Exploring the design of new human health risk assessment approaches for Indigenous community contexts

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ABSTRACT

Environmental pollution poses unique and complex health risks to many Indigenous communities in Canada. These risks arise through both disproportionate exposure to contaminants and associated impacts on culture, spirituality, language, and traditional food systems that are unique to Indigenous communities. To date, institutionalized human health risk assessment (HHRA) approaches have not been developed or implemented with these unique contexts in mind, and thus often fail to capture health risks of relevance to Indigenous Peoples and communities. Recent proposed amendments to the Canadian Environmental Protection Act through Bill S-5 demonstrates regulatory interest in developing new approaches to risk assessments that are more efficient and ethical than conventional methods. This paradigm shift presents an opportunity to increase the relevance of HHRA approaches for the Indigenous communities in which they may be ultimately applied. However, despite the need for Indigenous community relevant HHRA approaches, and increasing regulatory support in this area, to date there has been minimal research conducted on the design of HHRA approaches for and by Indigenous Peoples and in Indigenous community contexts.

The objective of this thesis is to explore, ideate, test, and develop new approaches to human health risk assessment that are relevant for use for Indigenous community contexts, in collaboration with communities themselves. Doing so hinges on the consideration of diverse perspectives, and thus the research uses an interdisciplinary methodological design and data collection approach. The chapters follow the iterative process of design thinking (empathize, define, ideate, prototype, test). Chapter 3 presents an initial scoping review on the topic of contaminated sites and Indigenous Peoples, which compares information from three data streams

finding an overall diverse and disparate body of literature on the topic and identifying areas for further research. Chapter 4 presents a multi-sector survey study exploring human health and ecological risk assessment practice in Indigenous communities in Canada, which narrows in on key challenges and priorities and compares these amongst sectors. Chapter 5 tests the use of an HHRA approach of regulatory interest, RISK21, through two collaborative case studies involving three distinct Indigenous communities (Chipewyan Prairie First Nation, Cold Lake First Nations, and Apsáalooke (Crow) Tribe). Chapter 6 presents an initial regional-level pilot test of an existing approach to organizing and measuring Indigenous Health Indicators of relevance to risk assessment work. Chapter 7 provides an overview of an iterative methodological approach to designing an Indigenous Health Indicators tool by the Kanien'kehá:ka community of Kanesatake, and presents the initial findings of semi-structured, qualitative interviews on this topic. The health indicators tool may be used by the Kanesatake Environment Department to contextualize environmental assessments with community-defined health information.

Together, the chapters in this thesis aim to support the development of HHRA approaches for contaminants that are relevant, useful, and meaningful for the Indigenous communities in which, and by whom, they may ultimately be used. To do so, this work includes individual community-level design work towards risk assessment tools that are useful locally, simultaneously providing an example of a methodological 'roadmap' for other communities that may increase understanding of how to design, test, and validate new risk assessment tools to suit their unique contexts. The work also encompasses contributions to a broader understanding of some of the challenges and priorities with HHRA design and implementation at a national scale, which is important for eventual regulatory development and adoption.

RÉSUMÉ

La pollution environnementale pose des risques uniques et complexes pour la santé de nombreuses communautés autochtones au Canada. Ces risques découlent à la fois d'une exposition disproportionnée aux contaminants et des impacts associés sur la culture, la spiritualité, la langue et les systèmes alimentaires traditionnels particuliers aux communautés autochtones. À ce jour, les méthodes institutionnalisées d'évaluation des risques pour la santé humaine (ERSH) n'ont pas été élaborées ou mises en œuvre en tenant compte de ces contextes particuliers, et ne parviennent donc souvent pas à cerner les risques pour la santé qui concernent les peuples et les communautés autochtones. Les amendements récents proposés à la *Loi Canadienne sur la Protection de l'Environnement* par la *Loi S-5* démontrent l'intérêt des autorités réglementaires pour le développement de nouvelles approches d'évaluation des risques plus efficaces et plus éthiques que les méthodes conventionnelles. Ce changement de paradigme offre la possibilité d'améliorer la pertinence des approches d'ERSH pour les communautés autochtones dans laquelle elles pourraient en fin être appliquées. Toutefois, malgré la nécessité d'adopter des approches d'ERSH adaptées aux communautés autochtones, et le support règlementaire croissant dans ce domaine, peu de recherches ont été menées à ce jour sur la conception d'approches d'ERSH pour et par les peuples autochtones et dans les contextes particuliers des communautés autochtones.

L'objectif de cette thèse est d'explorer, concevoir, tester et développer des nouvelles approches de l'évaluation de risques pour la santé humaine qui soient adaptées aux contextes des communautés autochtones, et ce, en collaboration avec les communautés elles-mêmes. Pour ce faire, il faut tenir compte de diverses perspectives. La recherche utilise donc une conception méthodologique interdisciplinaire et une approche de collecte de données. Les chapitres suivent

le processus itératif de la pensée design (empathie, définition, idéation, prototypage, évalue). Le troisième chapitre présente un premier examen de la portée au sujet des sites contaminés et des populations autochtones, qui compare les informations provenant de trois sources de données, ce qui permet de constater la diversité et la disparité de la documentation sur le sujet et d'identifier les domaines dans lesquels la recherche doit être poursuivie. Le quatrième chapitre présente une étude multisectorielle explorant les pratiques d'évaluation des risques pour la santé humaine et l'environnement dans les communautés autochtones du Canada, qui met en évidence les principaux défis et priorités et les compare entre les différents secteurs. Le cinquième chapitre évalue l'utilisation d'une approche d'ERSH d'intérêt réglementaire, RISK21, par le biais de deux études de cas collaboratives impliquant trois communautés autochtones distinctes (Chipewyan Prairie First Nation, Cold Lake First Nations et Apsáalooke (Crow) Tribe). Le sixième chapitre présente un essai pilote initial au niveau régional d'une approche existante pour organiser et mesurer les indicateurs de santé des communautés autochtones pertinents pour le travail d'évaluation des risques. Le septième chapitre présente un aperçu d'un approche méthodologique itérative pour concevoir un outil d'indicateurs de santé propre à la communauté Kanien'kehá:ka de Kanesatake, et présente les premiers résultats d'entrevues qualitatifs semi-structurés sur ce sujet. L'outil d'indicateurs de santé pourrait être utilisé par le département de l'environnement de Kanesatake pour contextualiser les évaluations des risques à l'aide d'informations sur la santé définies par la communauté.

Ensemble, les chapitres de cette thèse visent à soutenir le développement d'approches d'ERSH pour les contaminants qui sont pertinentes, utiles et significatives pour les communautés autochtones dans lesquelles et par lesquelles elles pourraient être utilisées. Pour ce faire, ce travail comprend de conception au niveau de la communauté individuelle vers des outils d'évaluation des risques qui sont utiles localement. En même temps, il fournit un exemple de "feuille de route" méthodologique pour d'autres communautés qui peuvent améliorer la compréhension de la façon de concevoir, évaluer et valider de nouveaux outils d'évaluation de risques pour s'adapter à leurs contextes particuliers. Ce travail contribue également à une meilleure compréhension de certains défis et les priorités de la conception et de la mise en œuvre de l'ERSH à l'échelle nationale, ce qui est important pour l'élaboration et l'adoption éventuelles d'une réglementation.

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The word ‘community’ has become centrally important to me over the course of this degree- the communities with whom I worked on these thesis chapters, and the communities that I find myself a part of in all aspects of my life. Through community, a network of support extends well beyond the pages of this thesis, without which none of it would have been possible.

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CONTRIBUTIONS TO ORIGINAL KNOWLEDGE

This thesis explores the design and development of new approaches to human health risk assessment for environmental contaminants that are of relevance for Indigenous communities compared to conventional methods. Summarized below are the contributions to knowledge in this field:

- **Considering Indigenous perspectives in the design of new risk assessment approaches:** While the development of New Approach Methodologies (NAMs) for chemicals risk assessment is well underway, and the disproportionate impact of contaminants on Indigenous communities and lands is well-known, there has not been, to my knowledge, work that aims to understand how Indigenous perspectives might be considered in NAMs design. Chapters 4, 5 and 7 demonstrate the inclusion of Indigenous Peoples and communities in the design of new risk assessment tools and approaches through diverse methods: engaging representatives from Indigenous health and environment centers and local governments and distinguishing these voices from other involved parties in a survey (Chapter 4); collaborating with three unique communities on case studies exploring their perspectives on the use of a relatively new risk assessment tool (Chapter 5); and developing the local, community-based design of an Indigenous Health Indicators tool through open-ended interviews (Chapter 7). Moreover, the thesis as a whole contributes to the goals of a project co-led by the Kanienke:ha'ka community of Kanesatake.

- **Provide an example of a methodological roadmap to developing new approaches to human health risk assessment that are of relevance to communities.** Collectively, the chapters of this thesis demonstrate an iterative design thinking approach progressing through empathizing, defining, ideating, prototyping, and testing new approaches to human health risk assessment for contaminants that are more relevant for Indigenous communities than conventional methods. Communities (both Indigenous and non-Indigenous) may use a similar process in developing their own community-relevant environmental assessment approaches. This overarching contribution is one of few case studies on the topic.

- **Respond to priorities outlined by the Assembly of First Nations in response to Bill S-5:** In response to Bill S-5 (proposed amendments to the *Canadian Environmental Protection Act 1999*), the Assembly of First Nations (AFN) submitted recommendations to the House of Commons Committee on Environment and Sustainable Development. These recommendations outline the priorities of the AFN to undertake broad and holistic approaches to evaluating cumulative effects of substances- this includes moving beyond the narrow definition of interacting chemical effects and including physical and mental health and the maintenance of traditional practices. This thesis contributes to our understanding of how Indigenous-defined health risks and impacts from contamination can be more meaningfully considered in risk assessment methods. Chapters 4-7 explore the ideation, modification, and testing of such methods.

- **Respond to priorities identified by regulatory bodies in Bill S-5 and Canada's Chemicals Management Plan regarding context-relevant risk assessment and consideration of vulnerable populations:** This thesis works on developing human health risk assessment methods for Indigenous community contexts (i.e.: 'context-relevant') and considers various methodologies to answer specific questions on population health, as recommended by Canada's Chemicals Management Plan Science Committee. Specifically, Chapter 5 examines how a new risk assessment approach, RISK21, might be applied and adapted for Indigenous community contexts. Chapter 6 tests an existing tool (Indigenous Health Indicators approach) in a new context (First Nations regional level data), developing our understanding of how it may be scaled. Chapter 7 explores the initial design of a community-specific Indigenous Health Indicators tool, which may be used to contextualize risk assessment findings and provides a case study on the use of a community-based approach. To my knowledge, these chapters are the first to focus on Indigenous community contexts in response to these regulatory and scientific priorities in Canada.

- **First multi-sector Canada-wide work on risk assessment practice in Indigenous communities:** Chapter 4 details a survey study exploring the challenges with current risk assessment practice in Indigenous communities across Canada, and the priorities for new risk assessment methods, from the perspectives of a variety of disciplines and sector actors that work on risk assessments for contaminants in Indigenous communities. The survey found that those collaborating with communities (i.e.: academics and consultants), those who regulate risk assessments (i.e.: federal, provincial government), and those working from within communities themselves (i.e.: health and environment center employees, local government) have different challenges with risk assessment practice and priorities for the design of new approaches. This was also, to our knowledge, the first survey to gather perspectives from across Canada on the topic, addressing a paucity of national-level studies with the literature largely comprised of single community cases.

- **Develop and test the RISK21 approach by piloting it's use in Indigenous community contexts:** In collaboration with three unique communities, Chapter 5 tests out the use of a NAMs-based tool of regulatory interest (Health and Environmental Science's Institute's RISK21). While this tool has been tested in several community contexts, this is the first test which considers how it may be used by Indigenous communities, according to one of its lead developers. We found that while this tool is useful for advancing risk assessment practice in general, adaptations may improve its relevance for the collaborating communities- including modifications to the visual outputs for community-level communication and making assessments more holistic by considering non-chemical information of importance to communities (for example, qualitative/descriptive information and storytelling).

- **Explore the use of Indigenous Health Indicators methods for human health risk assessment on a regional scale:** Methods for identifying and measuring community-relevant health indicators for use as part of environmental assessment strategies have been developed and tested in a couple of community case studies, however more examples are needed to understand how they may be used as a new risk assessment tool. Chapter 6 explores the use of health indicators approaches (*Swinomish Indigenous Health Indicators* and *Piikani Well-Being Index*) for the organization and visualization of non-chemical health information in the context of contamination, drawing data from a Canada-wide study (First Nations Food, Nutrition, and Environment Study). This is the first regional case study using a health indicators approach to contextualize the findings of a conventional HHRA. The results highlight some of the challenges with scaling such approaches and considerations for representing both quantitative and descriptive health indicator information.

- **Ideate the design of an Indigenous Health Indicators tool for use in the context of environmental assessment work in Kanesatake:** In Chapter 7, following methods published by the Swinomish Tribal Community, and under the direction of the Kanesatake Environment Department, we report on the initial development of a community-specific Indigenous Health Indicators tool which can be used to contextualize environmental assessments with community defined understandings of health and well-being. Chapter 7 first, outlines the guiding principles of our team that involves Indigenous and non-Indigenous researchers, including our shared intentions and methodological approach consistent with community and cultural norms; and second, reports on our initial findings from conducting qualitative, open-ended interviews with Kanesatake community members towards the development of an Indigenous Health Indicators tool. Chapter 7 adds to a small handful of examples of the development of community-specific Indigenous Health Indicators. It may serve as a case example and methodological reference for the ongoing development of an Indigenous Health Indicators tool in Kanesatake, and for other communities conducting similar work.

PREFACE and CONTRIBUTION OF AUTHORS

This thesis follows a manuscript-based format, comprised of five manuscripts (Chapters 3-7) of which I am the first author. Academic supervision, conceptualization, writing and editing support was provided primarily by Dr. Niladri Basu. For each manuscript chapter, the CreDiT author statement is outlined.

Chapter 3: "Contaminated Sites and Indigenous Peoples in Canada and the US: A Scoping Review" [Published in *Integrated Environmental Assessment and Management, 20, 5, (1306-1329), 2024*]

Katherine Chong: Data curation; formal analysis; investigation; methodology; visualization; writing—original draft; writing—review and editing.

Niladri Basu: Conceptualization; funding acquisition; methodology; project administration; supervision; writing—review and editing.

Chapter 4: Exploring Practice, Challenges, and Priorities for Human Health and Ecological Risk Assessments in Indigenous Communities in Canada [Published in *Integrated Environmental Assessment and Management, 20, 5, (1677-1692), 2024*]

Katherine Chong: Conceptualization, methodology, formal analysis, investigation, data curation, writing-original draft, review and editing, visualization, project administration.

Gordon Hickey: Conceptualization, methodology, writing-review and editing.

Laurie Chan: Methodology, writing-review and editing.

Niladri Basu: Conceptualization, methodology, supervision, writing-review and editing, funding acquisition.

Chapter 5: Exploring the Use of the RISK21 Approach for Indigenous Community-Based Human Health Risk Assessments: Two Case Studies [Published in *FACETs, 10, (1-16), 2025*]

Katherine Chong: Conceptualization, investigation, writing-original draft, visualization, project administration.

Madisan Chavez: Resources, writing-review and editing.

Ave Dersch: Resources, writing-review and editing.

John Doyle: Resources, writing-review and editing.

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Myra J Lefthand: Resources, writing-review and editing.

Findlay MacDermid: Resources, writing-review and editing.

Claire McAuley: Resources, writing-review and editing.

Vanessa Simonds: Resources, writing-review and editing.

Sara L Young: Resources, writing-review and editing.

Niladri Basu: Conceptualization, writing-review and editing; supervision; funding acquisition.

Chapter 6: Indigenous Health Indicators (IHIs) as a New Approach to Human Health Risk Assessments for Contaminants- Pilot Testing IHI Operationalization on a Regional Scale [Manuscript prepared for submission to the Kanesatake Environment Department]

Katherine Chong: Conceptualization, writing-original draft, visualization.

Niladri Basu: Conceptualization, writing-review and editing; supervision; funding acquisition.

Chapter 7: Putting our minds together: Kanesatake Kanien'kehá:ka Perspectives on Developing a Health Indicators Tool – Progress Report [Report prepared for submission to the Kanesatake Environment Department]

Katherine Chong: Conceptualization, methodology, formal analysis, investigation, data curation, writing-original draft, review and editing, visualization, project administration.

Valerie Gabriel: Conceptualization, methodology, formal analysis, investigation, data curation, writing- review and editing, visualization, project administration.

Niladri Basu: Conceptualization, writing- review and editing, supervision, funding acquisition

List of Abbreviations

As- Arsenic

BAPHE- Baseline Assessment Program on Health and the Environment

Cd- Cadmium

CEPA- Canadian Environmental Protection Act

CINE- Center for Indigenous Poples' Nutrition and Environment (McGill University)

CPBR- Community-based participatory research

CRA- Cumulative Risk Assessment

ECHIP- Kanesatake Environmental Contaminants and Health Impact Project

ERA- Ecological Risk Assessment

HESI- Health and Environmental Sciences Institute

HHRA- Human Health Risk Assessment

HI- Hazard Index

HQ- Hazard Quotient

IHI- Indigenous Health Indicator

FNECP: First Nations Environmental Contaminants Program

FNFNES: First Nations Food, Nutrition and Environment Study

Mg- Magnesium

NAMs- New Approach Methodologies

NCP- Northern contaminants program

US EPA- United States Environmental Protection Agency

$NO3^-$ - Nitrous oxide

OCAP®- Ownership, Control, Access, and Possession (First Nations data sovereignty principles)

OECD- Organization for Economic Cooperation and Development

RfD- Reference Dose

RISK21- HESI Risk Assessment in the 21^{st} Century Project

U- Uranium

UNDRIP- United Nations Declaration on the Rights of Indigenous Peoples

US EPA- United States Environmental Protection Agency

CHAPTER 1: GENERAL INTRODUCTION

1.1 Knowledge Gap

Environmental pollution poses unique and complex risks to many Indigenous communities in Canada, often through both disproportionate exposure (Fernandez-Llamazares et al., 2020) and impacts on culture (Harris, 2000; O'Neill, 2000), socio-economics (Burger & Gochfeld, 2011), spirituality, language (Fernández-Llamazares et al., 2020), and traditional food systems (Chan et al., 2021). Human health risk assessment (HHRA) methods are used to assess health risks from exposure to contaminants and are widely used to make decisions about environmental management, industrial development, and cleanup of contamination on and near Indigenous lands (Government of Canada, 2019; Sandlos 2016). However, the currently used conventional HHRA approaches are generic and institutionalized, often failing to meet the unique risk assessment contexts of Indigenous communities (Harris and Harper, 2000; Harris, 2000; Assembly of First Nations, 2022).

There is a current scientific and regulatory paradigm shift in chemicals risk assessment, focused on reducing the cost, time, and resource use of conventional methods. In Canada, there is regulatory interest in developing new HHRA approaches, which was most recently highlighted in Bill S-5's proposed amendments to the *Canadian Environmental Protection Act* (CEPA) (Government of Canada, 2022). As the design and development of new risk assessment approaches is underway, there is an opportunity to increase their relevance for the Indigenous communities in which they may be ultimately applied. While there are numerous case studies of conventional HHRAs in the context of Indigenous communities, to date there is minimal information available on the design of new risk assessment approaches for and by Indigenous communities, despite their unique and often disproportionate risk contexts. Importantly, Indigenous Peoples across Canada are not a homogenous group. While there are many common contaminant-related health concerns, new risk assessment approaches must be both consistent and useable by regulatory bodies while flexible to adapt to unique and specific contexts of individual communities (Barzyk et al., 2015). Also, in support of the right of Indigenous Peoples to self-determination and self-governance (United Nations, 2007), new risk assessment methods need not only be relevant to, but usable by the communities in which they are applied and aligned with their environmental standards, priorities, and community protocols.

1.2 Overall Objective

The objective of this thesis is to explore, ideate, test, and develop new approaches to HHRA that are relevant for Indigenous community contexts, in collaboration with communities themselves. To do so, this thesis identifies priorities and challenges with conventional HHRA methods and subsequently tests and adapts new HHRA approaches and tools in the context of community-level risk assessments. This approach serves the dual function of first, gathering and synthesizing information and perspectives on a broad scale, and second, providing community-level case studies, which are needed to validate and improve the use of the approaches, and to refine methods for operationalizing new risk assessment tools in new contexts. Further, these chapters contribute to an ongoing collaborative project based in the Kanien'kehá:ka community of Kanesatake, by providing information and tools with which to conduct more efficient and relevant risk assessment work.

1.2.1 Local Context: Environmental Contaminants and Health Impacts in Kanesatake

To operationalize the broad overall objective of this thesis, the activities presented are based on, and led by, a specific and local community context. The Kanien'kehá:ka community of Kanesatake is located at the confluence of the Ottawa and St-Lawrence rivers, north-west of the island of Tiohtià:ke (Montreal) (Figure 1-1). Kanesatake has been facing environmental justice concerns over several decades. One prominent concern is a large unregulated dump site (G and R Recyclage) with industrial wastes of unknown content entering the community from the surrounding urban and peri-urban area. This has resulted in concerns from community members regarding the potential health risks related to the contamination. In 2019, the Kanesatake Environment Department in collaboration with McGill University (The lab of Dr. Niladri Basu) and Terra Humana Solutions (a research consulting company) launched the environmental contaminants and health impact project (ECHIP). ECHIP has involved collecting soil, food, water, and human biomonitoring (hair and urine) samples and conducting a HHRA for local and traditional foods, to gain an understanding of the potential health risks related to contamination in the community. More recently, the collaborative team has launched a project exploring new approaches to contaminant risk assessment for Indigenous community contexts. This thesis is situated within the ongoing environmental assessment and health impact work in Kanesatake, and the project team has informed its overall objectives. I have worked on various aspects of the ECHIP, including field work collecting soil, food and water samples, conducting food frequency questionnaires for a HHRA, attending and assisting with the organization of community events, preparing community communications, training students, developing a training manual, data management and analysis, and attending regular team meetings. While the results of the ECHIP are not included in this thesis, my experience working with and in the community has informed, led and inspired the work. The tools and approaches that are developed and designed in this thesis serve as resources for the Kanesatake Environment Department in their ongoing projects.

Figure 1-1: Map depicting the location of the community of Kanesatake, northwest of the island of Montreal (Tiohtià:ke). Map retrieved from: mohawknationnews.com.

1.2.2 Design Thinking and Interdisciplinary Approach

To respond to the overall objective, the presented thesis aims are based upon a 'design thinking' approach. Design thinking is a process used to address complex problems by understanding needs, challenging assumptions, and creating innovative solutions, with a focus on the needs of end-users (Abookire et al., 2020). While the term 'design thinking' originated from professional design and has traditionally been applied in business and information technology, it has become a new paradigm for problem-solving across many different sectors (Dorst, 2011). For example, this approach has been found to contribute to a greater understanding of problems and the development of more resource and cost-efficient solutions when applied in a public health context, compared to conventional problem-solving methods (Abookire et al., 2020). Research in the natural sciences, particularly sustainability science, has also leveraged design thinking, though its integration in this field is still relatively limited (Maher et al., 2018). Design thinking approaches generally progress through five stages: Empathize (i.e.: understanding the needs of the users of a tool or approach, including through interviews or background research), define (i.e.: stating the problems and priorities), ideate (i.e.: generate ideas to address the identified problem), prototype (i.e.: experiment with the proposed solutions), and test (i.e.: try the solutions out) (Figure 1-2) (Interaction Design Foundation, 2024). The five stages involved with design thinking are highly iterative, which allows for gradual improvement of a solution over time (Tschimmel, 2012).

HHRA methods and their results are used by a diversity of disciplines and stakeholders, and thus the presented design thinking process involves a variety of research methods, data collection approaches, and engagement across disciplines (Figure 1-2, Table 1-1). The chapters of this thesis also involved engagement with those who are a part of, or work in, a diversity of communities across Canada (Figure 1-3). Interdisciplinary research is defined as “a means of solving problems and answering questions that cannot be satisfactorily addressed using single methods or approaches” (Klein, 1990), and its definition may overlap with transdisciplinary research, which aims to understand multiple values and ideologies and achieve meaningful outcomes for science and society (Witjes and Vermeulen, 2020). Both approaches are relevant to this thesis and are integrated throughout its chapters (Table 1-1), though this work is more closely aligned with interdisciplinary research, which creates connections between disciplines, while transdisciplinary research transcends disciplinary boundaries (Witjes and Vermeulen, 2020). Central to the process is the design of HHRA methods for and by the Indigenous communities in which they may be ultimately applied.

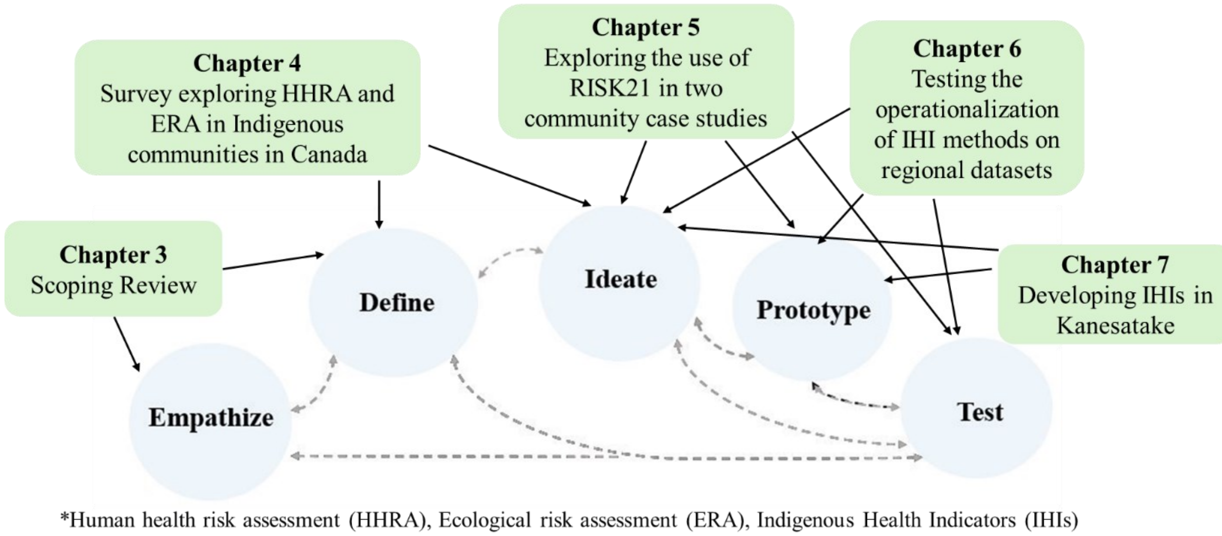

Figure 1-2: Visual representation of design thinking and how the chapters of this thesis fit into the process. The blue circles represent the steps of the design thinking process, with the green boxes representing the corresponding chapters. The process is iterative as opposed to linear, as shown by the dotted arrows, and each chapter spans multiple stages of the design thinking process. See Section 1.3 *Specific Aims* for details on the objectives of each chapter.

Table 1-1: An overview of the methodological approaches used for each chapter. See section 1.3 *Specific Aims* for a description of each chapter's objectives.

THESIS CHAPTER	METHODOLOGY	DISCIPLINE/ FIELD
3	**Scoping Review** PRISMA ScR; SYMBALS (a systematic review strategy blending active learning and snowballing) (Tricco et al., 2018); Joanna Briggs Institute Methodology for Scoping Reviews (Peters et al., 2015)	Evidence Synthesis
4	**Online Survey** Following Dillman's Online Survey Methodology (Dillman et al., 2014). Survey approach adapted from Mondou et al. (2020); and Vachon et al. (2017)	Social Sciences; Natural Sciences
5	**Case Studies (Community-based)** RISK21 Methodologies outlined by Health and Environmental Sciences Institute (HESI) (Embry et al., 2014; Moretto et al., 2017)	Natural Sciences; Health Sciences
6	**Case Study (Regional)** Follows approaches used to develop the Piikani Well-Being Index (Quantitative) (Paul et al., 2023) and Swinomish Indigenous Health Indicators (Qualitative), (Donatuto et al., 2018)	Health Sciences; Natural Sciences
7	**Key Informant Open-Ended Qualitative Interviews** Community-based participatory research (CBPR); Swinomish Tribal Community's Method for Developing Indigenous Health Indicators (Donatuto et al., 2018);	Social Sciences; Health Sciences, Natural Sciences

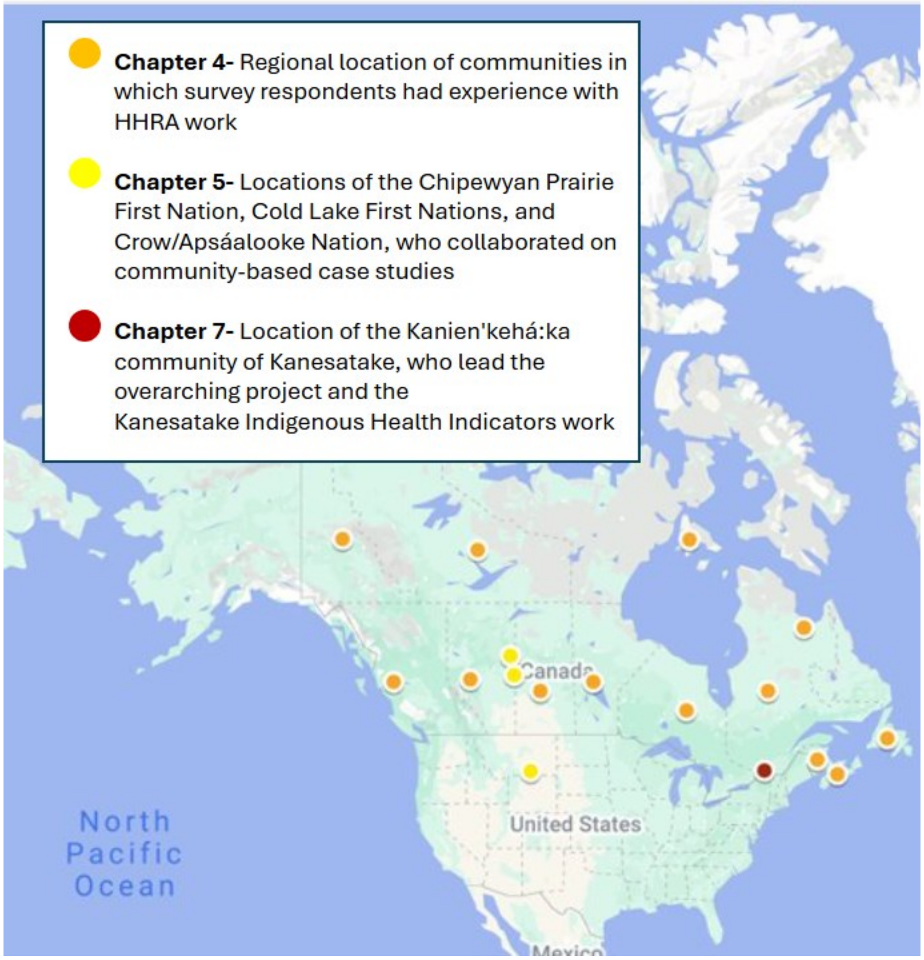

Figure 1-3: Map depicting the locations of individuals and communities that were involved in Thesis chapters 4, 5, and 7. Chapter 4 involved individuals as survey respondents, who worked with or in communities to conduct HHRAs. Chapters 5 and 7 involved collaboration with communities to develop HHRA methods. Map generated using Google MyMaps.

