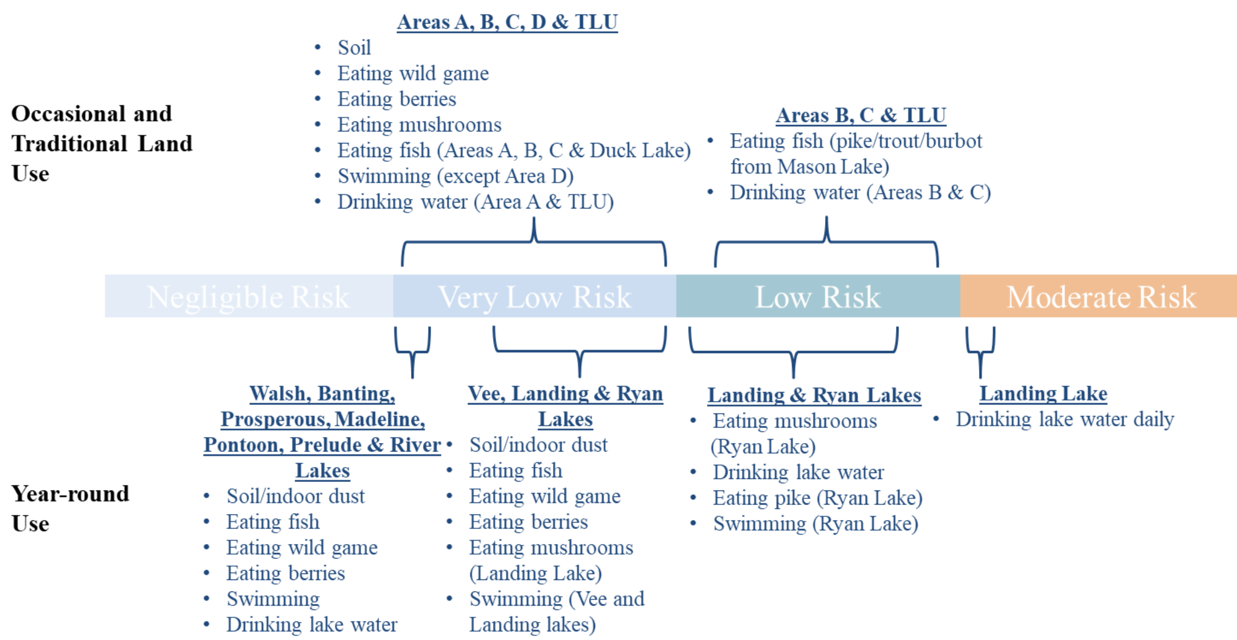
Figure 7.1 also demonstrates that traditional activities within the TLU area can continue and represent a low risk. Additionally, arsenic concentrations in water from Hay, Mason, and Duck lakes are below the drinking water guideline and it is safe to drink as long as you boil or treat the water.

Advice from the Chief Public Health Office indicates that people should not to drink untreated water from lakes. If people were to drink water in the study area from small lakes while running, hiking, camping, harvesting, or other recreational activities, the risks would increase slightly. Eating fish (particularly pike/trout/burbot) from Mason Lake within the TLU area also increases the cancer risk, although the risks are still equivalent to having a CT scan. Eating mushrooms from within 25 km of Yellowknife only results in slightly increased risks; however, as per advice from the GNWT HSS, mushrooms from within 10 km of Yellowknife should not be consumed.

Figure 7.1 also shows that the risks are very low from year-round exposure at inland lakes with cabins/houses to soil, eating fish, drinking water daily, swallowing water and sediment while swimming, and eating berries and game, regardless of diet. The exception is Ryan Lake, where the risks are higher for a person with a mixed supermarket/country food diet as a result of eating northern pike from Ryan Lake. The arsenic concentrations in northern pike in Ryan Lake are higher than in other lakes with similar water and sediment concentrations. Eating mushrooms increases the risks slightly.