1.3 Specific Aims

CHAPTER 3 *(Empathize and Define)*: Examine the state of available evidence and identify specific knowledge gaps.

- Conduct a scoping review to identify and map information (peer-reviewed literature, grey literature, and federal contaminated site data) on contaminated sites and Indigenous Peoples in Canada and the US. The review aims to understand and present the state of knowledge on:

  1) The relationship between contaminated sites and Indigenous Peoples, and their land and food systems;

  2) Strategies, challenges, and successes for contaminated sites assessment and management on Indigenous lands;

  3) Indigenous leadership and inclusion in contaminated site assessment and management.

CHAPTER 4 *(Define and Ideate)*: Understand the challenges with risk assessment in Indigenous communities in Canada, and the priorities for new approaches.

- Conduct an anonymous mixed-methods survey of those involved with human health and ecological risk assessments in Indigenous communities in Canada with the aims of:

  1) Understanding risk assessment practice in Indigenous communities;
  2) Exploring challenges with conventional assessment methods and comparing these across sectors;
  3) Gathering initial perspectives on the development of new risk assessment approaches.

CHAPTER 5 *(Ideate, Prototype, Test)*: Explore the use and adaptation of existing new risk assessment tools in Indigenous community contexts.

- Conduct two case studies piloting the use of a new approach to HHRA of regulatory interest, RISK21, in collaboration with three unique communities (Cold Lake First Nations, Chipewyan Prairie First Nation, Apsáalooke/Crow Nation) that have published conventional HHRAs. Through these case studies, this chapter aims to:
  1) Reflect upon the benefits and challenges of using RISK21 in these contexts;
  2) Compare RISK21-based to conventional assessments;
  3) Ideate adaptations and improvements to the approach.

CHAPTER 6 (*Ideate, Prototype, Test):* Explore and pilot test existing approaches to organizing and evaluating non-chemical health indicator information in risk assessment contexts.

- Create a demonstrative case study using an existing Indigenous Health Indicators (IHI) Approach on a regional dataset (health and contaminant risk assessment data from the First Nations Food, Nutrition, and Environment Study (FNFNES)). In doing so, we aim to:
  1) Pilot the use of selected IHI methods in a new context, producing a case study, of which there are few;
  2) Explore the feasibility of scaling existing IHI methods for regional indicator datasets;
  3) Consider how both qualitative/descriptive and quantitative indicator measurement methodologies can be used in an assessment;

4) Ideate how the methods might be considered as part of newly developed human health risk assessment approaches.

CHAPTER 7 *(Ideate, Prototype):* Explore the development of an Indigenous Health Indicators tool relevant to the context of the Kanien'kehá:ka Community of Kanesatake.

- Establish foundational principles of working together collaboratively, forming a basis for a project lead by the Kanesatake Environment Department that aims to develop an Indigenous Health Indicators tool for understanding and assessing community health and well-being in the context of environmental assessments. Then, guided by the foundational principles, conduct open-ended, qualitative interviews with key Kanesatake community members to gather initial perspectives on the topic. The specific aims of this chapter are to:

1) Detail the community-led approach to developing Kanesatake Health Indicators, including intentions, key guiding principles, and methodological design;
2) Provide an overview of initially identified health indicator themes from interviews with community members, which lays a groundwork for the next stages of this iterative process.

1.4 Positionality Statement

This thesis is primarily conducted by a non-Indigenous person of color who is a doctoral student at McGill. This positionality and worldview places limitations on the work. Moreover, McGill University, and the academic research body in general, has not historically conducted ethical research involving Indigenous Peoples and past and current colonial practices from these institutions continue to harm Indigenous Peoples and communities today. The location in which this thesis was primarily conducted (McGill University, Montreal/Tiohtià:ke) is the traditional territory of the Kanien'kehá:ka. In acknowledging this positionality, I sought to align the work presented here with the priorities identified and recommended by the Indigenous communities with which I work and understand that the validity and significance of this work is best judged by those for and by whom the risk assessment approaches described herein are designed.

While this thesis is centered around the prioritization of Indigenous perspectives in the development of new risk assessment approaches and tools that may eventually enter the regulatory realm, it is notable that the some of the approaches, concepts, and methods used throughout this thesis, to my knowledge, were not developed by Indigenous people. However, the work seeks to ‘flip the script’ in terms of adapting methods to better serve Indigenous communities such as Kanesatake, as opposed to asking Indigenous Peoples to adapt to fit regulated and applied tools that they are consulted about too late. The work is based out of, and approved by, McGill’s Centre for Indigenous Peoples’ Nutrition and Environment (CINE). CINE was created to respond to Indigenous Peoples’ priorities and concerns on their traditional food systems and environments. It serves as a resource centre and point of interdisciplinary information exchange and cooperation between McGill researchers and Indigenous communities.

My situation within CINE and the resources it provides brings awareness and support to this work. Acknowledging the limitations of my positionality, I intentionally work to listen actively, reflect, and engage throughout the research process.

CHAPTER 2- LITERATURE REVIEW

In Canada, ‘Indigenous’ is an umbrella term that includes First Nations, Inuit, and Métis communities, though importantly these groups are not homogenous. For example, there are 630 distinct First Nations communities in Canada (The Canadian Encyclopedia, 2023), eight distinct ethnic Inuit groups in 63 communities in Canada’s North (Freeman, 2023), and five provincially associated Métis organizations (Government of Canada, 2024a). In the US, there are 574 federally recognized Native American Tribes, 346 of which are in the contiguous US and the remaining are Alaska Natives (USAGov, 2024). While there are differences between Canada and the US in their government-to-government and nation-to-nation relationships with Indigenous Peoples, conventional approaches are used to conduct HHRAs on Indigenous lands in both countries. Similarly, there are common environmental justice issues related to environmental contamination and Indigenous Peoples at each administrative level (i.e.: municipality/province/territory/state/nationally) in both countries, and globally. Thus, while the focus of this literature review is primarily from a Canadian perspective, literature from Tribal communities and case studies based in the US are also discussed here and referenced throughout the thesis chapters.

2.1 Human Health Risk Assessment and Indigenous Communities

Risk assessment is defined as the “qualitative and quantitative evaluation of the risks posed to human health and/or the environment by the actual or potential presence and/or use of specific pollutants” (US EPA, 1992). Human Health Risk Assessment (HHRA) uses a generic framework for calculating human health risks from exposure to contaminants, and generally involves the steps of problem formulation, exposure assessment, hazard identification, dose-response assessment, and finally risk characterization (Figure 2-1). HHRA methods have been used to make decisions about environmental and risk management in Indigenous communities across Canada and the US for several decades (EPA, 2022; Health Canada, 2019; National Research Council, 1983; van der Vegt et al., 2022).

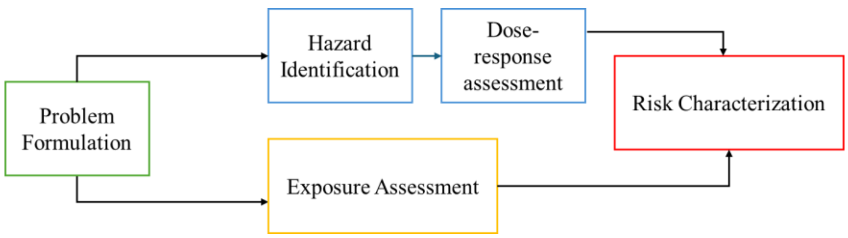

Figure 2-1: Conventional Human Health Risk Assessment (HHRA) Framework. Adapted from US EPA "Conducting a Human Health Risk Assessment" (https://www.epa.gov/risk/conducting-human-health-risk-assessment)

Environmental contamination in the context of Indigenous communities is distinct from the general population for several reasons. First, Indigenous communities are disproportionately exposed to contaminants, as is evident in the disproportionate siting of industrial activities and waste sites on and near Indigenous lands across the country (Government of Canada, 2024b). As an example, as of 2024 approximately 4600 contaminated sites are located on reserve land in Canada, accounting for nearly 20% of the total number of sites (Government of Canada, 2024b), while reserve land makes up an estimated 0.5% of Canada's total land mass (OECD, 2020). Race has long been an independent predictor of where hazardous wastes are sited (Bullard et al., 2007). While the environmental justice movement has brought some awareness to this problem, the issue remains pervasive. The disproportionate siting of contaminated sites on Indigenous lands may be in part due to polluting industries tending to follow the path of ‘least resistance’ by preying on Indigenous communities who have limited resources to resist or that fall through the regulatory cracks (Bullard et al., 2007). This issue is perpetuated by a lack of timely and adequate responses by federal and provincial governments to pollution in Indigenous communities (Sharp et al., 2016; Solatyavari et al., 2022).

Furthermore, and often less quantifiable, the presence of environmental contaminants has unique impacts on the cultures (Harris & Harper, 2000; O'Neill, 2000), socioeconomics (Burger & Gochfeld, 2011), spiritualities, languages (Fernández-Llamazares et al., 2020), and traditional food systems of many Indigenous communities (Chan, Fediuk, et al., 2021; Chan, Singh, et al., 2021; Fernández-Llamazares et al., 2020). Recently in Canada, the First Nations Food, Nutrition and Environment Study was conducted between 2008 and 2018, and sampled 2061 traditional foods from 92 communities. The study found many of these samples to have elevated concentrations of mercury, lead, cadmium, and arsenic (Chan, Singh, et al., 2021). Exposure to such contaminants is associated with physical health risks such as organ damage, neurodegenerative diseases, cancer, and reproductive and developmental disorders (Briffa et al., 2020; Engwa et al., 2019). Beyond these physical risks, however, contamination of traditional foods has contributed to a ‘nutrition transition’ for many communities, characterized by the westernization of diet and lifestyle and a reliance on nutrient-poor market foods, increasing the prevalence of chronic disease and resulting in cultural losses (Chan, Fediuk, et al., 2021; Damman et al., 2008). Overall, environmental contamination poses multiple, complex and cumulative health risks to Indigenous Peoples that are distinct from the general population, and thus require unique risk assessment methods.

Overview of the literature

Literature on the topic of HHRAs in Indigenous communities includes both peer-reviewed literature and a variety of grey literature sources (i.e.: government reports and guidelines, project reports, and documents from organizations such as the Assembly of First Nations). The large majority of information on HHRAs and Indigenous communities document assessments that use conventional methods, with some literature on the topic reporting the challenges with using conventional methods in these contexts. There is minimal information on the topic from the perspectives of Indigenous Peoples and communities themselves. Additionally, much of the literature that is available from community perspectives is focused on single case studies. While important contributions to the body of literature, these cases represent the voices of a small handful of Indigenous communities and Peoples on the challenges with HHRAs for contaminants, in comparison to the relatively large number of contaminated sites on or near Indigenous lands.

Conventional risk assessment work in Indigenous communities

There is a sizeable body of available literature on the conduct of HHRA work in Indigenous community contexts. In Canada, the First Nations Environmental Contaminants Program (FNECP) and Northern Contaminants Program (NCP) fund communities in support of gathering data on local contamination and conducting risk assessments. In part through the

FNECP and NCP, a variety of case studies have emerged that document community-specific HHRA studies, most of which focus on contaminated traditional food sources (Daley et al., 2018; Doyle et al., 2012; Golzadeh et al., 2021; Golzadeh et al., 2020; Lemire et al., 2015; Matwee & Pietrock, 2019; McAuley et al., 2018; Moriarity et al., 2020; Moriarity et al., 2023; Thompson et al., 2017). Most recently, the aforementioned First Nations Food, Nutrition and Environment Study (FNFNES) lead by the Assembly of First Nations was conducted across 92 First Nations communities (Chan et al., 2018). This regional study included an HHRA for traditional foods and is an important contribution to Indigenous-owned regional risk assessment data. Studies that use conventional methods make up the bulk of the available information on HHRA work in Indigenous communities. However, several critiques in the literature suggest that the design and implementation of conventional HHRA methods in these contexts are limited.

Challenges with risk assessment in Indigenous communities

First, an ongoing challenge with conventional HHRA work is the misrecognition and exclusion of Indigenous Peoples and communities in the process (Arsenault et al., 2019; Brock et al., 2021; OECD, 2020). In 2011, Canada published a guidance document on "Involving Aboriginal Peoples in Contaminated Sites Management", outlining stages of the environmental assessment process where consultation with Indigenous Peoples is recommended (Health Canada, 2010). While such documents demonstrate regulatory awareness of the need for community engagement in risk assessment processes, the current approach to engagement in risk assessment has been described as inadequate in its recognition of Indigenous Peoples and communities as rightsholders (Darling et al., 2023), and attempts to consult with Indigenous

Peoples in environmental assessment processes have been critiqued as largely tokenistic and lacking meaningful collaboration (Holifield, 2012; Brock et al., 2021).

As another example, in 2022, the government of Canada proposed *Bill S-5,* which amends the *Canadian Environmental Protection Act. Bill S-5* represents the first recognition of Indigenous Peoples' right to a healthy environment as outlined in the United Nations Declaration on the Rights of Indigenous Peoples, and promotes additional considerations for risk assessments that are specific to vulnerable populations. However, in a response to Bill S-5, the Assembly of First Nations highlights that it is unclear how the Canadian government plans to maintain these provisions (Assembly of First Nations, 2022). Specifically, it is recommended by the Assembly of First Nations to further amend CEPA to consider meaningful consultation with Indigenous Peoples that respects Nation-to-Nation partnership, and meaningful integration of Indigenous Knowledge systems in human health and environmental risk assessments (Assembly of First Nations, 2022).

Second, HHRA methods have been critiqued for their lack of relevance to Indigenous Peoples, worldviews, and definitions of health. For example, literature identifies that conventional risk assessments do not produce locally relevant information (Burger & Gochfeld, 2011; Donatuto et al., 2020; Harper et al., 2012; Harris & Harper, 2000), and fail to include holistic definitions of health that go beyond physical contaminant-related risks (Harris, 2000; McOliver et al., 2015; Van Oostdam et al., 2005), including nutritional losses related to a dietary shift (Van Oostdam et al., 2005); and social-cultural losses (Harris & Harper, 2000). When these factors are considered in risk assessment work, they are supplemental to the 'core' risk assessment most valued by decision-makers, and this type of inclusion has been critiqued as inadequate. Furthermore, unique exposure pathways, such as the use of medicinal plants in ceremony, are often considered outliers and may be left out of analyses (Burger & Gochfeld, 2011). As conventional risk assessment methods tend to examine outliers on an exceptional basis, this often results in risks specific to Indigenous Peoples being left out of the assessment (Burger & Gochfeld, 2011). Risk assessments that do not include Indigenous epistemologies and values ultimately produce risk information that cannot be used or communicated locally (Donatuto et al., 2020; Gregory et al., 2016; United Nations, 2007). Indigenous environmental leadership has requested for decades that risk information be produced at both community and system levels and include eco-cultural metrics (Harris, 2000).

Third, conventional risk assessment methods are often costly, time consuming, and resource intensive, which limits the capacity of many Indigenous communities to conduct their own risk assessment work (Pastoor et al., 2014). Many chemicals found at contaminated sites lack toxicity data necessary for conventional hazard identification and dose-response analysis, which prevents the establishment of health reference values that inform clean up level (Pastoor et al., 2014). The lack of available toxicity data for the tens of thousands of chemicals available on the global market is a universal problem, but it's impacts disproportionately affect Indigenous communities near whom contamination is often sited. Further, according to federal data, the clean-up of contaminated sites on reserve land in Canada often takes decades to progress from initial assessment to remediation (Government of Canada, 2024b), which is likely due to both insufficient resources and inefficient risk assessment processes. Finally, while several federal programs in Canada fund risk assessment work in Indigenous communities (ex: the FNECP and NCP), such programs often require communities to partner with an external 'expert' academic and are restricted to finite timelines which may not meet the necessary time to establish trusting relationships within communities (Indigenous Services Canada, 2024; Sharp et al., 2016). These resource and time requirements may limit the ability for many communities to conduct risk assessments that are aligned with their priorities.

While the above identified challenges are notable, the body of literature from which they arise is small, with most publications on the topic coming from single case studies. There is minimal information from the perspectives of communities on the challenges with conventional risk assessment approaches, which makes finding solutions difficult. There is a handful of literature that includes adaptations to conventional assessment methods, which have the potential to improve their relevance to community contexts. These include bridging Indigenous and western scientific knowledge in risk assessments; considering culturally relevant exposure pathways; and developing expanded risk frameworks and cumulative risk assessment approaches.

Indigenous Knowledge and risk assessment

Central to the discourse on the use of risk assessments for Indigenous community contexts is the question of how to bridge Indigenous Knowledge and western science, in a way that is appropriate and meaningful. Indigenous Knowledge (also often referred to as Traditional Knowledge, local knowledge, and Traditional Ecological Knowledge), in the context of Canada is the knowledge held by First Nations, Metis, and Inuit Peoples (IPCA, 2025; McGregor, 2021; Liboiron, 2021). Indigenous Knowledge has no single formal definition, and the terms and language of choice should be verified in the context of working with any Indigenous community, organization, or government (IPCA, 2025; McGregor, 2021; Liboiron, 2021). The term Indigenous Knowledge is increasingly preferred over other terminology as it refers specifically to knowledge that is an integral part of Indigenous societal systems (Indigenous Knowledge Systems) and is applied here (McGregor, 2021). As we acknowledge the increasing movement away from the term ‘Traditional Knowledge’ (including during the progression of this thesis), we note that some of the published manuscripts (in particular, Chapter 3) include this term.

Several efforts to include Indigenous Knowledge in conventional risk assessment methods are documented. One such effort is to use Indigenous Knowledge to inform various aspects of the risk assessment process, particularly to more accurately assess human exposures (i.e.: traditional food sources, exposure pathways, preparation and harvesting techniques) (Daley et al., 2018; Golzadeh et al., 2021; Golzadeh et al., 2020; Lemire et al., 2015; Matwee & Pietrock, 2019; McAuley et al., 2018; Robert J Moriarity et al., 2020; Robert J Moriarity et al., 2023; Thompson et al., 2017). The Government of Canada has published several guidelines that include considerations for Indigenous community consultation and Indigenous Knowledge utilization in HHRA work. These include guidelines for conducting a HHRA for country foods (Health Canada, 2018), and for involving Indigenous Peoples in contaminated site assessment and management (Health Canada, 2010).

The importance of Indigenous Knowledge in environmental assessment and management is generally well-acknowledged and information on country food location, preparation, and consumption may help to improve the relevance of HHRAs in community contexts. However, the framing of Indigenous Knowledge as supplemental, and ultimately secondary, to conventional risk assessment approaches has been described in the literature as problematic (Ellis, 2005). Furthermore, discussions around Indigenous Knowledge and its use in environmental assessment and management have historically incorrectly assumed that Indigenous Knowledge is a resource that is free for access and use by non-Indigenous researchers (Liboiron, 2021). A recent systematic review of research on the Alberta oil sands identified multiple challenges with research that braids Indigenous Knowledge and Western-based sciences, including power imbalances and a lack of resources and funding (Wilcox et al., 2023). Writings from Indigenous scholars highlight barriers between western science and Indigenous Knowledges, which may arise from misunderstandings of Indigenous Knowledges as sources of data (i.e.: knowledge), as opposed to broader ways of knowing (Liboiron, 2021; Kimmerer, 2013). Overall, there remains a lack of consensus and understanding from the scientific community on appropriate and meaningful engagement of multiple knowledge systems in risk assessments, and more support is needed to promote work in this area. Some publications in the literature outline how collaboration between communities and non-Indigenous researchers may be further harmonized, and Indigenous Knowledge and western science be bridged, towards an improved risk assessment. For example, Buell et al (2020) describe how conventional risk assessment protocols might be 'deconstructed' and rebuilt through improved engagement, community interviewing, and collaborative fieldwork. Data-gathering methods that meaningfully engage communities have also been proposed in the literature, which aim to promote accuracy, align with community norms, and consider community values (Donatuto & Harper, 2008).

Exposure scenarios

A commonly cited method for making community-based HHRAs more relevant for Indigenous Peoples is using exposure scenarios. First developed by Harris and Harper (1997), exposure scenarios involve the consideration of exposure pathways of cultural and social relevance that may differ from the general population, for example the inhalation of contaminants through ceremony (Tilousi & Hinck, 2024) and the ingestion of soil from locally harvested plants (Doyle et al., 2012; Doyle et al., 2010). The gathering of local consumption information as opposed to using generic consumption estimates has also been used to make risk assessments more community-specific and improve the accuracy of consumption advisories (Garvin, 2018). While such efforts to more holistically characterize exposures provide a step-up from conventional and generic methods, some literature advocates a more formal way of integrating unique exposure pathways into risk assessments, beyond the 'ad hoc' basis of conventional methods. For example, Burger and Gochfeld (2011) published a conceptual model for evaluating unique and non-standard exposures characteristic of environmental justice communities. Overall, the use of exposure scenarios has advanced conventional risk assessment approaches towards greater context relevance, however this approach does not include an assessment of 'non-physical' contaminant-related health risks of importance to many communities.

Expanded and Holistic HHRA approaches

In response to the above identified challenges, several publications have proposed modified HHRA methods to increase their relevance to Indigenous community contexts, often using expanded risk assessment structures. For example, Indigenous environmental leaders have advocated for risk analysis models that include a holistic view of interconnected human, ecological, and sociocultural risks (Harris, 2000). Harris and Harper (2000) propose an expanded risk assessment model that captures the uses and services associated with areas at risk from contamination. The use of community-specific definitions of risk and health in environmental assessment has also been advocated for in the literature (Arquette et al., 2002). There are several community-based examples of risk assessment approaches that aim to be more holistic by drawing upon Traditional Knowledge or incorporate existing cultural and spiritual frameworks as a basis for assessment. The Pictou landing First Nation utilized a Mi'kmaw framework for more holistically assessing community health impacts (Lewis et al., 2021) and a risk assessment of Uranium Mining impacts on the Havasupai Tribe was conducted under a holistic framework that included Traditional Knowledge (Carletta Tilousi & Jo Ellen Hinck, 2024). The Swinomish Tribal community has published several studies over the last decade and a half that detail the development and use of community defined Indigenous Health Indicators, which can be used in parallel with risk assessments to understand the impacts of environmental resource changes such as contamination (Donatuto et al., 2008; 2020). Such approaches explore potential ways forward from conventional HHRA methods towards more holistic assessments. However, there is minimal information on if and how such approaches may be applied in other contexts as they are typically based on single community case studies.

Cumulative risk assessment

Aligned with these expanded frameworks, another approach that may be useful in increasing the relevance of risk assessments to communities is cumulative risk assessment. Cumulative risk assessment (CRA) is the assessment of combined chemical and non-chemical stressors and vulnerability factors (Payne-Sturges et al., 2018), which are not addressed in conventional risk assessment methods (Pose-Juan et al., 2016). CRA is increasingly being promoted as a more holistic way to assess environmental health risks, especially in the context of communities who are disproportionately exposed or vulnerable to pollution (Callahan & Sexton, 2007; Sexton, 2012), including Indigenous communities. A recent systematic review on the topic of CRA for environmental and psychosocial stressors found 90 articles, with the majority focused on community settings and for the purposes of reducing environmental protection inequities (Tong & Zhang, 2023). Over the years, the term "Cumulative Risk Assessment" has been variably defined, ranging from the assessment of combined effects from a mixture of chemicals to the assessment of multiple chemicals and non-chemical stressors, vulnerability factors, and impacts, both quantitative and qualitative (Callahan & Sexton, 2007; Sexton, 2012; Sexton, 2015). For the purposes of this work, we consider the latter broad and holistic definition of CRA.

CRA methods have been largely quantitative to date, including for example measuring biomarkers of stress and the concept of allostatic load (Payne-Sturges et al., 2018). There has also been a rise in the development of GIS-based screening methods using epidemiologic and demographic data, such as the US EPA's EJ Screen, CFERST, and EnviroScreen (Lievanos, 2018; Min et al., 2019). Such "Environmental Justice Screening" tools are proposed for use in the prioritization and allocation of resources to communities, including Indigenous communities, that are disproportionately affected by environmental hazards, such as contamination. While such tools begin to fill an important gap in understanding and assessing cumulative risks, the focus on quantitative data may miss elements of risk important to Indigenous communities, including those that are qualitative or descriptive. There is minimal research on how to meaningfully and adequately incorporate community-relevant health information into quantitative CRAs. In recent years research progress has been made in understanding the applications of CRA in community-based participatory research on environmental contamination, utilizing multidisciplinary approaches involving epidemiology, toxicology, social science and statistical methods (Eggers et al., 2018; Hoover et al., 2015; Payne-Sturges et al., 2018), though examples of Indigenous community-based CRAs are few. Existing examples include a community-engaged CRA from the Apsáalooke/Crow Tribe's Environmental Health Steering Committee, which explored exposure to well water contaminants and interview data on economic, cultural, and behavioral factors related to contamination (Eggers et al., 2018). Harris and Harper have also described the use of an "eco-cultural dependency web" approach to measuring and characterizing social-cultural impacts of contamination on health as part of a more holistic and cumulative risk assessment (Harris & Harper, 2000). While these advances are notable, there is a gap in the number of available case studies of cumulative risk assessment in Indigenous communities, and a lack of methodological consensus on CRA approaches in general (Sexton, 2012; Tong & Zhang, 2023).

Overall, while conventional HHRA methods are commonly used, these have been critiqued as insufficient for assessing health risks of importance to Indigenous communities. There is minimal information on the development of new risk assessment methods that can meet the multi-dimensional challenges of the old methods. While there are a few publications outlining community-relevant risk assessment approaches, there are minimal case studies that test them out, and thus limited knowledge on their operationalization in other communities facing similar challenges.

2.2 Regulatory Context for New Approaches to Risk Assessment in Canada

It is well-established in the literature that the risks posed by environmental contaminants are different for many Indigenous communities than the general population due to unique risk contexts such as exposure pathways and other non-chemical stressors, and thereby require unique risk assessment methods (Burger & Gochfeld, 2011; Eggers et al., 2018; Fernández-

Llamazares et al., 2020; Harris, 2000; O'Neill, 2000; Van Oostdam et al., 2005). In Canada, *Bill S-5* commits to the development of new approaches to risk assessment that include cumulative risks and consider vulnerable populations (Government of Canada, 2023a), which is highly relevant to Indigenous communities. These changes are part of an ongoing paradigm shift in how risk assessments are conducted, and decisions are made related to contaminants. Canada's Chemicals Management Plan (CMP) Science Committee report in 2016 noted that governing bodies, including Health Canada and Environment and Climate Change Canada, are developing a roadmap for integrating New Approach Methodologies (NAMs) with traditional (i.e.: conventional) risk assessment (Government of Canada, 2017). NAMs are emergent risk assessment tools and methods that are increasingly embraced by governing bodies as a replacement for conventional methods. There are a wide variety of NAMs that are currently being developed and tested for their ability to improve the efficiency, cost-effectiveness, resource intensity and ethics of conventional HHRAs (Table 2-1) (Government of Canada, 2017). Increasing focus has been placed on the acceptability and validation of NAMs for use in regulatory and chemical risk assessment (Mondou et al., 2021). The design of NAMs-based tools to date has been largely focused on advances in biotechnology (e.g., in silico modeling, high-throughput screening, toxicogenomics) (Wolf et al., 2022; Government of Canada, 2022b; Sewell et al., 2024), towards the more efficient production of mechanistic toxicity information (Government of Canada, 2017; Committee on Human and Environmental Exposure Science in the 21st Century, et al., 2012). Another purported benefit of NAMs-based risk assessments is that they are 'fit-for-purpose' and context-specific- NAMs may thereby be useful for addressing a variety of different risk assessment goals, including those of importance to Indigenous communities, whereas conventional methods generally apply a one-size-fits-all approach

(Mondou et al., 2021). Less popular in the 'NAMs' discourse is the integration of interdisciplinary approaches that include diverse information sources (for example, epidemiologic and social information), which is important for capturing the 'non-chemical' health risks posed by environmental contaminants, and ultimately the advancement of methods that are relevant to communities. There is minimal information available on new, alternative risk assessment methods in the context of their use for, and by, Indigenous communities.

Table 2-1- Key characteristics that differentiate conventional approaches vs. New Approach Methodologies in terms of human health risk assessment (Government of Canada, 2017; Committee on Human and Environmental Exposure Science in the 21st Century, et al., 2012)

	Conventional Approaches	**New Approach Methodologies (NAMs)**
Animals	Use of many live animals (in-vivo testing)	Reduced number of animals for toxicity testing (in-vitro, in-chemico, and in silico)
Resources	Expensive Resource intensive	Use of available resources, resource-efficient, less costly
Time	Lengthy	Efficient (high-throughput methods)
Data quality and scope	Data not available for many chemicals Minimal information on the effects of multiple chemical and non-chemical stressors (i.e.: cumulative effects)	Ability to mimic human biology and provide mechanistic toxicity information Potential to account for cumulative effects Chemical prioritization
Applicability	Generic, institutionalized	"Fit-for-purpose" Facilitates Science Communication

To my knowledge, new approaches to chemicals risk assessment of regulatory interest have yet to be used or validated by Indigenous communities. There is a current paradigm shift in the design and application of HHRA methods. Such new methods may eventually be adopted for regulatory use and applied in the context of Indigenous community-level risk assessments, which are used to make decisions that impact environmental management and community health. Therefore, in response to advocacy from Indigenous leadership (Assembly of First Nations, 2022), now is the time to design, test, and validate new approaches to risk assessments for and by Indigenous Peoples and communities. This is opposed to repeating the past in which Indigenous Peoples are consulted only after these approaches have already entered the regulatory realm.

2.3 Research and the Rights of Indigenous Peoples, UNDRIP

The present work requires an understanding of the ethical conduct of research that involves Indigenous Peoples, and its historical context. Research involving Indigenous Peoples over the last several decades has been the center of much discussion as it has presented several ongoing challenges, including the ‘use’ of Indigenous Knowledge without benefit to Indigenous Peoples. A history of communities being over-researched to the benefit of academic researchers, and attempts to integrate Indigenous Knowledge into the dominant western scientific body, is a form of colonization and exploitation for many Indigenous Peoples (Assembly of First Nations, 2018). The structure within which academic research is carried out often approaches Indigenous communities as research subjects as opposed to partners and involves the ‘extraction’ of information from communities following which academics never return (Johnson et al., 2023). This history has damaged the relationships between many Indigenous communities and academia and understandably resulted in a mistrust of academic researchers by many Indigenous people. Thus, when conducting research in collaboration with Indigenous Peoples, there are several important principles that should form the basis of such collaborations, which have been described by the Assembly of First Nations and other Indigenous governing bodies.

First, established research guidelines should be appropriately used to maintain researcher accountability for ethical engagement and research conduct. The principles of Ownership, Control, Access, and Possession (OCAP) are First Nations developed guidelines on data use, control, and access (Schnarch, 2004). OCAP is intended to promote Indigenous self-determination in research and protect the rights of Indigenous Peoples to the control and collective ownership of their data (Schnarch, 2004). OCAP principles are thereby used as a basis for collaborative research practice. The Tri-Council Policy Statement (TCPS) Chapter 9 on research involving Indigenous Peoples is another important guiding document (Government of Canada, 2022). The TCPS is the official human research ethics policy of Canada's research agencies and is a mandatory component of institutional review of research proposals, outlining considerations for ethical conduct in all aspects of the research process- for example, reflecting on the risks and benefits of research, obtaining community permissions to conduct research, and creating a research agreement. Positively, major federal granting agencies are increasingly prioritizing and supporting Indigenous leadership and collaboration on research in Indigenous communities. Federal research grating agencies in Canada released a strategic plan to support Indigenous research in Canada in 2019, which supplements the TCPS (Government of Canada, 2019). Research guidelines specific to Indigenous community-based work are important to understand as a component of research accountability to the communities that are involved in this thesis.

Further, of importance in research involving Indigenous Peoples is a knowledge of conceptualizations on the co-use of multiple knowledge systems. With the challenging history of research that privileges western-scientific worldviews while often subsuming Indigenous epistemologies, several models have been proposed towards a more ethical collaboration between these knowledge systems. A popular conceptualization is two-eyed seeing (*Etuaptmumk* in Mi'kmaw), which was envisaged by Mi'kmaw Elder Dr. Albert Marshall, and is defined as 'learning to see from one eye with the strengths of Indigenous knowledge and ways of knowing, and from the other eye with the strengths of mainstream knowledge and ways of knowing, and using both eyes together, for the benefit of all' (Reid et al., 2021). 'Weaving' and 'Braiding' are also common conceptualizations which bring together knowledge systems with respect for each system, aiming to go beyond integration or incorporation of one knowledge system into another more dominant body (Johnson et al., 2023). The two terms are beginning to be distinguished, with 'weaving' additionally including self-determined Indigenous methodologies and research paradigms (Government of Canada, 2024c). Third, 'ethical space' is an approach to shifting asymmetrical power dynamics towards equalized forms of knowledge and involves a dialogue between worldviews and mutual respect and reciprocity (Nikolakis & Hotte, 2022). All three of these approaches get at a similar goal of improving collaborations and relationships between western-scientific and Indigenous knowledges and values, for mutual benefit. While the institutionalization of these approaches in research practice has not yet been realized, and the dominance of the western scientific body remains, understanding these principles is an essential step in engaging with meaningful and ethical collaboration with Indigenous communities.

Reflexive research practice and researcher positionality is another important component of this thesis work. Positionality statements have become increasingly popular in research involving Indigenous communities. A positionality statement ideally is used as an ongoing part of a researcher's reflexivity, in which they critically reflect on their own personal and sociohistorical relationships, assumptions, and privileges, and how they are situated within and interact with the research context (King, 2024). While not a stand-alone solution to the historical lack of ethical research conduct in communities, positionality statements may be one tool that can help researchers to continue to reflect upon how knowledge systems interact in their work and to understand their limitations. Enacting self-awareness and ongoing self-reflection are important considerations for research involving Indigenous communities.

Finally, and importantly, the *UN Declaration on the Rights of Indigenous Peoples* (UNDRIP) outlines key principles that are essential foundational knowledge for research involving Indigenous Peoples. UNDRIP was adopted by the United Nations General Assembly in 2007 and was endorsed by Canada in 2016. Royal Assent was received for Canada's *'UN Declaration Act'* in 2021, and an action plan for its implementation was released in 2023. Cross-cutting across First Nations, Inuit, and Métis priorities in Canada are the rights to self-determination and self-governance (Government of Canada, 2023b). Further, the *UN Declaration Act* commits to Indigenous Peoples' rights related to a healthy environment, which includes meaningful participation in impact assessment processes, and the consideration of socio-economic factors and cumulative effects (Government of Canada, 2023b). These are a few of many inherent rights that are related to the presented works of this thesis. These rights underpin an understanding of Indigenous Peoples and communities as rightsholders, as opposed to simply stakeholders, when it comes to natural resources assessment and management (Darling et al., 2023). Working to develop Indigenous-specific and led risk assessment approaches is one potential contribution towards the realization of Indigenous rights of self-determination and governance and the right to a healthy environment.

2.4 References

Arquette, M., Cole, M., Cook, K., LaFrance, B., Peters, M., Ransom, J., Sargent, E., Smoke, V., & Stairs, A. (2002). Holistic risk-based environmental decision making: A native perspective. *Environmental Health Perspectives, 110*, 259-264. https://doi.org/10.1289/ehp.02110s2259

Arsenault, R., Bourassa, C., Diver, S., McGregor, D., & Witham, A. (2019). Including Indigenous Knowledge systems in environmental assessments: restructuring the process. *Global Environmental Politics, 19*(3), 120-132. https://doi.org/10.1162/glep_a_00519

Assembly of First Nations. (2018). *First Nations ethics guide on research and Aboriginal Traditional Knowledge*. Retrieved June 20 2024 from https://achh.ca/wp-content/uploads/2018/07/Guide_Ethics_AFN.pdf

Assembly of First Nations. (2022). *SUBMISSION TO THE HOUSE OF COMMONS COMMITTEE ON ENVIRONMENT AND SUSTAINABLE DEVELOPMENT. Study on Bill S-5 An Act to amend the Canadian Environmental Protection Act, 1999, to make related amendments to the Food and Drugs Act and to repeal the Perfluorooctane Sulfonate Virtual Elimination Act*. Retrieved June 20 2024 from https://www.ourcommons.ca/Content/Committee/441/ENVI/Brief/BR12143095/br-external/AssemblyOfFirstNations-e.pdf

Briffa, J., Sinagra, E., & Blundell, R. (2020). Heavy metal pollution in the environment and their toxicological effects on humans. *Heliyon, 6*(9), e04691. https://doi.org/https://doi.org/10.1016/j.heliyon.2020.e04691

Brock, T., Reed, M. G., & Stewart, K. J. (2021). Indigenous community participation in resource development decision-making: Practitioner perceptions of legal and voluntary arrangements. *Journal of Environmental Management, 283*, 111922. https://doi.org/10.1016/j.jenvman.2020.111922

Buell, M.-C., Ritchie, D., Ryan, K., & Metcalfe, C. D. (2020). Using Indigenous and Western knowledge systems for environmental risk assessment. *Ecological Applications, 30*(7), e02146. https://doi.org/https://doi.org/10.1002/eap.2146

Bullard, R., Mohai, P., Saha, R., Wright, B (2007). *Toxic Wastes and Race at Twenty 1987-2007.* United Christ of Church. Retrieved August 19 2024 from https://www.ucc.org/wp-content/uploads/2021/03/toxic-wastes-and-race-at-twenty-1987-2007_Part1.pdf

Burger, J., & Gochfeld, M. (2011). Conceptual environmental justice model for evaluating chemical pathways of exposure in low-income, minority, Native American, and other unique exposure populations. *American Journal of Public Health, 101*(S1), S64-S73. doi: 10.2105/AJPH.2010.300077

Callahan, M. A., & Sexton, K. (2007). If cumulative risk assessment is the answer, what is the question? *Environmental Health Perspectives, 115*(5), 799-806. https://doi.org/10.1289/ehp.9330

Chan, H. M., Fediuk, K., Batal, M., Sadik, T., Tikhonov, C., Ing, A., & Barwin, L. (2021). The First Nations Food, Nutrition and Environment Study (2008–2018)—rationale, design, methods and lessons learned. *Canadian Journal of Public Health, 112*(Suppl 1), 8-19. https://doi.org/10.17269/s41997-021-00480-0

Chan, H. M., Singh, K., Batal, M., Marushka, L., Tikhonov, C., Sadik, T., Schwartz, H., & Fediuk, K. (2021). Levels of metals and persistent organic pollutants in traditional foods consumed by First Nations living on-reserve in Canada. *Canadian Journal of Public Health, 112*(1), 81-96. https://doi.org/10.17269/s41997-021-00495-7

Committee on Human and Environmental Exposure Science in the 21st Century, et al. (2012). *Exposure Science in the 21st Century: A Vision and a Strategy*. National Academies Press (US), 7 September 2012. doi:10.17226/13507

Daley, K., Jamieson, R., Rainham, D., & Truelstrup Hansen, L. (2018). Wastewater treatment and public health in Nunavut: a microbial risk assessment framework for the Canadian Arctic. *Environmental Science and Pollution Research, 25*(33), 32860-32872. https://doi.org/10.1007/s11356-017-8566-8

Damman, S., Eide, W. B., & Kuhnlein, H. V. (2008). Indigenous peoples' nutrition transition in a right to food perspective. *Food Policy, 33*(2), 135-155. https://doi.org/https://doi.org/10.1016/j.foodpol.2007.08.002

Darling, S., Harvey, B., & Hickey, G. M. (2023). From 'stakeholders' to rights holders: How approaches to impact assessment affect indigenous participation in the Yukon Territory, Canada. *Environmental Impact Assessment Review, 99*, 107025. https://doi.org/https://doi.org/10.1016/j.eiar.2022.107025

Donatuto, J., & Harper, B. L. (2008). Issues in evaluating fish consumption rates for Native American tribes. *Risk Analysis: An International Journal, 28*(6), 1497-1506. https://doi.org/10.1111/j.1539-6924.2008.01113.x

Donatuto, J. L., Satterfield, T. A., & Gregory, R. (2011). Poisoning the body to nourish the soul: Prioritising health risks and impacts in a Native American community. Health, Risk & Society, 13(2), 103-127.

Donatuto, J., Campbell, L., & Trousdale, W. (2020). The "value" of values-driven data in identifying Indigenous health and climate change priorities. Climatic Change, 158(2), 161-180. https://doi.org/10.1007/s10584-019-02596-2

Doyle, J. R., Blais, J. M., Holmes, R. D., & White, P. A. (2012). A soil ingestion pilot study of a population following a traditional lifestyle typical of rural or wilderness areas. *Science of the Total Environment, 424*, 110-120. https://doi.org/10.1016/j.scitotenv.2012.02.043

Doyle, J. R., Blais, J. M., & White, P. A. (2010). Mass balance soil ingestion estimating methods and their application to inhabitants of rural and wilderness areas: A critical review. *Science of the Total Environment, 408*(10), 2181-2188. https://doi.org/10.1016/j.scitotenv.2010.02.007

Eggers, M. J., Doyle, J. T., Lefthand, M. J., Young, S. L., Moore-Nall, A. L., Kindness, L., Medicine, R. O., Ford, T. E., Dietrich, E., Parker, A. E., Hoover, J. H., & Camper, A. K.

(2018). Community Engaged Cumulative Risk Assessment of Exposure to Inorganic Well Water Contaminants, Crow Reservation, Montana. *International Journal of Environmental Research and Public Health, 15*(1), Article 76. https://doi.org/10.3390/ijerph15010076

Ellis, S. C. (2005). Meaningful consideration? A review of traditional knowledge in environmental decision making. *Arctic,* Vol. 58, No. 1 (Mar., 2005), pp. 66-77 https://www.jstor.org/stable/40512668

Engwa, G. A., Ferdinand, P. U., Nwalo, F. N., & Unachukwu, M. N. (2019). Mechanism and health effects of heavy metal toxicity in humans. *Poisoning in the modern world-new tricks for an old dog, Chapter 10*. DOI: 10.5772/intechopen.82511

EPA. (2022). *Human Health Risk Assessment*. [Webpage]. Retrieved November 10 from https://www.epa.gov/risk/human-health-risk-assessment

Fernández-Llamazares, Á., Garteizgogeascoa, M., Basu, N., Brondizio, E. S., Cabeza, M., Martínez-Alier, J., McElwee, P., & Reyes-García, V. (2020). A state-of-the-Art review of Indigenous Peoples and environmental pollution. *Integrated Environmental Assessment and Management, 16*(3), 324-341. https://doi.org/https://doi.org/10.1002/ieam.4239

Freeman, M. (2023). *Inuit.* In The Canadian Encyclopedia. Retrieved June 25, 2024 from https://www.thecanadianencyclopedia.ca/en/article/inuit

Garvin, E. M., Bridge, Cas F., Garvin, Meredith S. (2018). Edible wild plants growing in contaminated floodplains: implications for the issuance of tribal consumption advisories within the Grand Lake watershed of northeastern Oklahoma, USA. *Environmental Geochemistry and Health, 40*(3), 999-1025. https://doi.org/http://dx.doi.org/10.1007/s10653-017-9960-3

Gregory R., Easterling, D., Kaechele N., Trousdale, W. (2016). Values-based measures of impacts to Indigenous Health. *Risk Analysis.* 36 (8), 1581-1588. DOI: 10.1111/risa.12533

Golzadeh, N., Barst, B. D., Baker, J. M., Auger, J. C., & McKinney, M. A. (2021). Alkylated polycyclic aromatic hydrocarbons are the largest contributor to polycyclic aromatic compound concentrations in traditional foods of the Bigstone Cree Nation in Alberta, Canada. *Environmental Pollution, 275*, Article 116625. https://doi.org/10.1016/j.envpol.2021.116625

Golzadeh, N., Barst, B. D., Basu, N., Baker, J. M., Auger, J. C., & McKinney, M. A. (2020). Evaluating the concentrations of total mercury, methylmercury, selenium, and selenium:mercury molar ratios in traditional foods of the Bigstone Cree in Alberta, Canada. *Chemosphere, 250*, Article 126285. https://doi.org/10.1016/j.chemosphere.2020.126285

Government of Canada. (2017). *Committee report- November 16-17, 2016.* Retrieved June 20 2024 from https://www.canada.ca/en/health-canada/services/chemical-substances/chemicals-management-plan/science-committee/meeting-records-reports/committee-report-november-16-17-2016.html

Government of Canada. (2019). *Strengthening Indigenous Research Capacity.* Strategic Plan. Retrieved August 19 2024 from https://www.canada.ca/content/dam/crcc-ccrc/documents/strategic-plan-2019-2022/sirc_strategic_plan-eng.pdf

Government of Canada. (2021). *Federal Contaminated Sites Inventory* [Database]. Accessed June 20 2024 from https://www.tbs-sct.gc.ca/fcsi-rscf/home-accueil-eng.aspx

Government of Canada. (2022). *TCPS 2 (2022)- Chapter 9: Research involving the First Nations, Inuit, and Metis Peoples of Canada.* Panel on Research Ethics. Retrieved August 19 2024 from https://ethics.gc.ca/eng/tcps2-eptc2_2022_chapter9-chapitre9.html

Government of Canada. (2023a). *Bill S-5, Strengthening Environmental Protection for a Healthier Canada Act- Summary of Amendments*. Retrieved June 20 2024 from https://www.canada.ca/en/services/environment/pollution-waste-management/strengthening-canadian-environmental-protection-act-1999/bill-c-28-strengthening-environmental-protection-healthier-canada-act-summary-amendments.html

Government of Canada. (2023b). *United Nations Declaration on the Rights of Indigenous Peoples Act Action Plan*. Retrieved June 20 2024 from https://bctreaty.ca/wp-content/uploads/2023/07/2023-06-20_UNDA_Action_Plan_EN.pdf

Government of Canada. (2024a, Jan 16). *Métis.* Retrieved April 17 2025 from https://www.rcaanc-cirnac.gc.ca/eng/1100100014427/1535467913043

Government of Canada. (2024b). *Federal Contaminated Sites Inventory.* Accessed June 20 2024 from https://www.tbs-sct.gc.ca/fcsi-rscf/searchby-recherchepar-eng.aspx

Government of Canada (2024c, Mar 1). *Indigenous Science.* Environment and Climate Change Canada. Government of Canada. Retrieved April 18 from https://www.canada.ca/en/environment-climate-change/services/science-technology/indigenous-science.html

Harper, B., Harding, A., Harris, S., & Berger, P. (2012). Subsistence Exposure Scenarios for Tribal Applications. *Human and Ecological Risk Assessment, 18*(4), 810-831. https://doi.org/10.1080/10807039.2012.688706

Harris, S. G. (2000). Risk analysis: Changes needed from a Native American perspective. *Human and Ecological Risk Assessment, 6*(4), 529-535. DOI: 10.1080/10807030008951325

Harris, S. G., & Harper, B. L. (1997). A Native American exposure scenario. *Risk Analysis, 17*(6), 789-795. https://doi.org/10.1111/j.1539-6924.1997.tb01284.x

Harris, S. G., & Harper, B. L. (2000). Using eco-cultural dependency webs in risk assessment and characterization of risks to tribal health and cultures. *Environmental Science and Pollution Research, 2*(2), 91-100. Retrieved June 20 2024 from https://superfund.oregonstate.edu/sites/superfund.oregonstate.edu/files/harris_harper_2000_eco-cultural_dependency_webs_espr.pdf

Health Canada. (2010). *A Guide to Involving Aboriginal Peoples in Contaminated Sites Managament*. Retrieved June 20 2024 from https://publications.gc.ca/collections/collection_2011/sc-hc/H128-1-10-628-eng.pdf

Health Canada. (2018). *Guidance for evaluating human health impacts in environmental assessment: country foods*. Retrieved June 20 2024 from https://publications.gc.ca/collections/collection_2018/sc-hc/H129-54-5-2018-eng.pdf

Health Canada. (2019). *Guidance for Evaluating Human Health Impacts in Environmental Assessment: Human Health Risk Assessment*. Retrieved June 20 2024 from https://publications.gc.ca/collections/collection_2019/sc-hc/H129-54-6-2019-eng.pdf

Holifield, R. (2012). Environmental Justice as Recognition and Participation in Risk Assessment: Negotiating and Translating Health Risk at a Superfund Site in Indian Country. *Annals of the Association of American Geographers, 102*(3), 591-613. https://doi.org/10.1080/00045608.2011.641892

Hoover, E., Renauld, M., Edelstein, M. R., & Brown, P. (2015). Social science collaboration with environmental health. *Environmental Health Perspectives, 123*(11), 1100-1106. https://doi.org/10.1289/ehp.1409283

Indigenous Services Canada (2024). *First Nations Environmental Contaminants Program for Communities and Organizations South of the 60th Parallel.* Ottawa, Ontario: Government of Canada. Retrieved June 20 2024 https://www.sac-isc.gc.ca/eng/1654111962122/1654111988366

Johnson, L. R., Wilcox, A. A., Alexander, S. M., Bowles, E., Castleden, H., Henri, D. A., Herc, C., King, L., Provencher, J. F., & Orihel, D. M. (2023). Weaving Indigenous and Western ways of knowing in ecotoxicology and wildlife health: a review of Canadian studies. *Environmental Reviews, 31*(3), 452-470. http://dx.doi.org/10.1139/er-2022-0087

Kimmerer (2013). Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge and the Teachings of Plants. Milkweed Editions, Minneapolis, MN, USA, 408 p.

King, K. A. (2024). Promises and perils of positionality statements. *Annual Review of Applied Linguistics,* 1–8. doi:10.1017/S0267190524000035

Lemire, M., Kwan, M., Laouan-Sidi, A. E., Muckle, G., Pirkle, C., Ayotte, P., & Dewailly, E. (2015). Local country food sources of methylmercury, selenium and omega-3 fatty acids in Nunavik, Northern Quebec. *Science of the Total Environment, 509-510*, 248-259. https://doi.org/10.1016/j.scitotenv.2014.07.102

Lewis, D., Castleden, H., Apostle, R., Francis, S., & Francis-Strickland, K. (2021). Linking land displacement and environmental dispossession to Mi'kmaw health and well-being: Culturally relevant place-based interpretive frameworks matter. *The Canadian Geographer/Le Géographe canadien, 65*(1), 66-81. https://doi.org/10.1111/cag.12656

Lievanos, R. S. (2018). Retooling CalEnviroScreen: Cumulative Pollution Burden and Race-Based Environmental Health Vulnerabilities in California. *International Journal of Environmental Research and Public Health, 15*(4), 762. https://doi.org/http://dx.doi.org/10.3390/ijerph15040762

Liboiron, M. (2021). Pollution is Colonialism. Duke University Press, Durham, NC, USA, 197 pMatwee, L., & Pietrock, M. (2019). Parasites and metals in Walleye (Sander vitreus) and Northern Pike (Esox lucius) from Boreal Montreal Lake (Saskatchewan, Canada): Assessment of human health risks. *Bulletin of Environmental Contamination and Toxicology, 103*(2), 240-245. https://doi.org/10.1007/s00128-019-02624-y

McAuley, C., Dersch, A., Mouille-Malbeuf, S., Koppe, B., & Sowan, D. (2018). Cadmium tissue concentrations in kidney, liver and muscle in moose (Alces alces) from First Nations communities in Northern Alberta. *Frontiers in Sustainable Food Systems, 2*, 69. https://doi.org/10.3389/fsufs.2018.00069

McGregor, D. (2021). Indigenous knowledge systems in environmental governance in Canada. *KULA, Knowledge Creation, Dissemination, and Preservation Studies,* 5(1), 1-10. https://doi.org/10.18357/kula.148

McOliver C.A., Camper A.K., Doyle J.T., Eggers M.J., Ford T.E., Lila M.A., Berner J., Campbell L., and Donatuto J. Community-Based Research as a Mechanism to Reduce Environmental Health Disparities in American Indian and Alaska Native Communities. International Journal of Environmental Research and Public Health. 2015; 12(4):4076-4100. https://doi.org/10.3390/ijerph120404076

Min, E., Gruen, D., Banerjee, D., Echeverria, T., Freelander, L., Schmeltz, M., Saganić, E., Piazza, M., Galaviz, V. E., Yost, M., & Seto, E. Y. W. (2019). The Washington State Environmental Health Disparities Map: Development of a Community-Responsive Cumulative Impacts Assessment Tool. *International Journal of Environmental Research and Public Health, 16*(22). https://doi.org/http://dx.doi.org/10.3390/ijerph16224470

Mondou, M., Maguire, S., Pain, G., Crump, D., Hecker, M., Basu, N., & Hickey, G. M. (2021). Envisioning an international validation process for New Approach Methodologies in chemical hazard and risk assessment. *Environmental Advances, 4*, 100061. https://doi.org/10.1016/j.envadv.2021.100061

Moriarity, R. J., Liberda, E. N., & Tsuji, L. J. (2020). Subsistence fishing in the Eeyou Istchee (James Bay, Quebec, Canada): A regional investigation of fish consumption as a route of exposure to methylmercury. *Chemosphere, 258*, 127413. https://doi.org/10.1016/j.chemosphere.2020.127413

Moriarity, R. J., Liberda, E. N., & Tsuji, L. J. S. (2020). Subsistence fishing in the Eeyou Istchee (James Bay, Quebec, Canada): A regional investigation of fish consumption as a route of exposure to methylmercury [Article]. *Chemosphere, 258*, Article 127413. https://doi.org/10.1016/j.chemosphere.2020.127413

Moriarity, R. J., Tsuji, L. J., & Liberda, E. N. (2023). A probabilistic hazard and risk assessment of exposure to metals and organohalogens associated with a traditional diet in the Indigenous communities of Eeyou Istchee (northern Quebec, Canada). *Environmental Science and Pollution Research, 30*(6), 14304-14317. https://doi.org/10.1007/s11356-022-23117-2

Moriarity, R. J., Tsuji, L. J. S., & Liberda, E. N. (2023). A probabilistic hazard and risk assessment of exposure to metals and organohalogens associated with a traditional diet in the Indigenous communities of Eeyou Istchee (northern Quebec, Canada) [Article].

Environmental Science and Pollution Research, 30(6), 14304-14317. https://doi.org/10.1007/s11356-022-23117-2

National Research Council. (1983). *Risk Assessment in the Federal Government: Managing the Process*. National Academies Press (US). National Academy of Sciences. Accessed June 20 2024 from https://doi.org/10.17226/366

Nikolakis, W., & Hotte, N. (2022). Implementing "ethical space": An exploratory study of Indigenous-conservation partnerships. *Conservation Science and Practice, 4*(1), e580. https://doi.org/10.1111/csp2.580

O'Neill, C. A. (2000). Variable justice: Environmental standards, contaminated fish, and acceptable risk to Native peoples. *Stanford Environmental Law Journal, 19*, 3. Retrieved June 20 2024 from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2263492#

OECD. (2020). *Linking Indigenous Communities with Regional Development in Canada.* https://doi.org/doi:https://doi.org/10.1787/fa0f60c6-en

Pastoor, T. P., Bachman, A. N., Bell, D. R., Cohen, S. M., Dellarco, M., Dewhurst, I. C., Doe, J. E., Doerrer, N. G., Embry, M. R., & Hines, R. N. (2014). A 21st century roadmap for human health risk assessment. *Critical Reviews in Toxicology, 44*(sup3), 1-5. https://doi.org/10.3109/10408444.2014.931923

Payne-Sturges, D. C., Scammell, M. K., Levy, J. I., Cory-Slechta, D. A., Symanski, E., Carr Shmool, J. L., Laumbach, R., Linder, S., & Clougherty, J. E. (2018). Methods for evaluating the combined effects of chemical and nonchemical exposures for cumulative environmental health risk assessment. *International Journal of Environmental Research and Public Health, 15*(12), 2797. https://doi.org/10.3390%2Fijerph15122797

Pose-Juan, E., Fernández-Cruz, T., & Simal-Gándara, J. (2016). State of the art on public risk assessment of combined human exposure to multiple chemical contaminants. *Trends in Food Science & Technology, 55*, 11-28. http://dx.doi.org/10.1016/j.tifs.2016.06.011

Reid, A. J., Eckert, L. E., Lane, J. F., Young, N., Hinch, S. G., Darimont, C. T., Cooke, S. J., Ban, N. C., & Marshall, A. (2021). "Two-Eyed Seeing": An Indigenous framework to transform fisheries research and management. *Fish and Fisheries, 22*(2), 243-261. https://doi.org/10.1111/faf.12516

Schnarch, B. (2004). Ownership, control, access, and possession (OCAP) or self-determination applied to research: A critical analysis of contemporary First Nations research and some options for First Nations communities. *International Journal of Indigenous Health, 1*(1), 80-95. Retrieved June 20 2024 from https://jps.library.utoronto.ca/index.php/ijih/article/view/28934/24060

Sewell, F., Alexander-White, C., Brescia, S., Currie, R. A., Roberts, R., Roper, C., Vickers, C., Westmoreland, C., & Kimber, I. (2024). New approach methodologies (NAMs): identifying and overcoming hurdles to accelerated adoption. *Toxicology Research, 13*(2), tfae044. doi: 10.1093/toxres/tfae044.