The arsenic concentrations in drinking water in Ryan and Landing lakes are above the drinking water guideline and the evaluation demonstrated that it is not prudent to drink water on a daily basis from these lakes (especially Landing Lake) as there is a substantive increase in risk.

Figure 7.1 Summary of estimated incremental lifetime cancer risks from arsenic



In conclusion, the results for this assessment demonstrate that:

- occasional recreational activities such as running, hiking, swimming and camping represent a very low risk and can safely continue;
- traditional activities in the study area represent a low risk and can safely continue;

- living on the inland lakes in the study area and eating food from the area represents a very low risk;
- drinking water from lakes with arsenic concentrations below the drinking water guideline, such as Walsh, Banting, Prosperous, Madeline, Pontoon, Prelude, River, Hay, Duck, and Mason lakes, is safe as long as you boil or treat the water;
- people should not drink water from Landing and Ryan lakes on a continuous basis;
- eating lake whitefish from inland lakes in the study area represents a very low risk;
- people can eat the eyes, skin/fatty layer, and organs of fish from inland lakes;
- eating about 3 northern pike in a year from Ryan Lake represents a very low risk which increases to a low risk if you eat twice as much;
- a lower risk is associated with eating whitefish and trout from Mason Lake than eating northern pike and burbot from the lake;
- berries collected around the Yellowknife area are safe to eat; and
- mushrooms can be eaten outside of 10 km from the legacy areas with the exception of mushrooms from the Tricholomataceae family including pine mushrooms (*tricholoma*), common funnel mushrooms (*clitocybe*) and white mushrooms (*matsutake*) which should only be consumed if collected from greater than 25 km from the legacy mining areas.

The GNWT HSS identified mercury as a constituent of interest in fish and requested that it be evaluated in the HHRA. The study determined that mercury in fish in all of the inland lakes was below the Health Canada ML of 0.5 mg/kg wet weight (ww) with the exception of 1 large northern pike sample from Mason Lake and 14 out of 18 northern pike samples in Lower Martin Lake. All lake whitefish samples in Lower Martin Lake were below the Health Canada ML. The Chief Public Health Office has issued an advisory for eating northern pike in Lower Martin Lake.

A separate analysis was completed to evaluate the potential exposures and risks to people from eating Arctic grayling from Baker Creek (see Appendix L). The results of the analysis found that exposure to arsenic from eating Arctic grayling from Baker Creek does not represent a health concern for people living in Ndilǫ and Dettah and that people can continue to eat Arctic grayling caught in the Yellowknife area.

An additional evaluation was also completed for potential risks to outdoor workers that may be exposed to arsenic in soil along the Ingraham Trail/Highway 4 (see Appendix K). Overall, the results indicate that workers are at negligible risk from exposure to arsenic in soil while conducting various roadwork activities in the vicinity of the Giant Mine. Workers should nonetheless follow safe work practices, including the use of personal protection and safety equipment as required by the employer. The use of gloves on the job will further minimize the dermal exposure to arsenic in soil.

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APPENDIX A

DATABASE OF AVAILABLE DATA

APPENDIX B

QUESTIONNAIRE

APPENDIX C

SELECTION OF CONSTITUENTS OF POTENTIAL CONCERN

APPENDIX D

DEVELOPMENT OF BACKGROUND CONCENTRATIONS

APPENDIX E

SITE CHARACTERIZATION

APPENDIX F

RECEPTOR CHARACTERISTICS

APPENDIX G

EXPOSURE ASSESSMENT

APPENDIX H

TOXICITY REVIEW

APPENDIX I

DETAILED RESULTS

APPENDIX J

SAMPLE CALCULATIONS

APPENDIX K

EVALUATION OF EXPOSURE TO OUTDOOR WORKERS

APPENDIX L

EVALUATION OF EXPOSURE FROM EATING ARCTIC GRAYLING FROM BAKER CREEK