Sexton, K. (2012). Cumulative risk assessment: an overview of methodological approaches for evaluating combined health effects from exposure to multiple environmental stressors.

International Journal of Environmental Research and Public Health, 9(2), 370-390. https://doi.org/10.3390/ijerph9020370

Sexton, K. (2015). Cumulative health risk assessment: Finding new ideas and escaping from the old ones. *Human and Ecological Risk Assessment: An International Journal, 21*(4), 934-951. http://dx.doi.org/10.1080/10807039.2014.946346

Sharp, D., Black, A., & Mitchell, J. (2016). Using participatory research to communicate environmental health risks to First Nations communities in Canada. *Global bioethics, 27*(1), 22-37. https://doi.org/10.1080/11287462.2016.1145781

Solatyavari, L., Klis, A. A., & Groves, J. (2022). Superfund cleanup time and community characteristics: A survival analysis. *Journal of Environmental Management,* 320, 115705. https://doi.org/10.1016/j.jenvman.2022.115705

Thompson, K. L., Picard, C. R., & Chan, H. M. (2017). Polycyclic aromatic hydrocarbons (PAHs) in traditionally harvested bivalves in northern British Columbia, Canada. *Marine Pollution Bulletin, 121*(1-2), 390-399. https://doi.org/10.1016/j.marpolbul.2017.06.018

Tilousi, C., & Hinck, J. E. (2024). Expanded Conceptual Risk Framework for Uranium Mining in Grand Canyon Watershed—Inclusion of the Havasupai Tribe Perspective. *US Geological Survey Open-File Report, 2024*. https://doi.org/10.3133/ofr20231092

Tilousi, C., & Hinck, J. E. (2024). *Expanded conceptual risk framework for uranium mining in Grand Canyon watershed—Inclusion of the Havasupai Tribe perspective*. United States Geological Survey. 2331-1258. https://doi.org/10.3133/ofr20231092

The Canadian Encyclopedia. (2023). First Nations in Canada. In *The Canadian Encyclopedia.* Retrieved June 25, 2024 from https://www.thecanadianencyclopedia.ca/en/article/first-nations

United Nations. (2007). *United Nations Declaration on the Rights of Indigenous Peoples*. Retrieved June 20 2024 from https://www.un.org/development/desa/indigenouspeoples/wp-content/uploads/sites/19/2018/11/UNDRIP_E_web.pdf

USAGov. (2024). *Federally recognized American Indian tribes and Alaska Native entities.* Retrieved June 25 2024 from https://www.usa.gov/indian-tribes-alaska-native

US EPA. (1992). *Terms of Environmental Glossary Abbreviations and Acronyms*. Retrieved June 20 2024 from https://nepis.epa.gov/Exe/ZyNET.exe/200081E1.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1991+Thru+1994&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C91thru94%5CTxt%5C00000004%5C200081E1.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

van der Vegt, R. G., Maguire, S., Crump, D., Hecker, M., Basu, N., & Hickey, G. M. (2022). Chemical risk governance: Exploring stakeholder participation in Canada, the USA, and the EU. *Ambio, 51*(7), 1698-1710. https://doi.org/10.1007/s13280-021-01671-2

Van Oostdam, J., Donaldson, S. G., Feeley, M., Arnold, D., Ayotte, P., Bondy, G., Chan, L., Dewaily, E., Furgal, C., & Kuhnlein, H. (2005). Human health implications of environmental contaminants in Arctic Canada: a review. *Science of the Total Environment, 351*, 165-246. https://doi.org/10.1016/j.scitotenv.2005.03.034

Wilcox, AAE, Provencher JF, Henri, DA, Alexander, SJ, Taylor, JJ, Cooke, SJ, Thomas, PJ, and Johnson, LR. (2023). Braiding Indigenous knowledge systems and Western-based sciences in the Alberta oil sands region: A systematic review. *FACETS*. 8(): 1-32. https://doi.org/10.1139/facets-2022-0052

CONNECTING PARAGRAPHS

Chapters 1 and 2 outline the knowledge on HHRAs and Indigenous communities and describe the rationale for designing new approaches to risk assessment that better meet the priorities of communities themselves. While information on the topic is relatively minimal, it is generally clear from the literature that conventional HHRA approaches may not adequately address the unique risk contexts of Indigenous Peoples and communities. The process of design thinking begins with empathizing with and defining the complex 'problem' in question. In the context of environmental assessment and management in Indigenous communities, there are a variety of actors and perspectives beyond academia that need be considered as part of these empathize and define stages. Understanding the variety of available knowledge is necessary in establishing a 'complete picture' of the scope of the question this thesis aims to address.

Chapter 3 details a scoping review on the topic of contaminated sites and Indigenous Peoples in Canada and the US, exploring three distinct data streams: Scholarly literature, grey literature, and data on contaminated sites from Canadian and US databases. Comparing these three data streams overall demonstrates that the available knowledge on the topic is diverse yet disparate, with a small amount of literature on the topic relative to the large number of contaminated sites on Indigenous lands. Gaps in information and future research priorities identified through this review include community-specific and led assessment and management approaches, and the development of holistic and efficient methods that prioritize Indigenous epistemologies. These findings provide context for the subsequent stages of the design thinking process detailed in chapters 4-7. This chapter is additionally co-authored by Dr. Niladri Basu and was published in *Integrated Environmental Assessment and Management (Chong et al., 2023)*.

CHAPTER 3: Contaminated Sites and Indigenous Peoples in Canada and the US: A Scoping Review

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3.1 Abstract

Indigenous communities are disproportionately exposed to contaminated sites, and this poses unique challenges as many Indigenous peoples consider land as an integral part of their culture and economy. This scoping review aimed to identify and map information on contaminated sites and Indigenous peoples in Canada and the US, namely: 1) the relationship between contaminated sites and Indigenous people, and their land and food systems; 2) strategies, challenges, and successes for contaminated sites assessment and management on Indigenous land; and 3) Indigenous leadership and inclusion in contaminated site assessment and management. We followed a PRISMA-ScR (Transparent Reporting of Systematic Reviews and Meta-Analyses-Extension for Scoping Reviews) checklist to collect data that could be categorized into these three objectives. Between October 2021 and July 2023, information from three data streams was retrieved: systematic literature search; a grey literature search; and federal site data retrieval (Canada's Federal Contaminated Sites Inventory, US EPA's contaminated sites databases, including Superfund). This search yielded 51 peer-reviewed articles, 21 grey literature articles, and 11,404 federal site records, evidencing the contamination of the lands of 875 Indigenous communities and the presence of 440 different contaminants or contaminant groups. The body of information was categorized into three themes within the above objectives:

Objective 1) Indigenous communities and geographic patterns; Contaminated sites, sources, and media; Contaminated sites and Indigenous lands; Contaminated sites and Indigenous food systems; Contaminated sites and the health of Indigenous peoples; Objective 2) Site management and classification processes; Health risk assessment; Risk management; Long-term management; Objective 3) Collaborative research, Collaborative site management; Traditional knowledge and contaminated sites. Results highlighted a need to prioritize holism, efficiency, and Indigenous leadership in site assessment, management, and research, including a focus on community-specific approaches to site assessment and management; a re-conceptualization of risks that privileges Indigenous epistemologies; and greater collaboration between stakeholder networks.

3.2 INTRODUCTION

It is well known that pollution has profound effects on human and environmental health (Landrigan et al., 2018). In Canada and the United States (US), contaminated sites that arise from commercial, industrial, or waste disposal activities are a major source of pollution, with contaminant concentrations that can often pose a human or environmental health hazard (Contaminated Sites Management Working Group, 2000; EPA, 2021b). Federal Contaminated Sites (also termed “Superfund” or “Cleanups” in the US) are those for which federal governments are responsible. These sites disproportionately affect Indigenous People. For example, in Canada south of the 60^{th} parallel, there are an estimated 4486 Federal contaminated sites on Indigenous reserve land, making up over 20% of the total sites, although reserves make up only 0.5% of the total land mass, and Indigenous peoples make up 5% of the total population in Canada as of 2021 (Government of Alberta, 2023; Government of Canada, 2021; OECD, 2020). Similarly in the US, ~34% of Superfund sites are categorized under ‘Native American Interest’ by the Environmental Protection Agency (EPA), while Native American people make up only 2.9% of the total population (EPA, 2021a; Jones, 2021).

Many Indigenous peoples in Canada and the US have traditional ties to the land, including as an integral part of food systems, language, culture, community, and spirituality. The health of Indigenous communities cannot be understood independent of the health of the environment and thus contaminated sites present unique challenges to Indigenous People (Hoover, 2013). One of the most notable challenges is the impact of contaminants on Indigenous food systems, including agricultural and subsistence activities such as hunting, gathering, farming, and gardening (Fernández-Llamazares et al., 2020). As an example, the First Nations

Food and Nutrition Study in Canada recently sampled traditional foods from 92 communities, measuring 2061 samples and finding some of these to have elevated concentrations of metals, particularly mercury in fish and lead in mammals and birds compared to Canadian guideline values (Chan, Singh, et al., 2021). Exposure to such contaminants is associated with organ damage, neurodegenerative diseases, cancer, and reproductive and developmental disorders (Briffa et al., 2020; Engwa et al., 2019). Furthermore, contamination of traditional foods has contributed to a 'nutrition transition' for many Indigenous communities, characterized by the westernization of diet and lifestyle and a reliance on nutrient-poor market foods. This transition is fueling a high prevalence of chronic diseases including obesity and related cardiometabolic disorders (Chan, Fediuk, et al., 2021; Damman et al., 2008). Overall, exposure to contaminants results in both direct and indirect health effects for Indigenous peoples, contributing to a loss of food sovereignty, which is defined as the right to healthy, culturally appropriate, and self-determined food and agricultural systems, and is a key determinant of overall health (Coté, 2016; Fernández-Llamazares et al., 2020).

Unique solutions are required to address the challenges that contaminated sites pose to Indigenous communities, however environmental research and management processes often use western-institutionalized risk assessment tools and frameworks which are generic and poorly apply to Indigenous people (Arsenault et al., 2019; Sandlos & Keeling, 2016a; Wang et al., 2020). For example, the application of a generic (i.e.: western population focused) risk assessment model for mercury exposure to studies involving Indigenous populations did not yield results that were representative of the study population given differences in factors such as diet and genetics (Canuel et al., 2006). This issue is further complicated by the lack of toxicological data for the hundreds of chemicals found at contaminated sites (EPA, 2021a;

Government of Canada, 2021; Wang et al., 2020). Regulatory barriers further challenge contaminated sites management. The variety of US governmental programs, for example, that categorize and address contaminated sites has resulted in a fragmented tracking system and a poor understanding of the scope of the problem (EPA, 2021b). In Canada, Indigenous reserve land falls under federal jurisdiction, while most environmental management is provincially mandated (Eckert et al., 2020). The Indian Act constitutes federal legislation on reserve management, but fails to mention environmental protection, and Indigenous legal systems are not consistently recognized under the Canadian constitution on the same level as federal and provincial legislation (Eckert et al., 2020; Gunn K, 2021). Scientific and regulatory discourse that governs decision-making further highlights this gap. For example, a recent 400-page report from the US National Research Council that outlines alternatives for managing contaminated groundwater sites does not mention Indigenous peoples (National Research Council, 2013). Taken together, there are scientific gaps, regulatory barriers, and a lack of meaningful inclusion of Indigenous communities, which prevent improvements to the management of federal contaminated sites.

Contaminated sites threaten land-based food systems that are essential to many Indigenous communities' culture, spirituality, and overall health. Scientific, regulatory and epistemological barriers facing federal contaminated site management adds complexity beyond previous studies of pollution and Indigenous people in general (Fernández-Llamazares et al., 2020). However, to our knowledge, the topic of federal contaminated sites and Indigenous people has yet to be reviewed, preventing the advancement of solutions to these barriers. As such, the objective was this paper was to present the state of knowledge on 1) the relationship between contaminated sites and Indigenous people, and their land and food systems; 2) strategies, challenges, and successes for contaminated sites management on Indigenous land; and 3) Indigenous leadership and inclusion in contaminated sites management activities. In doing so, this scoping review maps the available information and identifies evidence gaps and priority actions pertaining to contaminated sites and Indigenous peoples in Canada and the US (Munn et al., 2018).

3.3 METHODS

3.3.1 Positionality Statement

This review was conducted by non-Indigenous researchers at McGill University in Montreal, Canada. The authors are non-Indigenous persons of color (a doctoral student and Professor). While every attempt was made to minimize biases, we acknowledge that this positionality and its historical context places limitations on the present work. The motivation for the review is an Indigenous community-based project lead by the Kanien'kehà:ka (Mohawk) Community of Kanesatake in Quebec, Canada, that addresses a local contaminated site. The authors are based in McGill's Centre for Indigenous Nutrition and Environment (CINE), which affords connections with many Indigenous communities and stakeholders and provides opportunities for the promotion of Indigenous methodologies and decolonizing research practices.

3.3.2 Search Strategy and Study Selection Criteria

The search strategy utilized three data streams, which included a systematic scholarly literature search, a grey literature search, and federal contaminated sites data repositories (Figure 3-1). First, a systematic search of peer-reviewed literature was conducted to identify the state of knowledge pertaining to the study objectives. Second, a search for grey literature, such as governmental reports, theses, news articles, and case studies was used to support the findings. Finally, publicly available federal contaminated site data was downloaded from the US and Canadian federal government websites. The results were compiled and scrutinized to map the existing evidence and to develop an understanding of priority scientific and environmental management gaps in a multidisciplinary context. The PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses- Extension for Scoping Reviews) checklist was utilized to ensure that methodology reporting was transparent (Tricco et al., 2018).

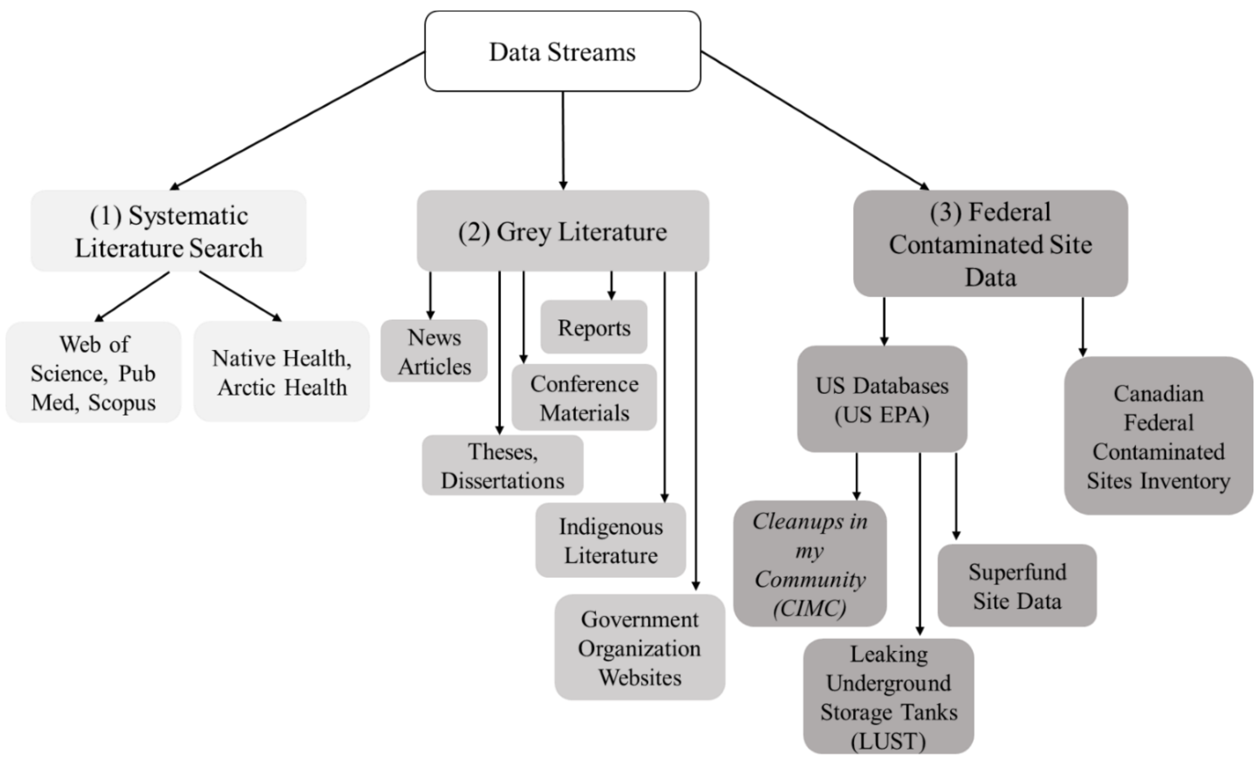

Figure 3-1: Overview of the three data streams used in this scoping review.

Systematic literature search. A systematic search of databases (Scopus, Web of Science, and Pubmed) was used to identify relevant articles. The final search was run on January 10, 2022, and updated July 4, 2023. Boolean operators were used to search each database as follows: ("First Nation*" OR "Indigenous people*" OR "Native American" OR "Aboriginal" OR "Inuit" OR "Metis" OR "American Indian" OR "Canadian Indian" OR "Traditional food" OR "Indigenous agriculture" OR "Country food*" OR "Tribal land" OR "reservation" OR "reserve land" OR "Indian country") AND ("contaminated site*" OR "superfund" OR "contaminated land" OR "brownfield" OR "abandoned mine"). The Scopus search was limited with the operator TI-ABS-KEY due to initial results from a full-text search that lacked specificity.

Overall, inclusion criteria were broad, to capture the diversity and scope of the information available on the topic. Papers were included that pertained to federal contaminated site(s) in Canada or the US, and to Indigenous peoples, communities, and environments exposed to the site. Both qualitative and quantitative studies were included. Both primary studies (i.e., involving the collection of primary data and direct measurement of an outcome of interest) and secondary studies (i.e., review papers or discussion papers) were included. Literature included was limited to Canada and the US and published in English. No date limit was placed on the studies. The review was limited to First Nations, Inuit, and Metis peoples in Canada, and all Native American peoples in the US, including those residing in non-contiguous states. Notably, many mainland Indigenous people such as the Haudenosaunee, Cree, and Anishinaabe live in both the US and Canada, due to the cutting of common cultural territory by the international border (*Native Land Interactive Map*, 2021). Furthermore, some Indigenous communities live on both sides of the US-Mexico Border, and these were considered if the literature was relevant to the US context. The review used the definition of 'contaminated site' as described by the US

EPA and Environment and Climate Change Canada (ECCC) (See Supplemental Materials, Glossary of Key Terms) (EPA, 2021b; Government of Canada, 2021). The review excluded literature on pollution and Indigenous people that was not specific to contaminated sites. The search and screening process, involving the reviewing of titles and abstracts, resulted in a total of 51 articles for analysis (Figure 3-2; Excel Table S1).

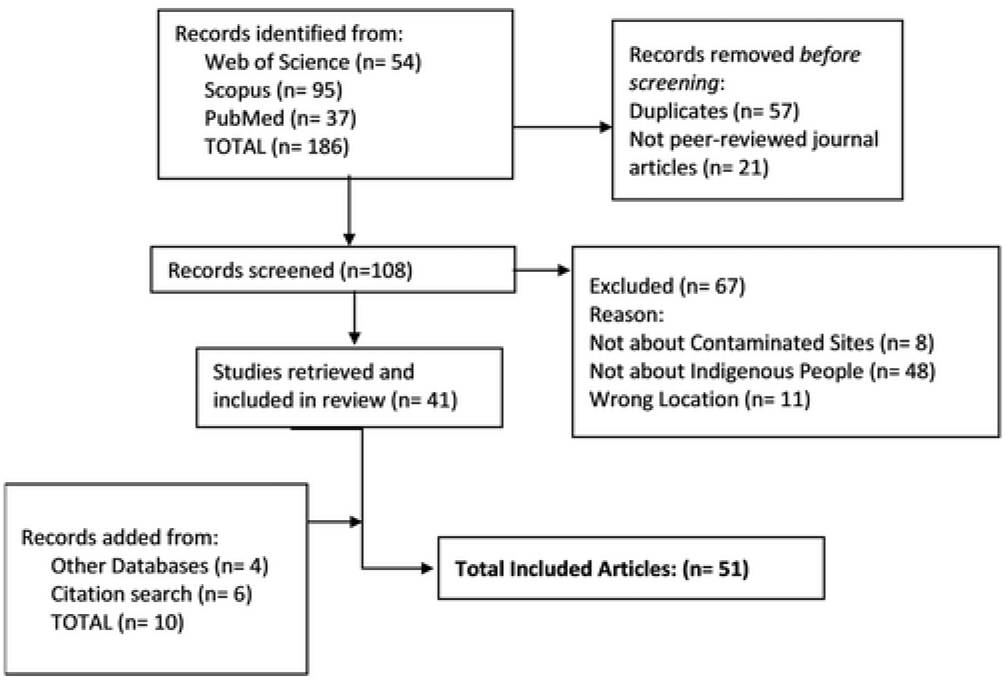

Figure 3-2: Flow diagram adapted from the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses- Extension for Scoping Reviews) guidelines, outlining the literature search process for the first data stream (peer-reviewed literature). Search last updated July 6, 2023.

Grey literature search. Due to the minimal number of publications in academic journals related to contaminated sites and Indigenous People in Canada and the US, and to capture a broader range of perspectives on the topic, a grey literature search was also conducted. Grey literature included multiple document types produced by all levels of government, academics, businesses and organizations, that are not controlled by commercial publishing (Mahood et al., 2014). The review used the search strategy 'SYMBALS' (a systematic review methodology blending active learning and snowballing), which uses backward snowballing to allow researchers to complement their set of relevant papers with additional sources such as grey literature (van Haastrecht et al., 2021). The grey literature search was conducted from January 2022 through to March 2022 inclusive.

Grey literature was yielded iteratively from relevant websites, governmental databases, organizations, and reference lists. Search terms were compiled from the authors' knowledge on the topic and information from previous searches. Notably, while we aimed to design a comprehensive search strategy for grey literature, the iterative and snowballing nature of this search likely misses key resources that may contain literature not captured here, and this is a limitation of the review. The search terms used fell into two main categories ("Indigenous People" and "Contaminated Sites") with the complete list available in Supplemental Materials (Table S1). News articles, reports, dissertations, and theses were found in ProQuest and included if relevant. Governmental websites, including Health Canada, Indigenous and Northern Affairs Canada, Environment and Climate Change Canada, US EPA and the Tribal Lands Assistance Center were searched. Information on Indigenous peoples and federal contaminated sites is often cited in technical reports and therefore, Google Scholar was searched, which has been cited as an acceptable database for grey literature searches (Haddaway et al., 2015). The search yielded a total of 21 selected grey literature articles (Excel Table S2), which included seven government documents (EPA, 2015; Government of Northwest Territories, 2021; Indigenous and Northern Affairs Canada, 2016; Michelsen, 2010; US Government Accountability Office, 2019; US Government Publishing Office, 2016; Woolford, 2017); four journal articles (non-peer-reviewed) (Castleden et al., 2017; Gallo, 2011; Gover, 2007; Lewis et al., 2015), one opinion article (Nolan, 2009), one thesis (Clark, 2020), three news articles (Bienkowski, 2012; Hansen, 2018; Indian Country Today, 2013), one research plan (Chan, 2019), and four conference materials (Ellison, 2012; Gailus, 2013; Hykin, 2016; Kent, 2016). Although not considered as grey literature in this review, information was also gathered from nine government webpages, to better understand the context of the findings (Table S2).

Federal data inventory search. Government websites (US EPA and Government of Canada) were used to identify available datasets for inclusion. Data on contaminated sites was publicly available in an Excel spreadsheet format for all federal contaminated sites on reserve land in Canada from the Federal Contaminated Sites Inventory (FCSI) (n= 6878) (Government of Canada, 2021) (Excel Table S3), which was downloaded on October 14, 2021. US federally managed and regulated sites were inventoried across several databases (Excel Tables S5-S7, Table S17). A search for US EPA Superfund sites categorized under "Native American Interest" (which includes sites that affect Native American peoples but are not on Tribal lands) from the Superfund Site Information database was run on October 4, 2021, and re-run on February 16, 2022 to include both the Superfund site data (n= 1236) (Excel Table S4) and an inventory of data on contaminants at Superfund sites (Excel Table S5) (EPA, 2021a). There was also some information on sites located on tribal lands available through the US EPA's 'Cleanups in my

Community' (CIMC) tool (EPA, 2023a) including brownfields, federal facilities, and Resource Conservation and Recovery Act (RCRA)-managed sites (total n=1969) (Excel Table S6). US EPA's Leaking Underground Storage Tanks (LUST) on Tribal Lands program identified an additional 1321 sites (EPA, 2023b) (Excel Table S7). All together, these searches of the Canadian and US databases resulted in a total of 11,404 records of contaminated site data for analysis. The information available within each dataset was variable. Canadian FCSI and Superfund datasets serve as the primary datasets for this review, as they include site location and Indigenous community affected, site status, risk classification and prioritization ranking, type of contaminant, and type of contaminant media. FCSI data included the management strategy and plan for the site, size of the area contaminated, the number of people living in proximity to the site, and expenditure estimates related to monitoring, remediation, assessment, and maintenance. Superfund data included indications of whether the contaminants were of human or ecological concern, the site type (i.e., source of contamination), and exposure control measures.

3.3.3 Data Extraction and Analysis

Included peer-reviewed literature were compiled into a data chart following a model outlined by the Joanna Briggs Institute Methodology for Scoping Reviews (Peters et al., 2015) (Excel Table S1). Per this guideline, the following data were extracted and charted: author(s), year of publication, country of origin, study purpose, location, study population (i.e., sample size), methodology, and key findings related to the scoping review questions. Additionally, data extracted that are specific to this study included: contaminated site name, contaminant name or contaminant class, contaminant media sampled, type (source) of contaminated site, Indigenous community of focus and/or territory of focus, the presence of a collaboration between Indigenous and non-indigenous researchers and/or Indigenous authorship, whether the article was a primary or secondary data source, whether the article collected qualitative or quantitative data, and the discipline in which the article was published. For quantitative data, descriptive statistics were used to map out and better understand the scope of the data. Qualitative data were iteratively analyzed to develop themes presented in the results section.

Data from both retrieved articles and federal databases were analyzed using Microsoft Excel Software (Microsoft 365 MSO (Version 2205))**,** and basic descriptive statistical analyses were run on these datasets. For example, data such as contaminants of focus, risk assessment information, and site locations were extracted and compared across data streams. Data was analyzed in answer to the three study objectives, with additional questions being developed iteratively as the data was explored. A narrative synthesis of qualitative data was integrated into this analysis. Complete datasets can be found in supplementary materials, which includes data extraction charts for peer-reviewed literature (Excel Table S1) and grey literature (Excel Table S2); and raw data retrieved from Canadian FCSI (Excel Table S3) and US EPA Superfund databases (Excel Tables S4-S7).

3.4 RESULTS

The themes identified from the thematic analysis of the data are organized according to this review's three objectives and presented in Box 3-1. Information available on contaminated sites and Indigenous peoples in Canada and the US included 51 peer-reviewed journal articles, 21 pieces of grey literature, and 11,404 contaminated site records from federal databases (Table 3-1). These sources provided data on the potential or actual contamination of the lands of 875 distinct Indigenous tribes and nations and indicated the presence of 440 different chemicals or chemical groups found at 4976 distinct contaminated sites. Peer-reviewed literature available on the topic has been published between 1996-2021. Of the 51 peer-reviewed articles, 37 were primary data sources (i.e., original data collection), while 14 were secondary, including reviews, historical reviews, and discussion papers. Of the articles collecting primary data, 26 collected quantitative data, three collected both qualitative and quantitative data, and eight collected qualitative data only. Throughout these sources, contamination of a wide variety of media, from soil, air, water, groundwater, and food to human biomarkers were described.

Box 3-1: Overview of themes identified from scoping review results
1. OBJECTIVE ONE: The relationship between contaminated sites and Indigenous Peoples, and their land and food systems *1.1 Indigenous communities and geographic patterns* *1.2 Contaminated sites, sources, and media* *1.3 Contaminated sites and Indigenous lands* *1.4 Contaminated sites and Indigenous food systems* *1.5 Contaminated sites and the health of Indigenous peoples* **2. OBJECTIVE TWO: Strategies, challenges, and successes for contaminated sites management on Indigenous lands** *2.1 Site management and classification processes* *2.2 Health risk assessment* *2.3 Risk management* *2.4 Long-term management* **3. OBJECTIVE THREE: Indigenous leadership and inclusion in contaminated sites management activities** *3.1 Collaborative research* *3.2 Collaborative site management* 3.3 *Traditional knowledge and contaminated sites*

Table 3-1: Meta-data from three data streams (systematic literature review, grey literature, and federal contaminated site databases)

Data	*Peer-reviewed Literature*	*Grey Literature* [a]	*Canadian Federal Contaminated Sites Inventory (FCSI)*	*US EPA Superfund and Cleanups Data*	*TOTAL*
Total # of records	51	21	6878	4526[b]	11 476
# of known active sites [c]	n/a	n/a	2428	701 (463 Superfund, 238 LUST)	3129
# of known archived sites [d]	n/a	n/a	2843	1856 (773 Superfund, 1083 LUST)	4699
# of suspected sites [e]	n/a	n/a	1607	n/a	1607
Indigenous [f] *communities identified*	41 (8 Canada, 30 US, 3 US and Canada)	11	576	299 (239 Superfund, 60 LUST)	875 [g]
# of contaminants identified	45	15	12	440	440 [g]

[a] Grey literature was collected iteratively using SYMBALs methodology [1], and therefore is not representative of the entire scope of grey literature on the topic
[b] Figure includes Superfund sites, RCRA (Resource Conservation and Recovery Act), Federal Facilities, Brownfields, and Leaking Underground Storage Tanks (LUST) (See supplemental materials Excel Tables S5-S7, and Table S17). Despite there being overlap between these programs, this number is likely an underestimation [2].
[c] "Active Sites": have not completed the process for addressing a contaminated site and continue to pose an environmental and/or financial liability to the federal government are classified as active [3]; US Data include only Superfund and LUST
[d] "Closed" or "Archived" sites are defined by federal governments as having shown acceptable levels of human and ecological risk by meeting national guidelines, remedial objectives have been achieved, and no further action is required [3]; US data include only Superfund and LUST
[e] A "suspected site" is one at which further assessment is required to determine if the site is 'contaminated' (i.e., remedial action may be required) [4]
[f] The literature review's definition of Indigenous included First Nations, Inuit, and Metis peoples in Canada, and all Native American peoples in the United States, including those residing in non-contiguous states; Canadian FCSI data was filtered by sites located on reserve land, and inventories the name of the Indigenous community that lives there; Superfund data specifies the Native American community which is affected by the site (with the site classified under "Native American Interest")
[g] duplicates removed

3.4.1 Objective 1: The relationship between contaminated sites and Indigenous Peoples, and their land and food systems

Indigenous communities and geographic patterns. Peer-reviewed literature described contaminated sites affecting 41 distinct Indigenous Tribes and Nations across Canada and the US (Table 3-1), with some literature focused on multiple Tribes or Nations. A total of 11 individual communities were the focus of grey articles, with the remaining grey articles focused on Indigenous Peoples in general as opposed to individual communities. In contrast, more communities were captured under the federal databases as the US EPA reported Superfund sites of interest to 239 Indigenous Tribes (EPA, 2021a), and 60 additional communities were listed in the LUST data (EPA, 2023b) (Excel Tables S4 and S7). Canada's FCSI included sites affecting 576 distinct Indigenous communities on 745 different reserve lands (Excel Tables S3 and S4) (Government of Canada, 2021). Notably, Canadian and US federal contaminated site data varied, in that Canada listed multiple "sites" with unique identifiers in the same geographic region, while Superfund tended to list one larger area with a single identifier. Of the 51 peer-reviewed journal articles that were included in the review, 31 were based in the US, 13 were based in Canada, and seven were based in both the US and Canada. In grey literature, the US EPA published a report in 2020 estimating that 146 605 Native American people live within one mile of a Superfund site, and 449 849 live within three miles (EPA, 2020). Canadian FCSI data provided an estimate of populations (which included Indigenous and non-Indigenous people) living near contaminated sites on reserves, totaling 2 096 197 people living within 1 km (Government of Canada, 2021). Canadian FCSI data also reported estimated sizes of the contaminated areas, which is the area of contaminated media that exceed environmental criteria (CCME, 2008). The estimates range from 0.0001 to 1,500,000 cubic square meters, with very small site estimates potentially related to a lack of available data (Government of Canada, 2021). Figure 3-3 displays contaminated site locations identified from the four data streams.

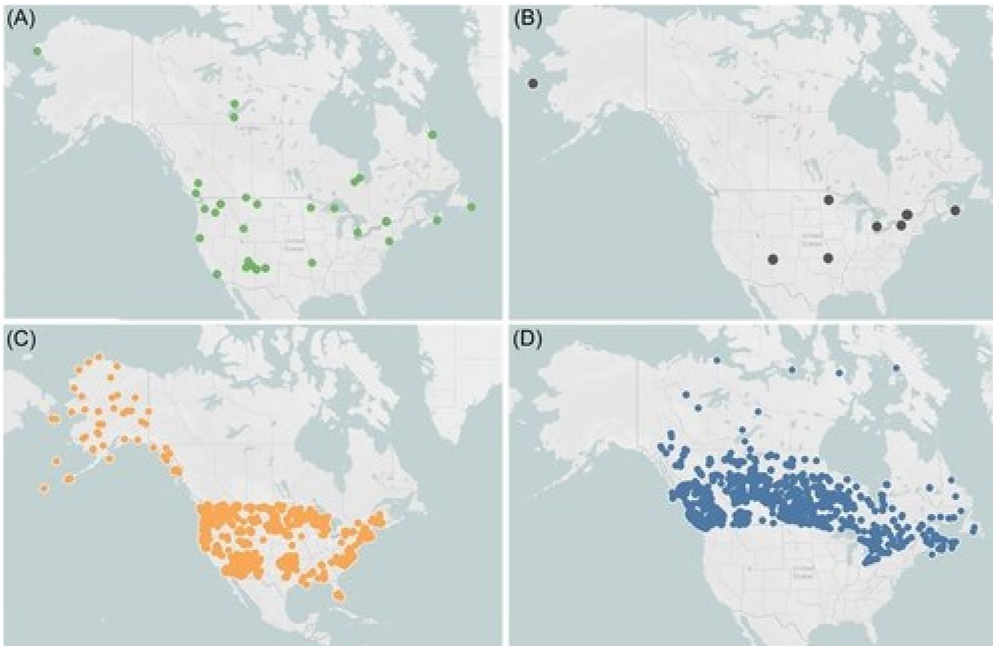

Figure 3-3: Co-location of Contaminated Sites affecting Indigenous Peoples based on a review of data from A) Site locations identified via the primary literature review; B) Site locations identified in grey literature; C) Site locations identified in US EPA Contaminated sites databases as being of "Tribal Interest" (both on and off reservations and trust lands) or "On Tribal Lands"; D) Site locations identified in Canadian Federal Contaminated Site Inventory Data (on-reserve). Each site is indicated with a dot (note: some site locations are the focus of more than one peer-reviewed article). The maps were generated using OpenStreet Maps and Tableau Software. The underlying database is available in the supplementary materials (Excel Tables S1-S7). For more information on Indigenous lands in Canada and the US, please visit the following government websites: Government of Canada Geoviewer: https://geo.aadnc-aandc.gc.ca/geoviewer-geovisualiseur/index-eng.html; US EPA EnviroAtlas: https://enviroatlas.epa.gov/enviroatlas/interactivemap/

Contaminated sites, sources, and media. Of the contaminated sites described in the 51 peer-reviewed articles, 25 were from mining activity, eight were industrial waste sites, six were hazardous waste sites, four were military radar, and one was from hydroelectric activities, with the remainder of unspecified origin (Excel Table S1). Ten grey articles were focused on specific contaminated sites, which included the mention of seven sites due to mining activities, two from industrial activities, one nuclear waste site, and one from an accidental spill. The US EPA reported on Superfund site types, including 159 due to manufacturing/processing/maintenance, 84 mining sites, 98 waste management sites, and 39 recycling sites (EPA, 2021a). However, we note that most of the sites (n=248) were classified as having "other" sources (EPA, 2021a). LUSTs contribute to 1321 contaminated sites requiring cleanup on Tribal lands in the US (EPA, 2023b). Canadian FCSI Data does not provide information on contaminant source (Government of Canada, 2021).

In the peer-reviewed literature, a total of 45 unique contaminants or contaminant groups were identified or discussed (Table 3-1). While most grey literature was focused on contaminated sites in general without referencing specific chemicals, eight articles referenced (but did not measure) specific contaminants of concern, which included lead, arsenic, PCBs, benzene, cadmium, formaldehyde, uranium, zinc, pentachlorophenol, dioxin, creosote, arsenic, antimony, lead, manganese, and vanadium. Superfund site data reported the measurement of 440 different contaminants or contaminant groups found at 296 contaminated sites, with lead, arsenic, and cadmium as the most common ones listed. Of these contaminants listed, 12% were flagged by US EPA as a potential ecological risk (EPA, 2021a). Canadian FCSI Data reported contaminant classes as opposed to single contaminants, for a total of 12 different contaminant classes found at 4680 contaminated sites (Table 3-1). The most commonly reported classes were petroleum hydrocarbons (PHCs), polycyclic aromatic hydrocarbons (PAHs), and metals, metalloids, and organometallics (Government of Canada, 2021). In Canadian FCSI Data, there were 2198 contaminated sites listed (~32%) without data on contaminants, and in Superfund site data there were 940 sites (~76%) without contaminant data.

Biological media, including human biomarkers and wildlife were the most common media tested for contaminants in peer-reviewed literature. Grey literature most often described the sampling of environmental media including water, food, and sediment, with one piece of grey literature describing the collection of samples for the measurement of human biomarkers. Both Superfund and FCSI datasets reported contaminant media tested, with soil being the most common in both databases, followed by groundwater (Table 3-2). Considering both biological and environmental media, there were several media utilized in scientific research that were not identified in federal site assessments. These include human biomarkers (Denham et al., 2005; Fitzgerald et al., 1996; Fitzgerald et al., 2004; Goncharov et al., 2008; Kegler & Malcoe, 2004; Kegler, Malcoe, et al., 2010; Rock et al., 2019; Tsuji et al., 2005), plants and plant foods (Fitzgerald et al., 1996; Fitzgerald et al., 2004; Garvin, 2018; Koch et al., 2013; Samuel-Nakamura et al., 2017; Sarkar et al., 2019), wildlife and wild game (Brown et al., 2014; Koch et al., 2013; Rock et al., 2019; Samuel-Nakamura et al., 2017), and tree bark (Flett et al., 2021).

Table 3-2: Number of contaminants reported by media type in peer-reviewed articles and federal site records.

Contaminant Media Type	# of contaminants detected per media in peer-reviewed articles [a] (% of total)	# of contaminants reported per media in FCSI data[b] (% of total)	# of contaminants reported per media in Superfund data[b] (% of total)
Soil (incl. surface soil)	4 (6.3%)	3493 (62.8%)	3817 (34.7%)
Groundwater	n/a	1022 (18.4%)	2618 (23.8%)
Sediment	3 (4.8%)	111 (2.0%)	1841 (16.8%)
Surface water	9 (14.3%)	133 (2.4%)	903 (8.2%)
Solid Waste	1 (1.6%)	Not reported	403 (3.7%)
Air	n/a	56 (1.0%)	184 (1.7%)
Other Media	46 (73%)	n/a	n/a
TOTAL #	63	5559	10 988

[a] To display data that is comparable to federal governmental databases, this column reflects the number of contaminants detected per media per peer-reviewed article collecting primary quantitative data. For a detailed chart on contaminants sampled including the number of samples taken in each study, see supplemental materials (Excel Table S1).

[b] Federal databases (both FCSI and Superfund) provided information on the name of contaminants or contaminant groups found at each site, and the media in which they were found. Notably, the databases do not indicate the number of samples taken per media or the contaminant level. This number therefore provides us with an idea of the prevalence at which each media is sampled, rather than the exact number of samples per media

Note: See Excel Tables S1, S3, and S5 for complete datasets (EPA, 2021a; Goncharov et al., 2008)

Contaminated sites and Indigenous lands. Six peer-reviewed studies focused on the assessment of contaminants found on Indigenous lands affected by contaminated sites (summarized in Table S4), and in five of these studies there was evidence of contaminant levels exceeding regulatory guidelines. A study on an abandoned mine waste site proximate to the lands of the Navajo Nation (Blue Gap Chapter, Arizona), revealed elevated levels of uranium (67-170 μg/L-1, US EPA reference value 30 μg/L-1) in spring water, and detected uranium (6,614 mg/kg−1), vanadium (15,814 mg/kg−1), and arsenic (40 mg/kg−1) in mine waste solids (Blake et al., 2015). Another study examined tree bark on the Spokane reservation (Washington), nearby the Midnight Mine Superfund site, finding a high geo-accumulation index for uranium and a moderate index for thorium (Flett et al., 2021). Uranium was also detected in stream sediments on Inuit Territory in Labrador, Canada, proximal to the Abandoned Kitts-U mine site (up to 214.46 mg/kg detected, exceeding the Canadian guideline reference value of 23 mg/kg) (Sarkar et al., 2019). Sediment toxicity tests in Inukjuak Inuit Territory (Saglek Bay, Labrador) near a military radar site revealed sediment PCB concentrations exceeding Canadian sediment quality guidelines by 41-fold (Brown et al., 2013). Local birds in Saglek Bay, the shorthorn sculpin and black guillemot, were found to be exposed to sediments with concentrations measuring 1000 ng/g within 3 km of a contaminated marine sediment site, exceeding the limits associated with risk to survival (750 ng/g for sculpin and 77 ng/g for guillemot) (Brown et al., 2013). Other studies examined the presence or origin of contaminants. For example, a study on the Yurok Indian Reservation's Klamath watershed (California) detected a wide variety of contaminants in water, including carbamates, dioxins/furans, mercury, microcystins, organochloride pesticides, and phenols including PCP and TCP (Middleton et al., 2019). The origin of copper contamination dispersed onto the land of the L'Anse Indian tribal lands

(Michigan) were confirmed to be from the Mass Mill Superfund close to the Keweenaw Peninsula in one study using sediment core dating (Kerfoot et al., 2020).

Contaminated sites and Indigenous food systems. Seven peer-reviewed articles examined contaminants and Indigenous peoples' food (both plant and wildlife) (Table S5) (Brown et al., 2014; Fitzgerald et al., 2004; Garvin, 2018; Koch et al., 2013; Rock et al., 2019; Samuel-Nakamura et al., 2017; Schmitt et al., 2006). A total of 58 varieties of plant and animal foods were sampled, including 42 plant species, four mushroom species, and 12 animal species. Seals that are a part of Inuit diets in Labrador, Canada were evidenced to contain PCBs and organochloride pesticides that exceeded adverse effects thresholds of 1.3 mg/kg (Brown et al., 2014). Hares, mushrooms, and wild berries at a variety of contaminated sites affecting First Nations in Canada were assessed for bioaccessible arsenic species, with the highest observed bioaccessibility in hare meat and mushrooms, and the lowest observed for berries and plants, through the results were highly variable between samples (Koch et al., 2013). Mutton consumed by Navajo Nation members in Arizona were found to exceed reference dietary intake levels for uranium, arsenic, cadmium, lead, molybdenum, and selenium (Rock et al., 2019; Samuel-Nakamura et al., 2017). In studies on the traditional foods of the Eight Tribes and Nations of Northeastern Oklahoma, fish and crayfish were found to contain lead and cadmium, posing a hazard to human consumers of carnivorous wildlife (lead consumption from crayfish up to 58.75 mg/kg/day (Toxicological Reference Value (TRV) 1.68), from carp up to 7.54 mg/kg/day; and cadmium from crayfish up to 1.66 mg/kg/day (TRV 1.47) (Schmitt et al., 2006), and 36 species of edible plants within a contaminated area were found to have significantly different levels of cadmium, lead, and zinc than plants outside of the contaminated area (Garvin, 2018). Overall, contaminants studied in food were primarily heavy metals (Garvin, 2018; Koch et al., 2013; Rock et al., 2019; Samuel-Nakamura et al., 2017; Schmitt et al., 2006), with one study examining PCBs and organochloride pesticides (Brown et al., 2014). Traditional foods and medicinal plants are not included as sampling media in Federal site data for Canada or the US (EPA, 2021a; Government of Canada, 2021).

Contaminated sites and the health of Indigenous peoples. Superfund data showed that 59% of contaminants found at Superfund sites were at levels that pose a risk to human health (EPA, 2021a). The Superfund database inventories 122 sites at which human exposures are "under control" (i.e., the exposure is under EPA limits or precautions have been put in place to prevent human exposure), while the human exposure status of 1075 sites remain unknown (EPA, 2021a).

In scholarly literature, a total of 3867 Indigenous participants were included across articles, with a total of 2224 participants in seven articles related to contaminant exposures and human health outcomes (summarized in Table S6), primarily from the Akwesasne Mohawk (Ontario, Quebec, and New York) (823 participants in 5 studies) and Navajo (Utah, New Mexico, and Arizona) (1304 participants in one study) Nations, and also from the Ramapough Lunaape Nation (New Jersey) (97 participants in one study) (Denham et al., 2005; Fitzgerald et al., 1996; Fitzgerald et al., 2004; Goncharov et al., 2008; Hund et al., 2015; Hwang et al., 2001; Meltzer et al., 2020). The majority of these articles examined PCBs (Denham et al., 2005; Fitzgerald et al., 1996; Fitzgerald et al., 2004; Goncharov et al., 2008; Hwang et al., 2001). A study conducted in the Mohawk community of Akwesasne evidenced the presence of PCBs in breast milk (Hwang et al., 2001) and serum (Fitzgerald et al., 2004) in a sample of 97 Akwesasne Mohawk women.

Among a sample of 138 Akwesasne Mohawk girls, low levels of serum lead (mean 0.49 ug/dL) were associated with significantly lower probability of having reached menarche, and serum PCBs (mean 0.12 ppb) were associated with a significantly higher probability of attaining menarche (Denham et al., 2005). Serum PCBs and pesticides were associated with heart disease in a sample of 335 Akwesasne Mohawk men (Goncharov et al., 2008). A large cohort study (1304 participants) examined chronic diseases in Navajo Nation members, finding self-reported kidney disease, diabetes, and hypertension to be highly prevalent in the population (43% of the sample had at least one of the three diseases, and 20% had at least two), and to be associated with self-reported exposure to uranium mine wastes (with a 28% higher risk of hypertension for those with an active exposure to mine wastes) (Hund et al., 2015).

Furthermore, five peer-reviewed articles explored the impacts of contaminated sites on Indigenous peoples using qualitative interviews (Table S7) (Cassady, 2007; Clausen et al., 2023; Hoover, 2013; Smith et al., 2010; Teufel-Shone et al., 2021). In the case of the Aamjiwnaang First Nation (Ontario), semi-structured interviews of 18 community members were conducted, with interviewees reporting fear related to contamination, unknown long-term health effects, and a changing relationship to the earth resulting from a large, contaminated site nearby ("Chemical Valley") (Smith et al., 2010). According to participants, these effects were not addressed by federal cleanup strategies, and continued to impact the community once the site was remediated (Smith et al., 2010). Loss of culture, language, and social connection was reported as an implication of Superfund sites affecting fishing activities in semi-structured interviews with 65 Akwesasne Mohawk community members (Hoover, 2013). Navajo Nation members in 12 at-home focus group interviews described that the Gold King Mine Spill (San Juan River, Northwestern US) was a continuation of colonial violence on Indigenous peoples which removed the community's agency and voice and forced their relocation (Teufel-Shone et al., 2021). An additional study of the Dine (Navajo) Peoples through focus groups described the harm to social relations across time and space, spiritual harm, and the community's focus on healing following the spill (Clausen et al., 2023). An ethnographic article that involved informal interviews with Inupiaq Inuit members (Alaska) described that the discovery of a contaminated site created suspicions about health effects such as cancer amongst the community (Cassady, 2007).

There are efforts described in grey literature to better understand the potential effects and impacts of contaminated sites on Indigenous peoples' health. One notable example is the Giant Mine Health Effects Monitoring Program, which monitors human biomarkers for Arsenic and other contaminants in the Ndilo and Dettah communities in Yellowknife, Northwest Territories and communicates these findings to communities (Chan, 2019). News articles in grey literature provided information on some Indigenous community members' perceptions of the health impacts of contaminated sites. For example, one article described a shift away from cultural practices due to a large contaminated site ("Chemical Valley") close to the Aamjiwnaang First Nation (Bienkowski, 2012), and another described the perceived threat of Superfund Sites to the overall health (including both cancer and non-cancer endpoints) of Native American people across the US (Hansen, 2018). A review article in the grey literature also described concerns of Native American communities on the potential effects of abandoned mine sites in the western US on child development (Lewis et al., 2015).

3.4.2 Objective 2: Strategies, challenges, and successes for contaminated sites management on Indigenous lands

Site management and classification processes. According to government documents in the grey literature, both US and Canadian contaminated site management programs follow a standard process for assessing, planning for, and remediating contaminated sites (Table S8). Contaminated sites on Indigenous lands are managed similarly to sites on non-Indigenous lands in North America, including the application of standardized risk assessment and management frameworks that fall under federal programs such as the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the US Department of Energy and Defense's Cleanup Programs in the US and Contaminated Sites Management Program (CSMP) in Canada (Contaminated Sites Management Working Group, 2000; EPA, 2021b). These programs provide guidelines for site classification and prioritization and outline a stepwise process for addressing federal contaminated sites.

Under these programs, 37.5% of Superfund sites are classified as "active" while the remainder have been "archived" (i.e.: remediated or assessed as not requiring remediation) in the federal data. Site status information was also available for LUSTs on Tribal lands, where 18% of sites were "Open" (EPA, 2023b). Similarly, 35.3% of Canadian sites are categorized as "active" while 23.4% are "suspected" and the remainder are "closed". FCSI data indicated the current stage of contaminated site management (Figure 3-4), with the largest proportion of active sites (n=1331) in the "detailed testing" stage. Superfund data reported on whether the site required "no further action/not eligible" (688 records), "referred to a cleanup program" (277 sites), or "assessment needed or ongoing" (62 sites). While it was not possible to categorize all 51 peer-reviewed articles by stages of contaminated site processes, these were tagged by the author based on the topic of focus, which was most commonly risk assessment (11 articles), environmental assessment (9 articles), risk management (9 articles), and socio-cultural impacts (10 articles), with fewer articles focused on post-remediation (3 articles) and long-term assessment/legacy impacts (1 article).

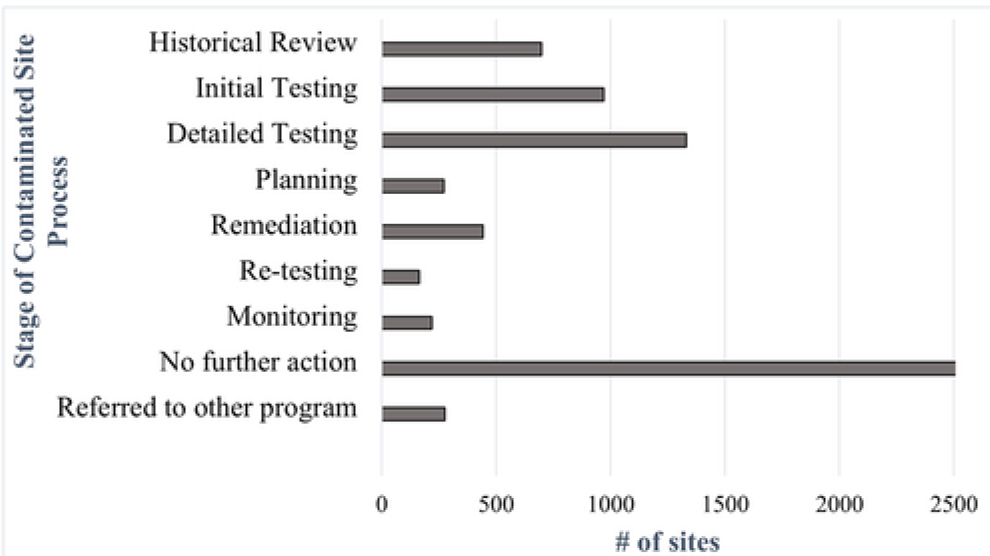

Figure 3-4: Bar graph representing the combined number of sites in Canada and the US (x-axis) at each stage of the contaminated sites management process (y-axis), as classified under federal management programs (CERCLA and CSMP) as of 04/10/2021 (Excel Tables S3 and S4).

Health risk assessment. In an effort to address the unique consumption patterns of subsistence populations, federal governments have published guidelines for more comprehensively assessing exposures to country foods, including in the context of frameworks such as the Human Health Risk Assessment (HHRA) and through the development of exposure scenarios (Harper, 2007; Health Canada, 2018). In peer-reviewed literature, the benefits and challenges of assessments for contaminated sites that include exposure scenarios for Indigenous communities were outlined in two primary and four secondary articles (Tables S9 and S10). Potential benefits were described in two case studies on the testing and validation of exposure scenarios related to hazardous waste contamination on the Umatilla Indian reservation (Oregon), and of uranium contamination on the Spokane reservation (Washington). These exposure scenarios were found to improve the holistic nature of risk assessments, which included the consideration of pre-site land use and socio-political factors associated with exposure, compared to generic risk assessments that do not measure community-specific exposure (Harper et al., 2012; Harper et al., 2002). Challenges to risk assessment were described in two peer-reviewed articles on the development of exposure scenarios for consumption patterns of the Confederated Tribes of the Umatilla Indian Reservation (Oregon) located near a Superfund (Department of Energy's Hanford Site) (Harris & Harper, 1997), and the validation of a risk assessment ingestion value by estimating soil ingestion by the Xeni Gwet'in First Nation (British Colombia) through the contaminated Chilko Watershed (Doyle et al., 2012). Both studies found inconsistencies between risks posed to Indigenous peoples and risks assessed in standard HHRAs, including soil ingestion values and exposures due to lifestyle factors, religious practices, and non-food exposures (Doyle et al., 2012; Harris & Harper, 1997). In qualitative research, interviews with 35 members of the Colombia river basin tribe (Umatilla, Oregon) highlighted that risk assessments in Indigenous communities measure risk on the same scales as non-Indigenous communities, despite evidence that contaminated sites create unique risks for Indigenous people that are not possible to quantify using traditional methods (Harris & Harper, 1997). Furthermore, two discussion articles critiqued standardized risk assessments due to a lack of consideration of cumulative effects of contaminants, incompatibility with tribal life ways (Holifield, 2012), the privileging of property owners and lack of benefit to Indigenous peoples, and the use of non-Indigenous definitions of health to define risks (Arquette et al., 2002). An article focused in the Akwesasne Mohawk community cited a lack of Indigenous involvement and resources allocated to the community as a major barrier to effective risk assessment (Arquette et al., 2002).

Grey literature evidenced risk assessments that were conducted for specific sites and communities, including for example an HHRA of legacy arsenic contamination as a response to concerns surrounding health risks from the Ndilo and Dettah (Dene) communities from exposure to contaminants from the Giant Mine (Yellowknife, Northwest Territories) (Government of Northwest Territories). According to government documents, under CERCLA and CSMP, health risk assessment is used to measure and quantify physical health risks and is part of the standardized process for contaminated site management. Notably, according to Canadian guidelines, conducting an HHRA typically requires the “hire of a qualified consultant with the necessary technical and scientific expertise to perform the work” (Contaminated Sites Management Working Group, 2000). In Canada, the National Classification System for Contaminated Sites is used to evaluate and classify sites based on the level of human and environmental risk posed by the site (Canadian Council of Ministers of the Environment, 2008). In Canadian FCSI Data, sites are ranked as either “High priority” (1016 site records), “Medium priority" (1198 site records), "Low priority" (491 site records), or "No priority for action" (429 site records) based on this system (Government of Canada, 2021). A site classified as "High priority" has imminent risks or documented adverse outcomes to both human and environmental health and are thus prioritized for risk management and remediation by the Canadian federal government (Canadian Council of Ministers of the Environment, 2008). The US EPA uses a similar tool, the Hazard Ranking System, to assign a quantitative value to the human and environmental risks posed by a site, which determines whether a Superfund site will be categorized under a "National Priorities List" (NPL) (EPA, 2017). The Superfund dataset categorized site records as "not NPL" (1022 records), "deleted NPL" (27 records), "removed from NPL" (one record), "proposed NPL" (nine records), "part of an NPL site" (46 records), or "final NPL" (131), indicating that 186 sites are of high priority (i.e., classified as "NPL") (EPA, 2021a). Thus, across Canadian and US federal datasets, there are 1202 sites that are classified as "high priority" due to human and environmental health risks (Chan, Fediuk, et al., 2021; Samuel-Nakamura et al., 2017).

Risk management. The management of risks related to contaminated sites in Canada and the US involves removing or reducing contaminants and limiting the use of contaminated media by affected communities. Risk management strategies are unique to each site, and involve input from regulators, site owners, policies, and local communities (Contaminated Sites Management Working Group, 2000; EPA, 2022d). Five peer-reviewed research articles tested various risk management strategies related to contaminated sites and Indigenous communities (Table S11). A study on risk mapping of contaminants on the lands of the Navajo Nation (Churchrock Chapter, New Mexico) and a survey of 151 community members found that the maps were helpful in avoiding the risk of consumption of contaminated food and water arising from the Churchrock Uranium Mine Site (deLemos et al., 2009). Another study cited the effectiveness of safety protocols (education on the proper handling of hazardous wastes) for nine Fort Albany Cree First Nation workers (Ontario) employed to clean-up the Mid-Canada Radar contaminated site, finding no significant burden of blood lead and PCBs before and after the clean-up (Tsuji et al., 2005). Three studies explored the influence of a lay-health advisor intervention on blood lead concentrations in children living in proximity to the Tar Creek Superfund Site, comparing results between members of the Eight Tribes and Nations of Northeastern Oklahoma and Non-Indigenous, white participants that lived near the site. Influences on lead exposure prevention behaviors were first assessed through qualitative interviews with 380 children's caregivers (Bland et al., 2005). Then, caregiver-child pairs (n=331 pairs, 43.5% Native American) participated in a cross-sectional study, measuring children's blood lead, and conducting structured caregiver interviews before and after a 2-year intervention in which caregivers were trained by local community health advisors on how to prevent children from blood lead poisoning (Bland et al., 2005; Kegler & Malcoe, 2004). The study found a reduction in blood lead before and after the intervention. Of Native American children, blood lead levels decreased significantly from time 1 (6.00 ug/dL) to time 2 (4.97 ug/dL), with no significant difference from the white control group. Another study was conducted at a third time point (4 years later), finding improved lead preventative behaviors (handwashing) in Indigenous participants (167 Indigenous and 213 white participants) (Kegler, Malcoe, et al., 2010). Another review article described a precautionary principle for risk management at the Zortman-Landusky Mine Superfund Site on the Fort Belknap Reservation (Montana), home to the Assiniboine and Gros

Ventre Tribes, in which caution was exercised in site management when risk was unknown (Emel & Krueger, 2003).

Five peer-reviewed articles described the use of consumption advisories to manage risks related to country foods. One article focused on the territories of the Ahahminquus community of the Mowachaht Tribe and the Sliammon people (British Colombia) and analyzed the use of Canadian health advisories and fishery closures related to contaminated sites near the Gold River and Powell River fisheries. The study found that the risks are comparable when switching from country foods to market foods, and that such advisories may be substituting one risk for another (Wiseman & Gobas, 2002). The relationship between country foods and market foods was also examined in two studies focused on the Inupiaq Inuit and the Akwesasne Mohawk Nation (Cassady, 2007; Hoover, 2013). Advisories for consuming traditional fish resulted in inadequate nutrition and cultural loss for the Akwesasne Mohawk Community (Hoover, 2013). An ethnographic field study focused on the Project Chariot abandoned waste site (Alaska) described that Inupiaq Inuit considered traditional foods to be curative and preventive of health issues, despite the issuance of advisories, and also described local knowledge (e.g., visually checking wild game for tumors) that could be used to determine if food was contaminated (Cassady, 2007). Two articles in grey literature discussed the contamination of subsistence food resources in Indigenous communities in general (Bienkowski, 2012; EPA, 2015), with one article noting that studies of contaminants most often result in avoidance advisories (Bienkowski, 2012). One government document described successful implementations of consumption advisories and community education related to contaminated foods on the lands of several Indigenous communities after receiving federal grants from the US EPA Superfund, including the

Akwesasne Mohawk Nation, Anishinaabe Nation (Great lakes region of Canada and the US), and Yurok tribe (California) (EPA, 2015).

Long-term management. In peer-reviewed literature, information in five review articles described that communities continue to face long-term site-related challenges after a site is remediated and closed by the federal government, evidencing the difference in perspectives on the definitions of remediation and recovery between communities themselves and government regulators (Moore-Nall, 2015; Sandlos & Keeling, 2016a; Sandlos & Keeling, 2016b; Smith et al., 2010; Teufel-Shone et al., 2021). For example, one article described that a contaminated site resulted in alienation of Navajo Nation members (Arizona) from their traditional territory, even after remediation (Sandlos & Keeling, 2016b). Another article described that there was a lack of acknowledgement of the legacy impacts of contaminated sites by federal governments, despite advocacy efforts by the Dettah and Ndilo communities (Yellowknife) on the remediation of the Giant Mine in Canada (Sandlos & Keeling, 2016a). Long-term health impacts were also described in the context of the Los Alamos National Laboratory Superfund Site and the Tribes of the Southwestern US (Moore-Nall, 2015). The Gold King Mine spill was described in one review article as contributing to a history of relocation and lack of agency and voice for the Navajo (Dine) Nation, with lasting impacts on the community (Teufel-Shone et al., 2021).

Three semi-quantitative studies examined post-remediation land uses of contaminated sites (Table S12) (Burger, 2004a, 2004b; LeClerc & Keeling, 2015). Two of these studies utilized structured interviews and found that future land use preferences differed by ethnicity, with participants that were members of the Shoshone Bannock tribe (Idaho) rating camping, fishing, hunting, and returning the land to Native people higher than white participants did.

Native American participants were generally underrepresented, however, in both studies (324 out of 1370 participants (23.6%) and 11 out of 254 participants (3.5%)) (Burger, 2004a, 2004b). Another study involving semi-structured interviews of 18 members of the Dene and Metis communities of Fort Resolution (Northwest Territories) found that since the establishment and closing of the Abandoned Pine Point Mine site, the community's land use patterns had changed from a land-based economy to a mixed economy reliant on wage labor, concluding that post-remediation land use would likely be different than land uses before the site's establishment (LeClerc & Keeling, 2015).

In conference materials in grey literature, one document recommended designing remediation processes at Superfund sites that can more effectively account for tribal needs to permanently restore the land for tribal uses (Michelsen, 2010). Another article described that due to the political and financial dynamics associated with site remediation on reserve land in Canada, the federal government will remediate a site at the lowest possible cost, which often does not meet the standard that Indigenous communities desire for post-remediation land use and development (Gailus, 2013). In federal datasets, both Superfund and FCSI categorized most of the sites under "no further action required", with 2408 such sites in Canada and 688 sites in the US (EPA, 2021a; Government of Canada, 2021).

3.4.3 Objective 3: Indigenous leadership and inclusion in contaminated sites management activities

Collaborative research. Of the included peer-reviewed literature, 22 articles described a collaboration between academic researchers and Indigenous people or communities (Arquette et al., 2002; Blake et al., 2015; Denham et al., 2005; Fitzgerald et al., 1996; Fitzgerald et al., 2004; Flett et al., 2021; Goncharov et al., 2008; Harper et al., 2012; Hoover, 2013, 2016; Kegler & Malcoe, 2004; Kegler, Malcoe, et al., 2010; Kegler, Rigler, et al., 2010; Meltzer et al., 2020; Middleton et al., 2019; Rock et al., 2019; Sarkar et al., 2019; Smith et al., 2010; Teufel-Shone et al., 2021). Several articles described collaborative efforts between academic institutions and Indigenous communities, as well as community-led research projects (deLemos et al., 2009; Goncharov et al., 2008; Harper et al., 2012; Hoover, 2013, 2016; Kegler & Malcoe, 2004; Kegler, Malcoe, et al., 2010; Kegler, Rigler, et al., 2010; Rock et al., 2019). Some of these studies described such collaborations as mutually beneficial. For example, interviews with 64 Akwesasne Mohawk members on their collaboration with SUNY Albany, a public University in New York State, revealed that there were benefits to members such as education, job skills, grant money and information; and to researchers such as better results, access to the community and help of Mohawk workers in the field (Hoover, 2016). One article analyzed contaminated site response networks consisting of the Eight tribes of Northeastern Oklahoma and non-Indigenous organizations, concluding that there was an increase in collaboration over time (Kegler, Rigler, et al., 2010). Peer-reviewed literature supports that federal grants help to facilitate multi-study projects in communities, as was the case with a collaborative project between the Eight tribes of Northeastern Oklahoma and the University of Oklahoma entitled ‘Tribal Efforts Against Lead’ (Kegler & Malcoe, 2004; Kegler, Malcoe, et al., 2010; Kegler, Rigler, et al., 2010). Challenges to collaboration were also described in peer-reviewed literature. For example, members of the Akwesasne Mohawk community described difficulties with time constraints due to the finite nature of academic funding, a lack of trust between researchers and community members, and inadequate science communication (Hoover, 2016). Two review articles described an ongoing need for greater funding and resources allocated to collaborative Indigenous-lead research on contaminated sites in the United States (Lewis et al., 2017; Moore-Nall, 2015).

Grey literature and government websites indicated that federal funding agencies in both the US and Canada provide support to Indigenous communities to address contaminated sites (EPA, 2022c; 2021), which has helped to build capacity and resilience (Environment and Climate Change Canada, 2019; Hoover, 2016; United States Government Accountability Office, 2020). Examples of such programs include the First Nations Environmental Contaminants Program (FNECP) and the Northern Contaminants Program (NCP) in Canada, and funds allocated under CERCLA in the US, including the Superfund State and Indian Tribe Core Program Cooperative Agreements (EPA, 2022b). Government reports in grey literature describe that tribes in the US have used EPA grants to support capacity building in environmental programs, and that First Nations in Canada have benefitted from the FNECP (Environment and Climate Change Canada, 2019; Hoover, 2016; United States Government Accountability Office, 2020). Many federal granting agencies require that Indigenous communities partner with academic institutions (Ferguson, 2021; Indigenous Services Canada, 2021; National Institute of Environmental Health Sciences, 2022), which is aligned with the aforementioned peer-reviewed literature from academics involving collaborative efforts with Indigenous communities. Furthermore, grey literature from governmental funding agencies and review papers described that the requirement to partner with an established scientist trained in an academic institution

(Ferguson, 2021; Indigenous Services Canada, 2021; National Institute of Environmental Health Sciences, 2022) limits the ability of many communities to obtain funding independently, and often results in a large amount of scientific and monetary resources focused on a single community (Ferguson, 2021; Fitzgerald et al., 1996; Fitzgerald et al., 2004; Hoover, 2013, 2016; Kegler & Malcoe, 2004; Kegler, Rigler, et al., 2010), while other sites have minimal support.

Collaborative site management. Peer-reviewed literature described the methods of evaluation collaborations between Indigenous communities and non-Indigenous institutions, such as in the example of the Fort Albany Cree First Nation, wherein a Canadian governmental framework was used to evaluate whether a true partnership existed between the Canadian government and First Nation (Sistili et al., 2006), Another review article described a diminished societal, governmental, academic, and political response to the Sequoyah Corporation fuels release and the Church Rock spill, nuclear releases affecting the Cherokee (Oklahoma) and Navajo (New Mexico) nations, compared to contaminating events of a similar scale affecting white communities (Brugge et al., 2007). One article described that Indigenous-led tourism of contaminated sites helped tribal Nations in Oklahoma to engage with empowerment and promote Indigenous perspectives around contaminated site crises and may lead to alternative approaches to remediation (Chew Bigby et al., 2022).

The US and Canadian federal governments have a “Duty to Consult”, which is a legal obligation to engage in government-to-government consultation with Indigenous peoples when actions and decisions may affect Indigenous interests. This does not cover external stakeholders such as private environmental managers, although the government can delegate aspects of the consultation process to these groups (Brideau, 2019; EPA, 2011a). Government documents are available in grey literature on inclusion and collaboration with Indigenous communities on contaminated site processes. Canada has a federal guidance document indicating areas in which inclusion of Indigenous communities may occur, recommending that Indigenous people assist with the contaminated site process, and providing potential opportunities for Indigenous involvement (for example, community members performing media sampling or hiring Indigenous companies to carry out remediation work) (Health Canada, 2010). Indigenous inclusion on Superfund site management follows a consultation process outlined by the US EPA, which defines the establishment, appropriateness and extent of consultation and collaboration with federally recognized tribes (EPA, 2011a). After determining that there was insufficient consultation with tribes at NPL Superfund sites (18 NPL sites with documented consultation, 7 of which had incomplete data), the US Government Accountability Office recommended documented consultation with tribes at 4 of the 9 steps in contaminated site processes, which excludes initial assessment, remedial design, construction completion and post-construction completion (i.e., maintenance and long term actions) and post-remediation development (US Government Accountability Office, 2019).

Non-governmental grey literature highlighted a lack of Indigenous inclusion in contaminated sites assessment and management processes voiced by Indigenous peoples. For example, a news article described that members of the Akwesasne Mohawk Tribe (New York) were dissatisfied with their opportunities to provide input into remediation decisions on the US EPA Alcoa Grasse River Superfund site (Indian Country Today, 2013). Chief Glenn Nolan of the Missanabie Cree First Nation (Ontario) outlined the lack of Indigenous involvement in the assessment, management, and communication of risks associated with abandoned mine sites (Nolan, 2009). The article proposed actions to improve consultation with Indigenous people, including community involvement beginning from initial assessment, accessible communication of results, and the development of ongoing collaborative monitoring strategies (Nolan, 2009). While not a dominant theme in literature or government guidance documents, successful instances of Indigenous leadership in contaminated site management are evidenced in grey literature sources (Assembly of First Nations, 2001; EPA, 1996; Tribal Superfund Working Group, 2022). The Tribal Superfund Working Group, for example, has published several tribe-led efforts to fight community contamination, such as in the case of the Fort Mojave Indian Tribe (California) remediation project on the Topock site (Tribal Superfund Working Group, 2022). First Nations in Canada have also demonstrated leadership in reclaiming and remediating land contaminated by abandoned mines, for example, by leading discussions among the Assembly of First Nations (Canada-wide) on remediation options (Assembly of First Nations, 2001).

Traditional knowledge and contaminated sites. In peer-reviewed literature, one discussion article described the negative impacts of historical subsumption of Traditional Knowledge within technical contaminated site processes in the remediation of the Giant Mine, Northwest Territories, which was seen by the local Dene First Nation, Dettah and Ndilo (Navajo) communities as an inadequate and inappropriate inclusion of Traditional Knowledge (Sandlos & Keeling, 2016a). The article also describes that Traditional Knowledge is most often formally considered in wildlife and ecological management, and less so considered in remediation design or implementation, despite the importance of historical memories of social, economic, and environmental change associated with remediation activities (Sandlos & Keeling, 2016a). This is consistent with grey literature from the Tribal Superfund Working Group, describing that remedial design is not a required component of consultation with Tribes (Tribal Superfund

Working Group, 2023). Traditional Knowledge's important role in understandings of contamination and remediation is described in the context of the Inupiaq Inuit and Project Chariot (an abandoned hazardous waste site) (Cassady, 2007), and in the collaboration of the Fort Albany Cree First Nation in the remediation of a Radar Line contaminated site (Sistilli et al., 2006).

The US EPA recently published a document outlining the 'integration' of Traditional Knowledge into environmental science, policy, and decision-making processes, in response to tribal leaders' requests to enhance its use (Woolford, 2017). In grey literature, Health Canada lists Traditional Knowledge as a component of exposure assessment within the HHRA (Health Canada, 2018), and in a recent update of their Northern Contaminated Sites Management Plan (NCSMP), pledged to increase inclusion of Traditional Knowledge studies into project planning and implementation, although the operational methods of this are not published (Crown-Indigenous and Northern Affairs Canada, 2021).

3.5 DISCUSSION

This scoping review identified, mapped, and analyzed the existing information on contaminated sites and Indigenous peoples in Canada and the US, seeking to address three main objectives outlined in the introduction. The research was motivated by observations that contaminated sites disproportionately affect Indigenous communities (Fernández-Llamazares et al., 2020; Lewis et al., 2017), and that there is limited research on the subject matter, without which a deeper understanding cannot be realized to permit evidence-based solutions. Findings from 51 scholarly articles, 21 grey literature pieces, and US and Canadian federal contaminated site databases revealed a disparate yet also vast and multi-disciplinary body of information on contaminated sites affecting Indigenous peoples and their health, land, and food systems. The number of articles identified from the systematic literature search covers a relatively small proportion of the total number of federal contaminated sites identified from federal inventories that affect Indigenous peoples. Of the peer-reviewed literature retrieved, a total of 35 sites were described, while there were 11,404 sites inventoried by federal governments. According to a report from the US National Research Council, there is no information on the total number of sites with elevated contaminant levels, and many facilities are considered 'closed' while contamination remains, evidencing that this total site count is likely much greater (National Research Council, 2013). Information on 875 Indigenous communities was identified through this review, while there exist in total 574 Tribal entities in the US (National Conference of State Legislators, 2020) and in Canada there are 630 First Nations and 53 Inuit communities (Crown-Indigenous and Northern Affairs Canada, 2022), as well as eight Metis Settlements (although the majority of Metis in Canada do not live on official settlements). Thus, the information available identifies a substantial amount (approximately 64%) of Indigenous communities that are potentially impacted by federal contaminated sites, though this is likely an underestimation.

3.5.1 Objective 1: The relationship between contaminated sites and Indigenous peoples, and their land and food systems

We note through our mapping exercise that site locations in the US and Canada are widespread, however the majority are south of the 60th parallel in Canada, and that data from the three evidence streams may largely underrepresent the geographic scope of contaminated sites that affect Indigenous peoples. A discussion specific to federal contaminated sites is applicable to Indigenous communities that live on federally managed land. Notably, due to regulatory and legal provisions under the Indian Act, Canadian FCSI data primarily concerns First Nations reserves, which are considered federal lands and are mostly inhabited by First Nations communities with the majority being south of the 60th parallel. Approximately 328,048 (40 %) of First Nations members in Canada live on reserve land according to the 2016 census (Indigenous Services Canada, 2020). Accordingly, FCSI data does not represent the total amount of contaminated sites affecting Indigenous communities in the country, and furthermore, Inuit and Metis communities are likely most underrepresented, as the majority do not live on reserve land (Gailus, 2013). Contaminated sites affecting Indigenous communities off-reserve are usually managed provincially or privately and thus are not captured by federal databases (Government of Canada, 1985). Similarly in the US, there are state-run remediation programs that are not captured in this review, which focused only on sites inventoried at the federal level, and this is a limitation. One grey literature article estimated that 1200 Indigenous communities in Canada have either an active mine, an abandoned mine site, or a mine exploration project on their territory, which is more than double the number of communities listed in the FCSI, demonstrating that there are many sites of potential or actual concern to Indigenous communities that are not tracked by the federal government (Nolan, 2009). Similarly, the US EPA does not have explicit criteria for determining how a Superfund Site is deemed to be of 'Native American Interest', and many sites are managed by non-federal governing bodies (termed 'cleanups') or private industries (EPA, 2023a; US Government Accountability Office, 2019), which are not included in Superfund data. Thus, the information presented in this review is limited to federally managed and inventoried contaminated sites affecting Indigenous peoples, but there are many sites managed under other jurisdictions not accounted for by federal governments or this review.

Contaminated sites are a pervasive issue for Indigenous communities in Canada and the US, with peer-reviewed literature and federal data indicating that the largest proportion of these sites arise from mining activity and industrial development on or adjacent to lands inhabited by Indigenous peoples. It is notable that there are many sites for which the source of contamination is unknown or not documented, which includes no contaminant source information for sites listed in the FCSI, brownfields, RCRA sites, and other cleanups in the US, as well as 248 (20%) Superfund site records. This review also found that there is minimal primary scientific research on the assessment of contamination from these sites (i.e., 45 unique contaminants measured in scientific studies in the literature compared to 440 unique contaminants measured and recorded in federal datasets), with most studies examining a single contaminant or a handful of contaminants.

Indigenous peoples are exposed to contaminants from contaminated sites through a variety of pathways, which includes inhalation, ingestion of drinking water and contaminated foods, and contact with contaminated soil and sediments. Literature on traditional food systems across Canada and the US evidences a diversity of exposure pathways unique to Indigenous communities, including for example through subsistence diets that include wild foods and medicinal plants (Chan, Fediuk, et al., 2021; Fernández-Llamazares et al., 2020; Jonasson et al., 2019). Notably, while peer-reviewed literature examined in this review documents the presence of a variety of contaminants in plant foods, wildlife, wild game, and human biomarkers (Brown et al., 2014; Denham et al., 2005; Fitzgerald et al., 1996; Fitzgerald et al., 2004; Flett et al., 2021; Garvin, 2018; Goncharov et al., 2008; Kegler & Malcoe, 2004; Kegler, Malcoe, et al., 2010; Koch et al., 2013; Rock et al., 2019; Samuel-Nakamura et al., 2017; Sarkar et al., 2019; Tsuji et al., 2005), information on these potential exposure sources is not captured in federal databases. As Indigenous peoples have unique consumption and land use patterns compared to the general population, exposures that are estimated based on generic federal frameworks employed in environmental assessments may be limited (Arquette et al., 2002; Cassady, 2007; Doyle et al., 2012; Harris & Harper, 1997; Holifield, 2012; Lewis et al., 2017). In a search of the US EPA Exposure Factors Handbook with the keyword "Native American", six tables are available pertaining to exposure to contaminants through the consumption of fish, but there is no information pertaining to any other exposure pathway (EPA, 2022a). This is one example of the paucity of data and classification tools for environmental assessments involving Indigenous peoples. Furthermore, it is surprising to find that human biomarkers and wildlife were the most commonly tested media throughout the retrieved peer-reviewed literature, as abiotic media and plants are less resource-intensive to sample, and generally do not pose human ethics concerns. We hypothesize that this finding may not be an accurate representation of the commonly tested media at contaminated sites, and rather may reflect a bias in peer-reviewed publications for unique or interesting results (Huesemann, 2002).

Our review found that the current body of literature on the potential health impacts of contaminated sites on Indigenous peoples is relatively small and lacks diversity. We identified seven peer-reviewed articles with quantitative data on health outcomes. Four of these articles were focused on the Mohawk community of Akwesasne (Table S6), and they documented a range of chronic and developmental outcomes associated with exposure to chemical stressors (primarily lead and PCBs), including early menarche, heart disease, kidney disease, diabetes, and hypertension. In four qualitative peer-reviewed studies, factors that are considered to be social and environmental determinants of Indigenous peoples' health including culture, spirituality, language, and community, were found to be adversely influenced by contaminated site exposure (Cassady, 2007; Hoover, 2013; Reading & Wien, 2009; Smith et al., 2010; Teufel-Shone et al., 2021). There was evidence that many Indigenous communities face long-term site-related challenges including a changing relationship to the earth, fear related to contamination, and cultural loss (Moore-Nall, 2015; Sandlos & Keeling, 2016b; Smith et al., 2010; Teufel-Shone et al., 2021). While these findings are not easily generalizable (i.e., they report on findings from 6 of 815 communities identified by federal databases who are potentially exposed to contaminated sites), they alert us to the possibility that health risks are elevated in such impacted communities and call for the need to scale-up research in this area. Finally, the literature captured in this review was generally limited to single or isolated chemical exposures, which provides a limited picture of contaminant related risks. In reality, multiple chemical and non-chemical factors interact to modify risks. For example, the need for consideration of non-chemical and socio-cultural factors in risk assessment has been called for by communities, such as the Mohawk community of Akwesasne (Arquette et al., 2002) and the Crow Tribe in Montana (Eggers et al., 2018). As another example, research from the First Nations people of the Innu Community found that genetics and diet play a role in mercury exposure (Canuel et al., 2006). We recommend that future research efforts involve the development and use of cumulative risk assessment methods for contaminated sites in Indigenous community contexts.

3.5.2 Objective 2: Strategies, challenges, and successes for contaminated sites management on Indigenous lands

According to federal data, the progression through the ten-step process for addressing a contaminated site can take decades (EPA, 2021a; Government of Canada, 2021). In the Canadian commissioner's report on federal contaminated sites, it was identified that there are more sites in the inventory than funds available for their management, and as a result only the highest priority sites are addressed (Ellison, 2012; Government of Canada, 2012). Furthermore, existing regulations make it difficult for communities to receive federal funding for site remediation unless they can prove that there is a high risk to human health and the environment, the assessment of which involves lengthy and expensive technical processes that are often outsourced to experts in academia and consulting, for example, that conduct HHRAs (Gailus, 2013). This results in a catch-22 in which the current regulatory and federal funding structure requires that Indigenous communities rely on outsourcing work, which thus limits internal capacity building.

This review found that contaminated sites are often addressed by federal governments, industry, and the scientific community as an isolated, technical problem, (Contaminated Sites

Management Working Group, 2000; EPA, 2011b; 2019) while they are considered by many Indigenous peoples as part of a broader legacy of environmental injustice (Cassady, 2007; Holifield, 2012; Lewis et al., 2017; Moore-Nall, 2015; Sandlos & Keeling, 2016b; Smith et al., 2010; Teufel-Shone et al., 2021). Federal risk assessment systems are useful to organize and prioritize site management, however according to our review these assessments are not necessarily aligned with the needs of the communities affected by them (Contaminated Sites Management Working Group, 2000). Furthermore, there is evidence in peer-reviewed literature to suggest that the use of generic "one-size-fits-all" risk assessment models (such as the HHRA in Canada and the Hazard Ranking System in the US) for contaminated sites lack benefit to Indigenous people (Arquette et al., 2002; Cassady, 2007; Doyle et al., 2012; Harris & Harper, 1997; Holifield, 2012; Lewis et al., 2017). Although sites are 'closed' when they are deemed to be at a safe risk level by federal governments, this review found evidence that Indigenous peoples face long-term and cumulative challenges that are not supported by governmental resources and funding (Moore-Nall, 2015; Sandlos & Keeling, 2016a; Sandlos & Keeling, 2016b; Smith et al., 2010; Teufel-Shone et al., 2021). This current western scientific approach contradicts Indigenous epistemologies such as the Seven Generations Principle, a Haudenosaunee philosophy followed by many Indigenous communities in Canada and the US, in which decision-making considers the well-being of people and environments seven generations into the future (Joseph, 2020). These factors point to the need for a holistic approach from both academics and governments which includes moving beyond physical and finite impacts to understanding contaminated sites as complex, multi-faceted issues with long term and cumulative effects (Brugge et al., 2007; Holifield, 2012; Nolan, 2009; Sandlos & Keeling, 2016a; Smith et al., 2010; Teufel-Shone et al., 2021). Recent evidence affirms the positive benefit of environmental risk assessments that privilege Indigenous epistemologies and leadership, a strategy which may help to respond to the lack of prioritization of Indigenous conceptualizations of risk in contaminated site assessment (Buell et al., 2020). Taken together, these factors point to a need for efficient, low-cost, Indigenous-led and community-based assessment methods that can rapidly predict health and environmental risks, which would help to build community capacity and improve the efficiency and cost-effectiveness of current assessment and prioritization processes. There is an increasing focus on the development of New Approach Methodologies (NAMs) for environmental risk assessment by industry, government, and academics (Government of Canada, 2017; Krewski et al., 2010), and these findings suggest that Indigenous perspectives should be considered and prioritized as a part of current NAMs development.

The majority of peer-reviewed research on risk management included in this review was focused on avoiding contaminant exposure (for example, through the use of fish consumption advisories), which is consistent with a global pollution management trend in which risk reduction through public and community level intervention is replaced with risk avoidance that emphasizes individual level action (Fernández-Llamazares et al., 2020). It is possible that this 'downstream' approach to management of contaminated sites perpetuates the vulnerability narrative that is often associated with Indigenous communities by Western knowledge systems, having the potential to hinder communities from gaining greater autonomy (Haalboom & Natcher, 2012). For example, the consumption of country foods contributes to better dietary quality and adequacy compared to store-bought foods (Batal et al., 2021; Kuhnlein & Chan, 2000; Luongo et al., 2020; Sheehy et al., 2015). This has been evidenced in the recent First Nations Food, Nutrition, and Environment Study (FNFNES), which examined nutrient adequacy and nutrient sources of adults among ninety-two First Nations communities across Canada and found that greater intakes of key nutrients occurred on days when traditional foods were eaten (Batal et al., 2021). Furthermore, in addition to nutritional value, there are many other benefits known with certainty by Indigenous communities to using traditional food systems, including lower food costs, physical activity in the harvest, and sociocultural values (i.e.: cultural identity, community sharing, children's education, nature conservation), which is well-cited in reviews on the topic (Kuhnlein & Chan, 2000; Luongo et al., 2020). Consumption advisories have shown to have a potentially negative impact on communities including the disruption of social, psychological, nutritional, economic, and lifestyle aspects, potentially outweighing the risks of contaminant exposure (Kuhnlein & Chan, 2000; McAuley & Knopper, 2011). However, we note that there are cases where contaminants pose high risks to health and risk avoidance strategies are necessary in the short-term, and in these situations, community involvement may help to improve the effectiveness of such strategies. A review on consumption advisories describes that through the involvement of First Nations community members in the process, risk management approaches such as traditional food consumption advisories can positively benefit First Nations communities (McAuley & Knopper, 2011). Examples of this include the reduction of PCB body burdens for community members of Akwesasne First Nation in the US and Canada, reduction of mercury levels in hair of Northern Quebec Cree peoples, and behavioral changes in fishing practices to protect against contaminant exposures in the Chesapeake Bay area in the US, all of which were achieved through effective and community-engaged communication strategies (McAuley & Knopper, 2011). The optimization of such strategies in federal contaminated sites risk management is an area for further research. We also note that a large proportion of peer-reviewed articles (n=20) identified in this review were problem-based (Blake et al., 2015; Brown et al., 2014; Brown et al., 2013; Cassady, 2007; deLemos et al., 2009; Denham et al., 2005; Fitzgerald et al., 1996; Fitzgerald et al., 2004; Goncharov et al., 2008; Hoover, 2013; Hund et al., 2015; Hwang et al., 2001; Kerfoot et al., 2020; Koch et al., 2013; Meltzer et al., 2020; Middleton et al., 2019; Rock et al., 2019; Samuel-Nakamura et al., 2017; Smith et al., 2010; Teufel-Shone et al., 2021) as opposed to solution-focused. Notably, we did not find any peer-reviewed articles focused on specific remediation strategies nor restoring land back to pre-contamination conditions. While the advancement from risk identification to remediation is complex and faces political, legal, and social barriers, this gap highlights an opportunity to advance research in this area with a focus on Indigenous-led remediation and management.

3.5.3 Objective 3: Indigenous leadership and inclusion in contaminated sites management activities

Most research we found on contaminated sites and Indigenous peoples involved a collaboration between western academics and Indigenous communities (Excel Table S1). Several such partnerships, such as in the case of the Mohawk community of Akwesasne and SUNY Albany, have shown to provide mutual benefit (Hoover, 2016). While our review notes that industry, government, and the scientific community acknowledge the importance of Indigenous inclusion (Arquette et al., 2002; Ellison, 2012; Gover, 2007; Holifield, 2012; Michelsen, 2010; Nolan, 2009; Sistili et al., 2006), we found minimal evidence of Indigenous leadership in the management of contaminated sites. Recent literature from Indigenous scholars on natural resource management describes that the inclusion of and collaboration with Indigenous peoples in environmental management is often tokenistic (Parsons et al., 2021). The contribution of

Indigenous voices in contaminated site management often occurs too late in the federal process, which perpetuates the "downstream" approach to site management discussed earlier. Vague definitions of 'inclusion' of Indigenous peoples in contaminated site management were found throughout this review (Health Canada, 2010; EPA, 2011a), which risks the subsumption of Indigenous peoples into non-Indigenous management bodies (Fernández-Llamazares et al., 2020). Our review found that non-Indigenous stakeholders are the powerholders in the management of contaminated sites and largely control collaborations with Indigenous communities. For example, US and Canadian federal guidance documents outline how, when, and to what extent Indigenous peoples are to be included or consulted, omitting Indigenous leadership in designing the process or management plan, and thus maintaining federal governments as the power-holders (EPA, 2011a; Health Canada, 2010). In the US, under CERCLA, tribes are excluded from identifying contaminated sites for inclusion on the Superfund National Priorities List, unless they have Treatment-as-State (TAS) jurisdiction (Gover, 2007; Michelsen, 2010). While site identification is a resource-intensive process for which the US EPA is overall responsible for, such clauses limit the possibility of participation for tribes who do not have access to such funds or TAS jurisdiction. Furthermore, based on our findings, the information related to contaminated site management on Indigenous lands was dominated by non-Indigenous voices. Government documents and academic articles included in this review were primarily authored by non-Indigenous persons, while Indigenous voices could be found in news articles and other web-based grey literature. To this effect, platforms that provide a seat at the decision-making table for federal contaminated sites may underrepresent Indigenous peoples. These findings are consistent with a recent review highlighting the inadequate inclusion of Indigenous peoples in environmental management in general (Fernández-Llamazares et al., 2020). Increased efforts and research to strategize Indigenous leadership and prioritize Indigenous epistemologies in relation to contaminated site management may contribute to more holistic and sustainable contaminated site management processes.

Results indicated that federal governments, Indigenous communities, and academics acknowledge a complex relationship between Indigenous Traditional Knowledge and western science in the context of contaminated site management, but that the approaches to achieving successful collaboration are a work in progress (EPA, 2011a; Health Canada, 2010; Reid et al., 2021; Sandlos & Keeling, 2016a; Woolford, 2017). Recent publications demonstrate that increased efforts are being made to collaborate with Traditional Knowledge holders, including through increased federal funding for collaborations, working groups, and discussions around Traditional Knowledge (EPA, 2011a; Sandlos & Keeling, 2016a; Woolford, 2017). However, federal and academic collaboration initiatives in contaminated site management and research processes may in some cases continue to perpetuate paternalistic environmental practices if left unchecked, as we note that "Using", "Incorporating", and "Integrating" Traditional Knowledge into western science and governance has been described in academic literature as a form of assimilation (Reid et al., 2021). New approaches that engage Indigenous and Western ways of knowing harmoniously may continue to propel collaborative engagement between knowledge systems forward. One such approach is Two-Eyed Seeing, a term popularized by Mi'kmaw Elder Dr. Albert Marshall, through which we "learn to see from one eye with the strengths of Indigenous knowledges and ways of knowing, and from the other eye with the strengths of mainstream knowledge, and we use both eyes together" (Reid et al., 2021). Through this approach, Indigenous environmental management goals related to contaminated sites may begin to be realized through collaboration between networks such as Indigenous leadership, Indigenous community members, industry, federal governments, and the scientific community.

3.5.4 Strengths and Limitations of This Review

This is the first scoping review to examine the issue of federal contaminated sites and Indigenous peoples, and thus addresses a research gap. Given the disparate evidence base, the compilation and synthesis of data and information from the scholarly literature, federal data and grey literature is a major strength of this review, as it enables us to see with greater diversity, clarity, and objectivity the many perspectives involved in the subject matter. The use of both published and unpublished literature promotes the consideration of voices that are not typically heard in academic literature. Furthermore, the study used a rigorous and transparent search strategy, following the PRISMA guideline for scoping reviews (Tricco et al., 2018). To ensure a comprehensive search of the diversity of literature, the search strategy included three databases as well as reference list searches.

Despite the strengths of this work, there are some notable limitations. Foremost is the lack of data. Across the three data streams we relied on, there is relatively minimal information (i.e., contaminant sources and types, human exposure pathways, health outcomes) on federal contaminated sites to which Indigenous peoples are potentially exposed. Within federal databases, there are 3138 contaminated sites listed without data on contaminants, and a small fraction of these inventoried sites have been the focus of peer-reviewed scientific studies. Despite evidence from federal databases on the presence of hundreds of contaminants (i.e., 440 unique contaminants identified) present at contaminated sites, there is almost no peer-reviewed research on community-specific exposures or health outcomes in the literature. Such a lack of knowledge (i.e., unknown potential health and environmental effects) has been shown to create stress and fear for many Indigenous communities, thereby changing their relationship with the land (Cassady, 2007; Hoover, 2013; Smith et al., 2010; Teufel-Shone et al., 2021).

Furthermore, due to the relatively small and disparate body of knowledge on the issue of contaminated sites and Indigenous peoples in North America, it is difficult to draw strong conclusions on the findings (though our findings are generally consistent). While there has been a legacy of challenges related to contaminated sites for Indigenous peoples, the documentation of federal contaminated sites is relatively recent, with the US Superfund program established in 1980 (Beins, 2015) and the Canadian Contaminated Sites Working Group established in 1995 (Contaminated Sites Management Working Group, 2000). According to our review, peer-reviewed literature available on the topic is dated as early as 1996. In addition, Indigenous peoples across Canada and the US are not a homogenous group, and the findings of this review are not generalizable. However, the nature of a scoping review is that it provides a general overview of current knowledge on the topic and can thus provide some motivation and direction for future research.

This study did not identify all relevant grey literature, but rather sought grey literature iteratively as the review developed per the SYMBALS protocol described in the methods (van Haastrecht et al., 2021). This strategy thus failed to identify all relevant resources that may have contained grey literature of relevance to our study, which could have led to the omission of valuable information. For example, the Interstate Technology and Regulatory Council provides guidance documents and training to tribal stakeholders in the field of groundwater remediation, which was not captured within our strategy (Interstate Technology Regulatory Council, 2023). Despite these limitations, this strategy helped with the management of the breadth of concepts within the broad topic of contaminated sites and Indigenous communities and enabled the gathering of multiple perspectives on a single concept, as opposed to single perspectives on multiple topics. The included literature was reviewed by one reviewer, and this is a major limitation. However, the relatively small body of literature available allowed for the selected articles to be reviewed with a high degree of detail and rigor by one reviewer. We also note that while we used the PRISMA-ScR checklist for scoping reviews to ensure a rigorous search strategy, it is possible that relevant papers were still missed. Finally, and as elaborated in the methods section (Positionality Statement), we note that this review was conducted by non-Indigenous academics, who have a limited understanding of the experiences of Indigenous peoples and communities. Every attempt was made to acknowledge this positionality and ensure transparency in the process of writing this article.

3.5.5 Future Recommendations

Overall, our review demonstrated a need for more holistic, upstream, and efficient approaches in the assessment, management, and research of contaminated sites that impact Indigenous lands and communities. We recommend that future works focus on community-specific approaches to site management and a re-conceptualization of risks related to contaminated sites that privileges Indigenous epistemologies; greater collaboration between networks such as the scientific community, Indigenous communities, and federal governments;

and a re-evaluation of current frameworks in which contaminated sites are addressed with Indigenous leadership at the forefront.

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3.7 References

Arquette, M., Cole, M., Cook, K., LaFrance, B., Peters, M., Ransom, J., Sargent, E., Smoke, V., & Stairs, A. (2002). Holistic risk-based environmental decision making: A native perspective. *Environmental Health Perspectives, 110*, 259-264. https://doi.org/10.1289/ehp.02110s2259

Arsenault, R., Bourassa, C., Diver, S., McGregor, D., & Witham, A. (2019). Including indigenous knowledge systems in environmental assessments: restructuring the process. *Global Environmental Politics, 19*(3), 120-132. https://doi.org/10.1162/glep_a_00519

Assembly of First Nations. (2001, May 11-13). *After the Mine: Healing Our Lands and Nations- a workshop on abandoned mines.* The Assembly of First Nations and MiningWatch Canada, Sudbury, Ontario. https://miningwatch.ca/sites/default/files/afn_mwc_workshop_report.pdf

Batal, M., Chan, H. M., Ing, A., Fediuk, K., Berti, P., Sadik, T., & Johnson-Down, L. (2021). Nutrient adequacy and nutrient sources of adults among ninety-two First Nations communities across Canada. *Canadian Journal of Public Health,* 112 (Suppl 1), 29-40. https://doi.org/10.17269/s41997-021-00490-y

Beins, K. & L., Stephen. (2015). *Superfund: Polluters pay so children can play*. Center for Health, Environment, and Justice. https://chej.org/wp-content/uploads/Superfund-35th-Anniversary-Report1.pdf

Bienkowski, B. (2012, October 12). Contaminated Culture: Native People Struggle with Tainted Resources. *Scientific American*. Retrieved September 14 2023 from https://www.scientificamerican.com/article/contaminated-culture-native-people-struggle-with-tainted-resources/

Blake, J. M., Avasarala, S., Artyushkova, K., Ali, A.-M. S., Brearley, A. J., Shuey, C., Robinson, W. P., Nez, C., Bill, S., Lewis, J., Hirani, C., Lezama Pacheco, J., & Cerrato, J. M. (2015). Elevated concentrations of U and co-occurring metals in abandoned mine wastes in a northeastern Arizona Native American community. *Environmental Science & Technology, 49*(14), 8506-8514. https://doi.org/10.1021/acs.est.5b01408

Bland, A. D., Kegler, M. C., Escoffery, C., & Malcoe, L. H. (2005). Understanding childhood lead poisoning preventive behaviors: the roles of self-efficacy, subjective norms, and perceived benefits. *Preventive Medicine, 41*(1), 70-78. https://doi.org/10.1016/j.ypmed.2004.10.010

Brideau, I. (2019). *The Duty to Consult Indigenous Peoples- Background Paper.* Legal and Social Affairs Division, Parliament of Canada. Retrieved November 3 2023 from https://lop.parl.ca/sites/PublicWebsite/default/en_CA/ResearchPublications/201917E

Briffa, J., Sinagra, E., & Blundell, R. (2020). Heavy metal pollution in the environment and their toxicological effects on humans. *Heliyon, 6*(9), e04691. https://doi.org/https://doi.org/10.1016/j.heliyon.2020.e04691

Brown, T. M., Fisk, A. T., Helbing, C. C., & Reimer, K. J. (2014). Polychlorinated biphenyl profiles in ringed seals (Pusa Hispida) reveal historical contamination by a military radar station in Labrador, Canada. *Environmental Toxicology and Chemistry, 33*(3), 592-601. https://doi.org/https://doi.org/10.1002/etc.2468

Brown, T. M., Kuzyk, Z. Z. A., Stow, J. P., Burgess, N. M., Solomon, S. M., Sheldon, T. A., & Reimer, K. J. (2013). Effects-based marine ecological risk assessment at a polychlorinated biphenyl-contaminated site in Saglek, Labrador, Canada. *Environmental Toxicology and Chemistry, 32*(2), 453-467. https://doi.org/https://doi.org/10.1002/etc.2070

Brugge, D., delemos, J. L., & Bui, C. (2007). The Sequoyah Corporation fuels release and the Church Rock spill: unpublicized nuclear releases in American Indian communities. *American Journal of Public Health, 97*(9), 1595-1600. https://doi.org/10.2105/AJPH.2006.103044

Buell, M.-C., Ritchie, D., Ryan, K., & Metcalfe, C. D. (2020). Using Indigenous and western knowledge systems for environmental risk assessment. *Ecological Applications, 30*(7), e02146. https://doi.org/https://doi.org/10.1002/eap.2146

Burger, J. (2004a). Recreational rates and future land-use preferences for four Department of Energy sites: consistency despite demographic and geographical differences. *Environmental Research, 95*(2), 215-223. https://doi.org/10.1016/j.envres.2003.10.005

Burger, J. (2004b). Study of the future land use of a contaminated site: Preferences versus potential use. *Remediation Journal: The Journal of Environmental Cleanup Costs, Technologies & Techniques, 14*(4), 97-110. https://doi.org/10.1002/rem.20024

Canadian Council of Ministers of the Environment (CCME) (2008). *National Classification System for Contaminated Sites- Guidance Document*. https://www.ccme.ca/en/res/ncscs_guidance_e.pdf

Canadian Geographic. Metis Settlements and Farms. In *Indigenous People's Atlas of Canada*. Canadian Geographic. Accessed September 14, 2023. https://indigenouspeoplesatlasofcanada.ca/article/metis-settlements-and-farms/

Canuel, R., Grosbois, S. B. d., Atikessé, L., Lucotte, M., Arp, P., Ritchie, C., Mergler, D., Chan, H. M., Amyot, M., & Anderson, R. (2006). New evidence on variations of human body burden of methylmercury from fish consumption. *Environmental Health Perspectives, 114*(2), 302-306. https://doi.org/doi:10.1289/ehp.7857

Cassady, J. (2007). A tundra of sickness: the uneasy relationship between toxic waste, TEK, and cultural survival. *Arctic Anthropology, 44*(1), 87-97.

Castleden, H., Bennett, E., Lewis, D., & Martin, D. (2017). " Put It Near the Indians": Indigenous Perspectives on Pulp Mill Contaminants in Their Traditional Territories (Pictou Landing First Nation, Canada). *Progress in Community Health Partnerships: Research, Education, And Action, 11*(1), 25-33. doi:10.1353/cpr.2017.0004

Chan, H. M. (2019). *Health Effects Monitoring Program in Ndilo, Dettah, and Yellowknife.* Health Effects Monitoring Program. Retrieved November 3 2023 from https://ykhemp.ca/research-plan/.

Chan, H. M., Fediuk, K., Batal, M., Sadik, T., Tikhonov, C., Ing, A., & Barwin, L. (2021). The First Nations Food, Nutrition and Environment Study (2008–2018)—rationale, design, methods and lessons learned. *Canadian Journal of Public Health, 112*(1), 8-19. https://doi.org/10.17269/s41997-021-00480-0

Chan, H. M., Singh, K., Batal, M., Marushka, L., Tikhonov, C., Sadik, T., Schwartz, H., & Fediuk, K. (2021). Levels of metals and persistent organic pollutants in traditional foods consumed by First Nations living on-reserve in Canada. *Canadian Journal of Public Health, 112*(1), 81-96. DOI: 10.17269/s41997-021-00495-7

Chew Bigby, B., Hatley, E., & Jim, R. (2022). The potential of toxic tours: Indigenous perspectives on crises, relationships, justice and resurgence in oklahoma indian country. *Journal of Sustainable Tourism*, 1-22. https://doi.org/10.1080/09669582.2022.2116642

Clark, T. (2020). *A Comparison of Tribal Sovereignty, Self-Determination, Environmental Justice at the EPA's Onondaga Lake and Superfund Sites.* [Master's Thesis, City University of New York]. CUNY Academic Works. https://academicworks.cuny.edu/gc_etds/3739/

Clausen, R. J., Chief, C., Teufel-Shone, N. I., Begay, M. A., Charley Jr, P. H., Beamer, P. I., Anako, N., & Chief, K. (2023). Diné-centered research reframes the Gold King Mine Spill: Understanding social and spiritual impacts across space and time. *Journal of Rural Studies, 97*, 449-457. https://doi.org/10.1016/j.jrurstud.2022.12.021

Contaminated Sites Management Working Group (2000). *Federal approach to contaminated sites*. Government of Canada. Retrieved September 14, 2023 from https://www.canada.ca/en/environment-climate-change/services/federal-contaminated-sites/federal-approach.html

Coté, C. (2016). "Indigenizing" food sovereignty. Revitalizing Indigenous food practices and ecological knowledges in Canada and the United States. *Humanities, 5*(3), 57. https://doi.org/10.3390/h5030057

Crown-Indigenous and Northern Affairs Canada. (2021). *Evaluation of the Northern Contaminated Sites Program*. Government of Canada. https://www.rcaanc-cirnac.gc.ca/DAM/DAM-CIRNAC-RCAANC/DAM-AEV/STAGING/texte-text/ev_ncsp21_1628679495032_eng.pdf

Crown-Indigenous and Northern Affairs Canada. (2022). *Indigenous Peoples and Communities*. Crown-Indigenous and Northern Affairs Canada. Retrieved September 14, 2023 from https://www.rcaanc-cirnac.gc.ca/eng/1100100013785/1529102490303

Damman, S., Eide, W. B., & Kuhnlein, H. V. (2008). Indigenous peoples' nutrition transition in a right to food perspective. *Food Policy, 33*(2), 135-155. https://doi.org/https://doi.org/10.1016/j.foodpol.2007.08.002

deLemos, J. L., Brugge, D., Cajero, M., Downs, M., Durant, J. L., George, C. M., Henio-Adeky, S., Nez, T., Manning, T., Rock, T., Seschillie, B., Shuey, C., & Lewis, J. (2009). Development of risk maps to minimize uranium exposures in the Navajo Churchrock mining district. *Environmental Health, 8*(1), 29. https://doi.org/10.1186/1476-069X-8-29

Denham, M., Schell, L. M., Deane, G., Gallo, M. V., Ravenscroft, J., & DeCaprio, A. P. (2005). Relationship of lead, mercury, mirex, dichlorodiphenyldichloroethylene, hexachlorobenzene, and polychlorinated biphenyls to timing of menarche among Akwesasne Mohawk girls. *Pediatrics, 115*(2), e127-134. https://doi.org/10.1542/peds.2004-1161

Doyle, J. R., Blais, J. M., Holmes, R. D., & White, P. A. (2012). A soil ingestion pilot study of a population following a traditional lifestyle typical of rural or wilderness areas. *Science of the Total Environment, 424*, 110-120. https://doi.org/10.1016/j.scitotenv.2012.02.043

Eckert, L. E., Claxton, N. X., Owens, C., Johnston, A., Ban, N. C., Moola, F., & Darimont, C. T. (2020). Indigenous knowledge and federal environmental assessments in Canada: applying past lessons to the 2019 impact assessment act. *Facets, 5*(1), 67-90. https://doi.org/10.1139/facets-2019-0039

Eggers MJ, Doyle JT, Lefthand MJ, Young SL, Moore-Nall AL, Kindness L, Medicine RO, Ford TE, Dietrich E, Parker AE, Hoover JH, Camper AK. Community engaged cumulative risk assessment of exposure to inorganic well water contaminants, Crow Reservation, Montana. *International Journal of Environmental Research and Public Health*. 2018 Jan 5;15(1):76. doi: 10.3390/ijerph15010076

Ellison, M. (2012, September 26). *Development of Aboriginal Lands: Successes, risks and environmental concerns respecting contaminated sites*. Ratcliff and Company. Pacific Business and Law Institute, Vancouver, BC. https://www.ratcliff.com/wp-content/uploads/2020/10/Development-Of-Aboriginal-Lands-Successes-Risks-And-Environmental-Concerns-Respecting-Contaminated-Sites-Ratcliff.pdf

Emel, J., & Krueger, R. (2003). Spoken but not Heard: The promise of the precautionary principle for natural resource development. *Local Environment, 8*, 9-25. DOI: 10.1080/13549830306676

Engwa, G. A., Ferdinand, P. U., Nwalo, F. N., & Unachukwu, M. N. (2019). Mechanism and health effects of heavy metal toxicity in humans. *Poisoning in the Modern World, 10, 70-90*. DOI: 10.5772/intechopen.82511

Environment and Climate Change Canada. (2019, July 24). *Federal Contaminated Sites: Success Stories*. Environment and Climate Change Canada. Retrieved September 14, 2023 from https://www.canada.ca/en/environment-climate-change/services/federal-contaminated-sites/success-stories.html#kitasoo

EPA. (1996). *Third National Tribal Conference on Environmental Management*. US Environmental Protection Agency. Solid Waste and Emergency Response. https://nepis.epa.gov/Exe/ZyPDF.cgi/10000ZLB.PDF?Dockey=10000ZLB.PDF

EPA (2011a). *EPA Policy on Consultation and Coordination with Indian Tribes*. US Environmental Protection Agency. https://www.epa.gov/sites/default/files/2013-08/documents/cons-and-coord-with-indian-tribes-policy.pdf

EPA (2011b). *This is Superfund A community Guide to EPA's Superfund Program*. US Environmental Protection Agency. http://www7.nau.edu/itep/main/hazsubmap/docs/CERCLA/ThisIsSuperfundACommunityGuideToEPAsSuperfundProgram9.13.11.pdf

EPA (2015). *A Decade of Tribal Environmental Health Research: Results and Impacts from EPA's Extramural Grants and Fellowship Programs*. US Environmental Protection Agency Office for Research and Development. https://www.epa.gov/sites/default/files/2015-08/documents/results-impacts.pdf

EPA (2017). *Revised HRS Final Rule, 40 CFR 300*. US Environmtental Protection Agency. https://semspub.epa.gov/work/HQ/100002489.pdf

EPA (2020). *Population Surrounding 1857 Superfund Remedial Sites*. US Environmental Protection Agency. https://www.epa.gov/sites/default/files/2015-09/documents/webpopulationrsuperfundsites9.28.15.pdf

EPA (2021a). *Search Superfund Site Information.* [Data set]. US Environmental Protection Agency. Retrieved February 16, 2022 from https://cumulis.epa.gov/supercpad/cursites/srchsites.cfm

EPA (2021b). *Contaminated Land*. US Environmental Protection Agency. Retrieved September 14 2023 from https://www.epa.gov/report-environment/contaminated-land#roe-indicators

EPA (2022a). *EPA ExpoBox* [Database]. EPA Expobox. https://cfpub.epa.gov/ncea/risk/expobox/efhTableSearch.cfm

EPA (2022b). *Land Cleanup Funding Authorities Available to Tribal Governments*. Retrieved September 14, 2023 from https://www.epa.gov/tribal-lands/land-cleanup-funding-authorities-available-tribal-governments-0

EPA (2022c). *Land Cleanup Funding Authorities Available to Tribal Governments*. US Environmental Protection Agency. Retrieved May 27, 2022 from https://www.epa.gov/tribal-lands/land-cleanup-funding-authorities-available-tribal-governments-0

EPA (2022d). *Risk Management*. US Environmental Protection Agency. Retrieved May 30, 2022 from https://www.epa.gov/risk/risk-management

EPA (2023a). *Cleanups in My Community (CIMC)- Cleanups and Grants Listings Page.* US Environmental Protection Agency. [Data Set]. Retrieved July 4, 2023 from https://cimc.epa.gov/ords/cimc/f?p=CIMC:LIST

EPA (2023b). *Tribal UST and LUST Data*. [Data set]. Retrieved July 3, 2023 from https://www.epa.gov/ust/tribal-ust-and-lust-data

Ferguson, K. (2021). Indigenous environmental health research secures $1.3M grant. *Western News*. Retrieved September 14 2023 from https://news.westernu.ca/2021/08/indigenous-environmental-health-research-secures-1-3m-grant/

Fernández-Llamazares, Á., Garteizgogeascoa, M., Basu, N., Brondizio, E. S., Cabeza, M., Martínez-Alier, J., McElwee, P., & Reyes-García, V. (2020). A State-of-the-Art review of Indigenous peoples and environmental pollution. *Integrated Environmental Assessment and Management, 16*(3), 324-341. https://doi.org/https://doi.org/10.1002/ieam.4239

Fitzgerald, E. F., Brix, K. A., Deres, D. A., Hwang, S.-A., Bush, B., Lambert, G., & Tarbell, A. (1996). Polychlorinated biphenyl (PCB) and dichlorodiphenyl dichloroethylene (DDE) exposure among Native American men from contaminated Great Lakes fish and wildlife. *Toxicology and Industrial Health, 12*(3-4), 361-368. https://doi.org/10.1177/074823379601200308

Fitzgerald, E. F., Hwang, S.-A., Langguth, K., Cayo, M., Yang, B.-Z., Bush, B., Worswick, P., & Lauzon, T. (2004). Fish consumption and other environmental exposures and their associations with serum PCB concentrations among Mohawk women at Akwesasne. *Environmental Research, 94*(2), 160-170. https://doi.org/https://doi.org/10.1016/S0013-9351(03)00133-6

Flett, L., McLeod, C. L., McCarty, J. L., Shaulis, B. J., Fain, J. J., & Krekeler, M. P. S. (2021). Monitoring uranium mine pollution on Native American lands: Insights from tree bark particulate matter on the Spokane Reservation, Washington, USA. *Environmental Research, 194*, 110619. https://doi.org/https://doi.org/10.1016/j.envres.2020.110619

Gailus, J. (2013). *Management of Contaminated Sites on Indian Reserve Lands.* Site Remediation in British Colombia Conference, Vancouver. Retrieved September 14 2023 from https://www.dgwlaw.ca/wp-content/uploads/2014/12/Site_Remediation_Conference_Paper.pdf

Gallo, M. (2011). From wood treatment to unequal treatment: The story of the St. Regis Superfund site. *Law & Inequity, 29*, 175. Retrieved September 14 2023 from https://scholarship.law.umn.edu/cgi/viewcontent.cgi?article=1163&context=lawineq

Garvin, E. M., Bridge, Cas F, Garvin, Meredith S. (2018). Edible wild plants growing in contaminated floodplains: implications for the issuance of tribal consumption advisories within the Grand Lake watershed of northeastern Oklahoma, USA. *Environmental Geochemistry and Health, 40*(3), 999-1025. https://doi.org/10.1007/s10653-017-9960-3

Goncharov, A., Haase, R. F., Santiago-Rivera, A., Morse, G., McCaffrey, R. J., Rej, R., & Carpenter, D. O. (2008, 2008/02/01/). High serum PCBs are associated with elevation of serum lipids and cardiovascular disease in a Native American population. *Environmental Research, 106*(2), 226-239. https://doi.org/https://doi.org/10.1016/j.envres.2007.10.006

Gover, L. (2007). Twenty years later-Tribes and the Superfund program. *Natural Resources & Environment, 21*(3), 48-53. http://www.jstor.org/stable/40924830.

Government of Alberta. (2023). *2021 Census of Canada.* Retrieved November 3 2023 from https://open.alberta.ca/dataset/487a7294-06ac-481e-80b7-

5566692a6b11/resource/257af6d4-902c-4761-8fee-3971a4480678/download/tbf-2021-census-of-canada-indigenous-people.pdf

Government of Canada (1985). *Indian Act. R.S.C., 1985, c. I-5*. Justice Laws Website. Retrieved September 14 2023 from https://laws-lois.justice.gc.ca/eng/acts/i-5/fulltext.html

Government of Canada. (2012). *Report of the Commissioner of the Environmental and Sustainable Development- Federal Contaminated Sites and Their Impacts*. Retrieved September 14 2023 from http://www.oagbvg.gc.ca/internet/English/parl_cesd_201205_03_e_36775.html#hd5b,

Government of Canada. (2017). *Committee report- November 16-17, 2016.* Chemicals Management Plan Science Committee. Retrieved September 14 2023 from https://www.canada.ca/en/health-canada/services/chemical-substances/chemicals-management-plan/science-committee/meeting-records-reports/committee-report-november-16-17-2016.html

Government of Canada. (2019). *Action plan for contaminated sites*. Government of Canada. Retrieved May 24 2022 from https://www.canada.ca/en/environment-climate-change/services/federal-contaminated-sites/action-plan.html

Government of Canada. (2021). *Federal Contaminated Sites Inventory*. [Data set] Retrieved October 14 2021 from https://www.tbs-sct.gc.ca/fcsi-rscf/home-accueil-eng.aspx

Government of Northwest Territories. (2021). *Human Health Risk Assessment for Legacy Arsenic Contamination Around Yellowknife- Plain Language Summary*. https://www.enr.gov.nt.ca/sites/enr/files/resources/arsenic_human_health_risk_assessment_summary_june_2021_0.pdf

Gunn K. & O'Neil, C. (2021, January 20). *Indigenous Law and Canadian Courts*. First Peoples' Law. Retrieved September 14 2023 from https://www.firstpeopleslaw.com/public-education/blog/indigenous-law-canadian-courts

Haalboom, B., & Natcher, D. C. (2012). The power and peril of "vulnerability": Approaching community labels with caution in climate change research. *Arctic*, 319-327. https://www.jstor.org/stable/41758938

Haddaway, N. R., Collins, A. M., Coughlin, D., & Kirk, S. (2015). The role of Google Scholar in evidence reviews and its applicability to grey literature searching. *PLoS ONE, 10*(9), e0138237. https://doi.org/10.1371/journal.pone.0138237

Hansen, T. (2018, September 13). Kill the Land, Kill the People: There Are 532 Superfund Sites in Indian Country! *Indian Country Today*. Retrieved September 14 2023 from https://ictnews.org/archive/kill-the-land-kill-the-people-there-are-532-superfund-sites-in-indian-country?redir=1

Harper, B. (2007). *Traditional Tribal Subsistence Exposure Scenario and Risk Assessment Guidance Manual*. https://health.oregonstate.edu/sites/health.oregonstate.edu/files/research/pdf/tribal-grant/exposure_scenario_and_risk_guidance_manual_v2.pdf

Harper, B., Harding, A., Harris, S., & Berger, P. (2012). Subsistence exposure scenarios for tribal applications. *Human and Ecological Risk Assessment: An International Journal, 18*(4), 810-831. https://doi.org/10.1080%2F10807039.2012.688706

Harper, B. L., Flett, B., Harris, S., Abeyta, C., & Kirschner, F. (2002). The Spokane Tribe's multipathway subsistence exposure scenario and screening level RME. *Risk Analysis, 22*(3), 513-526. https://doi.org/10.1111/0272-4332.00047

Harris, S. G., & Harper, B. L. (1997, Dec). A Native American exposure scenario. *Risk Analysis, 17*(6), 789-795. https://doi.org/10.1111/j.1539-6924.1997.tb01284.x

Health Canada. (2010). *A Guide to Involving Aboriginal Peoples in Contaminated Sites Managament*. Retrieved September 14 2023 from https://publications.gc.ca/collections/collection_2011/sc-hc/H128-1-10-628-eng.pdf

Health Canada. (2018). *Guidance for evaluating human health impacts in environmental assessment: country foods*. Retrieved September 14 2023 from https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidance-evaluating-human-health-impacts-country-foods.html

Holifield, R. (2012). Environmental justice as recognition and participation in risk assessment: Negotiating and translating health risk at a Superfund site in Indian country. *Annals Of The Association Of American Geographers, 102*(3), 591-613.

Hoover, E. (2013). Cultural and health implications of fish advisories in a Native American community. *Ecological Processes, 2*(1), 1-12. https://doi.org/10.1186/2192-1709-2-4

Hoover, E. (2016). " We're not going to be guinea pigs;" Citizen science and environmental health in a native american community. *Journal of Science Communication, 15*(1), A05. https://doi.org/10.22323/2.15010205

Huesemann, M. H. (2002). The inherent biases in environmental research and their effects on public policy. *Futures,* 34(7), 621-633. https://doi.org/10.1016/S0016-3287(02)00004-6

Hund, L., Bedrick, E. J., Miller, C., Huerta, G., Nez, T., Ramone, S., Shuey, C., Cajero, M., & Lewis, J. (2015). A Bayesian framework for estimating disease risk due to exposure to uranium mine and mill waste on the Navajo Nation. *Journal of the Royal Statistical Society: Series A (Statistics in Society), 178*(4), 1069-1091. https://www.jstor.org/stable/43965784

Hwang, S.-A., Yang, B.-Z., Fitzgerald, E. F., Bush, B., & Cook, K. (2001). Fingerprinting PCB patterns among Mohawk women. *Journal of Exposure Science & Environmental Epidemiology, 11*(3), 184-192. https://doi.org/10.1038/sj.jea.7500159

Hykin, J. B. (2016, September 21, 2016). *Contaminated Sites on First Nations Lands* 2016 Site Remediation Conference, Vancouver, BC. http://www.woodwardandcompany.com/wp-content/uploads/pdfs/2016-09-20-Contaminated_Sites_on_First_Nation_Lands-Final.pdf

Indian Country Today. (2013). Mohawks Say EPA Alcoa-Superfund Cleanup Plan Falls Short. *Indian Country Today*. Retrieved September 14 2023 from https://indiancountrytoday.com/archive/mohawks-say-epa-alcoa-superfund-cleanup-plan-falls-short

Indigenous and Northern Affairs Canada. (2016). *Evaluation of the Contaminated Sites On-Reserve (South of the 60th Parallel) Program*. Retrieved from https://www.rcaanc-cirnac.gc.ca/DAM/DAM-CIRNAC-RCAANC/DAM-AEV/STAGING/texte-text/ev_css60_1511896979296_eng.pdf

Indigenous Services Canada. (2020). *Annual Report to Parliament.* Retrieved from https://www.sac-isc.gc.ca/DAM/DAM-ISC-SAC/DAM-TRNSPRCY/STAGING/texte-text/annual-report-parliament-arp-report2020_1648059621383_eng.pdf

Indigenous Services Canada. (2021). *First Nations Environmental Contaminants Program*. Retrieved January 31 2022 from https://www.sac-isc.gc.ca/eng/1583779185601/1583779243216

Interstate Technology Regulatory Council. (2023). *Guidance and Documents*. Retrieved February 8 from https://itrcweb.org/guidance

Jonasson, M. E., Spiegel, S. J., Thomas, S., Yassi, A., Wittman, H., Takaro, T., Afshari, R., Markwick, M., & Spiegel, J. M. (2019, 2019/12/01). Oil pipelines and food sovereignty: threat to health equity for Indigenous communities. *Journal of Public Health Policy, 40*(4), 504-517. https://doi.org/10.1057/s41271-019-00186-1

Jones, N. M., Rachel; Ramirez, Roberto; Rios-Vargas, Merarys. (2021, August 12, 2021). 2020 Census Illuminates Racial and Ethic Composition of the Country. *United States Census Bureau*. Retrieved September 14 2023 from https://www.census.gov/library/stories/2021/08/improved-race-ethnicity-measures-reveal-united-states-population-much-more-multiracial.html

Joseph, B. (2020, July 4). *What is the seventh generation principle?* Indigensou Corporate Training Inc. Retrieved September 14 2023 from https://www.ictinc.ca/blog/seventh-generation-principle

Kegler, M. C., & Malcoe, L. H. (2004). Results from a lay health advisor intervention to prevent lead poisoning among rural Native American children. *American Journal of Public Health, 94*(10), 1730-1735. https://doi.org/10.2105%2Fajph.94.10.1730

Kegler, M. C., Malcoe, L. H., & Fedirko, V. (2010). Primary prevention of lead poisoning in rural native American children: behavioral outcomes from a community-based intervention in a former mining region. *Family and Community Health*, 32-43. https://doi.org/10.1097/fch.0b013e3181c4e252

Kegler, M. C., Rigler, J., & Ravani, M. K. (2010). Using network analysis to assess the evolution of organizational collaboration in response to a major environmental health threat. *Health Education Research, 25*(3), 413-424. https://doi.org/10.1093/her/cyq022

Kent, T. (2016). *Tribal-Led Cleanup Activities at the Tar Creek Superfund Site.* Tribal Lands Environmental Forum. https://www7.nau.edu/itep/main/iteps/ORCA/6354_ORCA.pdf

Kerfoot, W. C., Urban, N., Jeong, J., MacLennan, C., & Ford, S. (2020). Copper-rich “Halo” off Lake Superior’s Keweenaw Peninsula and how Mass Mill tailings dispersed onto tribal lands. *Journal Of Great Lakes Research, 46*(5), 1423-1443. https://doi.org/https://doi.org/10.1016/j.jglr.2020.07.004

Koch, I., Dee, J., House, K., Sui, J., Zhang, J., McKnight-Whitford, A., & Reimer, K. J. (2013). Bioaccessibility and speciation of arsenic in country foods from contaminated sites in Canada. *Science Of The Total Environment, 449*, 1-8. https://doi.org/https://doi.org/10.1016/j.scitotenv.2013.01.047

Krewski, D., Acosta, D., Jr., Andersen, M., Anderson, H., Bailar, J. C., 3rd, Boekelheide, K., Brent, R., Charnley, G., Cheung, V. G., Green, S., Jr., Kelsey, K. T., Kerkvliet, N. I., Li, A. A., McCray, L., Meyer, O., Patterson, R. D., Pennie, W., Scala, R. A., Solomon, G. M., Stephens, M., Yager, J., & Zeise, L. (2010). Toxicity testing in the 21st century: a vision and a strategy. *Journal of Toxicology And Environmental Health. Part B, Critical reviews, 13*(2-4), 51-138. https://doi.org/10.1080/10937404.2010.483176

Kuhnlein, H. V., & Chan, H. M. (2000). Environment and contaminants in traditional food systems of northern Indigenous peoples. *Annual Review of Nutrition,* 20(1), 595-626. https://doi.org/10.1146/annurev.nutr.20.1.595

Landrigan, P. J., Fuller, R., Acosta, N. J. R., Adeyi, O., Arnold, R., Basu, N., Baldé, A. B., Bertollini, R., Bose-O'Reilly, S., Boufford, J. I., Breysse, P. N., Chiles, T., Mahidol, C., Coll-Seck, A. M., Cropper, M. L., Fobil, J., Fuster, V., Greenstone, M., Haines, A., Hanrahan, D., Hunter, D., Khare, M., Krupnick, A., Lanphear, B., Lohani, B., Martin, K., Mathiasen, K. V., McTeer, M. A., Murray, C. J. L., Ndahimananjara, J. D., Perera, F., Potočnik, J., Preker, A. S., Ramesh, J., Rockström, J., Salinas, C., Samson, L. D., Sandilya, K., Sly, P. D., Smith, K. R., Steiner, A., Stewart, R. B., Suk, W. A., van Schayck, O. C. P., Yadama, G. N., Yumkella, K., & Zhong, M. (2018). The Lancet Commission on pollution and health. *The Lancet, 391*(10119), 462-512. https://doi.org/10.1016/S0140-6736(17)32345-0

LeClerc, E., & Keeling, A. (2015). From cutlines to traplines: Post-industrial land use at the Pine Point mine. *The Extractive Industries and Society, 2*(1), 7-18. https://doi.org/https://doi.org/10.1016/j.exis.2014.09.001

Lewis, J., Gonzales, M., Burnette, C., Benally, M., Seanez, P., Shuey, C., Nez, H., Nez, C., & Nez, S. (2015). Environmental exposures to metals in native communities and implications for child development: basis for the Navajo Birth Cohort Study. *Journal of Social Work in Disability & Rehabilitation, 14*(3-4), 245-269. http://dx.doi.org/10.1080/1536710X.2015.1068261

Lewis, J., Hoover, J., & MacKenzie, D. (2017, 2017/06/01). Mining and Environmental Health Disparities in Native American Communities. *Current Environmental Health Reports, 4*(2), 130-141. https://doi.org/10.1007/s40572-017-0140-5

Luongo, G., Skinner, K., Phillipps, B., Yu, Z., Martin, D., & Mah, C. L. (2020). The retail food environment, store foods, and diet and health among Indigenous populations: a scoping review. *Current Obesity Reports*, 9(3), 288-306. https://doi.org/10.1007/s13679-020-00399-6

Mahood, Q., Van Eerd, D., & Irvin, E. (2014). Searching for grey literature for systematic reviews: challenges and benefits. *Research Synthesis Methods, 5*(3), 221-234.

McAuley, C., & Knopper, L. D. (2011). Impacts of traditional food consumption advisories: Compliance, changes in diet and loss of confidence in traditional foods. *Environmental Health, 10*(1), 55. https://doi.org/10.1186/1476-069X-10-55

Meltzer, G., Avenbuan, O., Wu, F., Shah, K., Chen, Y., Mann, V., & Zelikoff, J. T. (2020). The Ramapough Lunaape Nation: Facing Health Impacts Associated with Proximity to a Superfund Site. *Journal of Community Health, 45*(6), 1196-1204. https://doi.org/10.1007/s10900-020-00848-2

Michelsen, T. (2010). *Superfund on Tribal Lands: Issues, Challenges, and Solutions*. US EPA Conflict Prevention and Resolution Center, Washington. https://clu-in.org/conf/tio/NARPMPresents1_101211/Superfund-on-Tribal-Lands.pdf

Middleton, B. R., Talaugon, S., Young, T. M., Wong, L., Fluharty, S., Reed, K., Cosby, C., & Myers, R. (2019). Bi-directional learning: identifying contaminants on the Yurok Indian reservation. *International Journal Of Environmental Research And Public Health, 16*(19), 3513. https://doi.org/10.3390%2Fijerph16193513

Moore-Nall, A. (2015). The legacy of uranium development on or near Indian reservations and health implications rekindling public awareness. *Geosciences, 5*(1), 15-29. https://doi.org/10.3390/geosciences5010015

Munn, Z., Peters, M. D., Stern, C., Tufanaru, C., McArthur, A., & Aromataris, E. (2018). Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Medical Research Methodology, 18*(1), 1-7. https://doi.org/10.1186/s12874-018-0611-x

National Conference of State Legislators. (2020). *Federal and State Recognized Tribes*. National Conference of State Legislators. Retrieved June 27 2022 from https://www.ncsl.org/legislators-staff/legislators/quad-caucus/list-of-federal-and-state-recognized-tribes.aspx#State

National Institute of Environmental Health Sciences. (2022). *Superfund Research Program*. Retrieved September 14 2023 from https://www.niehs.nih.gov/research/supported/centers/srp/index.cfm

National Research Council. (2013). *Alternatives for managing the nation's complex contaminated groundwater sites*. National Academies Press. https://doi.org/10.17226/14668.

Native Land Interactive Map. (2021). Retrieved November 12 2022 from https://native-land.ca/

Nolan, C. G. (2009). Risk assessment and orphaned/abandoned mines in Canada—What role do aboriginal communities play in risk assessment? *Integrated Environmental Assessment and Management, 5*(3), 486-487. https://doi.org/10.1897/1551-3793-5.3.486

OECD. (2020). *Linking Indigenous Communities with Regional Development in Canada.* OECD Rural Policy Reviews. https://doi.org/doi:https://doi.org/10.1787/fa0f60c6-en

Parsons, M., Fisher, K., & Crease, R. P. (2021). Environmental justice and Indigenous environmental justice. *Decolonising Blue Spaces in the Anthropocene: Freshwater* *management in Aotearoa New Zealand*, 39-73. https://doi.org/10.1007/978-3-030-61071-5_2

Peters, M. D., Godfrey, C. M., Khalil, H., McInerney, P., Parker, D., & Soares, C. B. (2015). Guidance for conducting systematic scoping reviews. *JBI Evidence Implementation, 13*(3), 141-146. https://doi.org/10.1097/xeb.0000000000000050

Reading, C., & Wien, F. (2009). *Health Inequities and Social Determinants of Aboriginal Peoples' Health*. National Collaborating Centre for Aboriginal Health. https://www.ccnsa-nccah.ca/docs/determinants/RPT-HealthInequalities-Reading-Wien-EN.pdf

Reid, A. J., Eckert, L. E., Lane, J. F., Young, N., Hinch, S. G., Darimont, C. T., Cooke, S. J., Ban, N. C., & Marshall, A. (2021). “Two-Eyed Seeing”: An Indigenous framework to transform fisheries research and management. *Fish and Fisheries, 22*(2), 243-261. https://doi.org/10.1111/faf.12516

Rock, T., Camplain, R., Teufel-Shone, N. I., & Ingram, J. C. (2019). Traditional sheep consumption by Navajo people in Cameron, Arizona. *International Journal Of Environmental Research And Public Health, 16*(21), Article 4195. https://doi.org/10.3390/ijerph16214195

Samuel-Nakamura, C., Robbins, W. A., & Hodge, F. S. (2017). Uranium and associated heavy metals in Ovis aries in a mining impacted area in Northwestern New Mexico. *International Journal Of Environmental Research And Public Health, 14*(8), 848. https://doi.org/10.3390/ijerph14080848

Sandlos, J., & Keeling, A. (2016a). Aboriginal communities, traditional knowledge, and the environmental legacies of extractive development in Canada. *Extractive Industries And Society-An International Journal, 3*(2), 278-287. https://doi.org/10.1016/j.exis.2015.06.005

Sandlos, J., & Keeling, A. (2016b). Toxic legacies, slow violence, and environmental injustice at Giant Mine, Northwest Territories. *Northern Review*(42), 7–21-27–21.

Sarkar, A., Wilton, D. H. C., Fitzgerald, E., Sharma, A., Sharma, A., & Sathya, A. J. (2019). Environmental impact assessment of uranium exploration and development on indigenous land in Labrador (Canada): a community-driven initiative. *Environmental Geochemistry & Health, 41*(2), 939-949. https://doi.org/10.1007/s10653-018-0191-z

Schmitt, C. J., Brumbaugh, W. G., Linder, G. L., & Hinck, J. E. (2006). A Screening-Level Assessment of Lead, Cadmium, and Zinc in Fish and Crayfish from Northeastern Oklahoma, USA. *Environmental Geochemistry and Health, 28*(5), 445-471. https://doi.org/10.1007/s10653-006-9050-4

Sheehy, T., Kolahdooz, F., Roache, C., & Sharma, S. (2015). Traditional food consumption is associated with better diet quality and adequacy among Inuit adults in Nunavut, Canada. *International Journal of Food Science and Nutrition*, 66(4), 445-451. https://doi.org/10.3109/09637486.2015.1035232

Sistili, B., Metatawabin, M., Iannucci, G., & Tsuji, L. J. (2006). An Aboriginal perspective on the remediation of mid-Canada radar line sites in the Subarctic: A partnership evaluation. *ARCTIC*, 142-154.

Smith, K., Luginaah, I., & Lockridge, A. (2010). Contaminated'therapeutic landscape: the case of the Aamjiwnaang First Nation in Ontario, Canada. Geography Research Forum (30), 83-102.

Teufel-Shone, N. I., Chief, C., Richards, J. R., Clausen, R. J., Yazzie, A., Begay, M. A., Jr., Lothrop, N., Yazzie, J., Begay, A. B., Beamer, P. I., & Chief, K. (2021). Development of a culturally anchored qualitative approach to conduct and analyze focus group narratives collected in Diné (Navajo) communities to understand the impacts of the gold king mine spill of 2015. *Internaional Journal of Environmental Research and Public Health, 18*(17). https://doi.org/10.3390/ijerph18179402

Tribal Superfund Working Group. (2022). *Tribal Superfund Working Group*. Retrieved January 31 2022 from https://triballands.org/tlac/building-relationships/tribal-superfund-working-group/

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., Moher, D., Peters, M. D., Horsley, T., & Weeks, L. (2018). PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Annals of internal medicine, 169*(7), 467-473. https://doi.org/10.7326/m18-0850

Tsuji, L. J., Wainman, B. C., Weber, J.-P., Sutherland, C., Katapatuk, B., & Nieboer, E. (2005). Protecting the health of First Nation personnel at contaminated sites: A case study of Mid-Canada Radar Line Site 050 in northern Canada. *ARCTIC*, 233-240. http://dx.doi.org/10.14430/arctic424

United States Government Accountability Office. (2020). *EPA Grants to Tribes- Additional Actions Needed to Effectively Address Tribal Environmental Concerns*. https://www.gao.gov/assets/gao-21-150.pdf

US Government Accountability Office. (2019). *Superfund: EPA Should Improve the Reliability of Data on National Priorities List Sites Affecting Indian Tribes*. Retrieved September 14 2023 from https://www.gao.gov/products/gao-19-123

US Government Publishing Office. (2016). *Examining EPA's unacceptable response to Indian Tribes*. Retrieved September 14 2023 from https://www.govinfo.gov/content/pkg/CHRG-114shrg20899/html/CHRG-114shrg20899.htm

van Haastrecht, M., Sarhan, I., Yigit Ozkan, B., Brinkhuis, M., & Spruit, M. (2021). SYMBALS: A Systematic Review Methodology Blending Active Learning and Snowballing. *Frontiers in Research Metrics and Analytics, 6*. https://doi.org/10.3389/frma.2021.685591

Wang, Z., Walker, G. W., Muir, D. C. G., & Nagatani-Yoshida, K. (2020, 2020/03/03). Toward a global understanding of chemical pollution: a first comprehensive analysis of national and regional chemical inventories. *Environmental Science & Technology, 54*(5), 2575-2584. https://doi.org/10.1021/acs.est.9b06379

Wiseman, C. L., & Gobas, F. A. (2002). Balancing risks in the management of contaminated first nations fisheries. *International Journal Of Environmental Health Research, 12*(4), 331-342. https://doi.org/10.1080/0960312021000056438

Woolford, J. (2017). *Consideration of Tribal Treaty Rights and Traditional Ecological Knowledge in the Superfund Remedial Program*. US Environmental Protection Agency. Retrieved September 14 2023 from https://semspub.epa.gov/work/HQ/500024668.pdf

CONNECTING PARAGRAPHS

Chapter 3 presented a scoping review of available peer-reviewed literature, grey literature, and federal data on contaminated sites that affect Indigenous peoples in Canada and the US, identifying the large inventory of contaminated sites that affect Indigenous lands and communities, in contrast to a small and disparate body of literature on the topic. There is minimal information on how risk assessment methods may be made relevant to communities, with the existing literature coming from a handful of single-community case studies and often lacking Indigenous community-level perspectives.

Chapter 4 explores the practice of, challenges with, and priorities for human health and ecological risk assessment methods in Indigenous communities in Canada, by surveying a diverse set of participants from both within and outside of communities on the topic. As part of the 'define' and 'ideate' phases of the design thinking process, this chapter narrows in on defining the challenges with current risk assessment methods, from the perspectives of those who practice them, and identifies priorities for the design of new methods. The survey is Canada-wide, providing a different scale of understanding than the existing literature largely based on single case studies. The results highlight challenges with resource availability, risk communication, and cumulative risk assessment methods, which are priority areas for advancing risk assessment practice. Perspectives differed between sector groups, namely those who work for the federal or provincial government, academics, and those who work within communities. Respondents to the survey overwhelmingly agreed on the need for new approaches to risk assessment for Indigenous communities. This chapter is published in *Integrated Environmental Assessment and Management, 2024 (Chong et al., 2024a)*. I am the first author. It is additionally authored by Laurie Chan, Gordon Hickey, and Niladri Basu.

CHAPTER 4: Exploring Practice, Challenges, and Priorities for Human Health and Ecological Risk Assessments in Indigenous Communities in Canada

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4.1 Abstract

Indigenous peoples in Canada are disproportionately exposed to environmental contaminants and may face elevated health risks related to unique cultural, spiritual, and economic relationships to the land, including the use of traditional food systems. However, to date institutionalized approaches to assess risks to human and ecological health from contaminants have not been well developed or implemented with Indigenous community contexts in mind. There is regulatory interest in developing new approach methods (NAMs) for risk assessment, and thus an opportunity to increase their relevance for Indigenous communities in which they will be ultimately applied. Therefore, we conducted an anonymous mixed-methods survey of those involved with risk assessment in Indigenous communities in Canada to: first, understand risk assessment practice in Indigenous communities; second, explore challenges with conventional assessment methods and compare these across sectors; and third, gather perspectives on the development of new approaches. A total of 38 completed survey responses were received (14% response rate). Respondents were from Indigenous community environment and health offices (21% of respondents), Indigenous governments (8%), federal and provincial governments (21%), and academia (45%). Risk communication was seen as the most challenging

part of risk assessment (71% responded “difficult”), and there was agreement amongst nearly all respondents that time (86%), cost (76%), and resource availability (86%) were “moderate” to “serious” problems. Few respondents (16%) had heard of “New Approach Methods” for risk assessment, while 76% of respondents (and 100% of community-based respondents) agreed on the need to develop improved risk assessment approaches. To modernize risk assessment, respondents recommended advancing cumulative risk assessment methods, improving risk communication, and promoting Indigenous leadership and Traditional Knowledge in assessment activities.

4.2 BACKGROUND

Indigenous communities in Canada are disproportionately exposed to environmental contaminants compared to the general population. For example, approximately 4500 contaminated sites are located on reserve land in Canada, accounting for 29% of the total number of sites (Government of Canada, 2022a). It is established in the literature that health and ecological risks posed by environmental contaminants are different for many Indigenous communities than the general population due to unique exposure pathways and non-chemical stressors, including impacts on culture (Harris, 2000; O'Neill, 2000), socio-economics (Burger & Gochfeld, 2011), spirituality, language (Fernández-Llamazares et al., 2020), and traditional food systems (Chan et al., 2021).

In Canada, federal and provincial environmental policies regulate industrial activities and contaminated site remediation (Government of British Columbia, 2021; Government of Canada, 2023a). Government-published guiding documents detail the well-established methods to assess human health and ecological risks related to environmental contamination, including frameworks for Human Health Risk Assessment (HHRA) and Ecological Risk Assessment (ERA), which are used across sectors (Government of British Columbia, 2023; Health Canada, 2019). However, these conventional approaches are generic and institutionalized and thus may be limited in their ability to address the complex and unique risk contexts that many Indigenous communities face (Arquette et al., 2002; OECD, 2020). For example, the steps and data sources of typical HHRAs do not necessarily include exposure scenarios relevant to many Indigenous peoples, including ceremonial events (ex.: smudging) and consumption of traditional foods (Burger & Gochfeld, 2011). Conventional risk assessment methods have also been critiqued for their lack of ability to meet community-specific needs or include Indigenous perspectives and priorities (OECD, 2020).

The methods are also fiscally costly and time-consuming for communities to conduct (Pastoor et al., 2014), and the risk information produced may not be locally useful (Harper et al., 2012; Harris, 2000). Further, conventional methods typically assess health risks based on exposure to single chemicals, whereas many Indigenous communities are concerned about the cumulative effects of multiple stressors on well-being, including the impacts on both physical and mental health (Arquette et al., 2002; Mitchell, 2019).

While HHRA and ERA methods follow the same principal framework (i.e.: hazard assessment; dose-response assessment; exposure assessment; risk characterization), the methodology of each step differs. For example, hazard identification in ERA involves the assessment of indicator species and ecosystem indices for evaluating the impact of chemical stressors, whereas HHRA examines risks to a single species (humans) (Burger and Gochfeld, 1996; National Research Council, 2009). While there are methodological distinctions between HHRA and ERA, writings from Indigenous environmental leaders suggest that they should not be considered as separate entities, as the interconnection of human and ecological health is central to many Indigenous communities globally (Redvers et al., 2022). Indigenous environmental leaders have advocated for risk analysis models that include a holistic view of interconnected human, ecological, and socio-cultural risks (Harris, 2000).

A few studies have been published on community-based risk assessment work, with adaptations to conventional methods for Indigenous community contexts (Doyle et al., 2012; Harris & Harper, 1997; McAuley et al., 2016; McAuley et al., 2018; Middleton et al., 2019; Schmitt et al., 2006). One such adaptation, as demonstrated in several community-based risk assessment studies, aims to include Traditional Knowledge within the conventional risk assessment process, including through the incorporation of traditional harvesting and preparation practices for country foods into sampling methods (McAuley et al., 2016; McAuley et al., 2018), and community-based monitoring programs that rely on Traditional Knowledge to identify contaminant sources and media relevant to the community (Middleton et al., 2019). Government and regulatory bodies have also documented the need to include Traditional Knowledge and context-specific information in risk assessment work. Health Canada provides supplemental guidance on Human Health Risk Assessment (HHRA) for country foods (Health Canada, 2018), including in the context of contaminated sites (Health Canada, 2010a), and on involving Indigenous peoples in contaminated sites management (Health Canada, 2010b). However, some literature has indicated that such methods of inclusion of Traditional Knowledge and Indigenous peoples, while an improvement, are insufficient. Specifically, writings on the topic suggest that attempts to include Traditional Knowledge within a dominant Western knowledge system do not adequately address the problem (Arsenault et al., 2019), as the core assumptions, definitions, and structures inherent to current risk assessment approaches remain, many of which do not align with Indigenous worldviews.

A few modified risk assessment methods have been proposed to further increase their holism and relevance to Indigenous communities. Arquette et al. (2002) proposed a new risk assessment paradigm that links community health, risk assessment, and environmental restoration, emphasizing the use of community-specific definitions of risk and health. Buell et al. (2020) more recently described a collaborative process of deconstructing and rebuilding conventional risk assessment methods with elements that simultaneously recognize Indigenous and Western Knowledge systems. Both proposed frameworks highlight the need for Indigenous inclusion, holism, and a re-framing of Western-institutionalized assumptions as a basis for a new risk assessment paradigm. While these approaches are an improvement to conventional methods, they are typically based on single-community cases, and have yet to be recognized or utilized in the context of decision-making in Canada. There is minimal information on how such approaches may be employed in wider contexts.

Proposed updates to the *Canadian Environmental Protection Act (CEPA) 1999* through the recent Bill S-5 aim to modernize HHRA and ERA methods to practices that are more ethical, efficient, and predictive than conventional methods. In particular, this modernization aims to leverage newly developed tools, technologies and approaches termed New Approach Methods (NAMs), with the expectation that they will eventually be used for regulatory purposes (Government of Canada, 2017, 2022b). Risk assessment modernization is increasingly being embraced and promoted by governing bodies such as Health Canada (Barton-Maclaren et al., 2022; Bhuller et al., 2021). Bill S-5 also commits to the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP), which includes the right to self-determination. While there has been a rapid acceleration in the development of NAMs to reduce the need for animal testing and leverage advances in biotechnology (e.g., in-silico modeling, high-throughput screening, toxicogenomics) (Wolf et al., 2022; Government of Canada, 2022b), there is much less focus and information available on the topic of new, alternative risk assessment methods in the context of their use for, and by Indigenous communities themselves (Chong and Basu, 2023). In response to Bill S-5, the Assembly of First Nations recommended that the amendments include considerations for the meaningful integration of Indigenous Knowledge systems in human health and environmental risk assessments and studies (Assembly of First Nations, 2022).

There is a need for new risk assessment approaches for environmental contaminants in Indigenous communities, and these approaches must meaningfully include Indigenous peoples. There is minimal information available on the practice of risk assessment or on the design of new risk assessment methods from the perspectives of Indigenous communities and those they collaborate with. Thus, the objectives of this study are threefold: first, to gain an understanding of those who practice HHRAs and ERAs for environmental contaminants in Indigenous communities in Canada; second, to identify the challenges with currently used HHRA and ERA methods in this context and compare them across sectors; and third, to gather initial perspectives on the development of new risk assessment approaches. This work aims to improve our understanding of risk assessment in Indigenous communities across Canada to inform the design of new risk assessment approaches.

4.3 METHODS

4.3.1 Positionality and context

This study contributes to, and is driven by, a collaborative body of work that is led by members of the Kanien'kehá:ka community of Kanesatake, which aims to develop new risk assessment approaches that are community-relevant. The authors of this paper are non-Indigenous academics from McGill University's Center for Indigenous Peoples' Nutrition and Environment (CINE) (KC, NB); McGill University's Faculty of Agricultural and Environmental Science (GH, KC, and NB), and the University of Ottawa's Faculty of Science (HMC). This positionality limits the perspectives and worldviews through which this work is written. However, every effort has been made to limit potential biases, including the pre-testing of data collection instruments and member checking the results.

4.3.2 Recruitment and data collection

The study was reviewed and approved by McGill University's Research Ethics Board for research involving humans and follows the Tri-Council Policy Statement (TCPS) on research involving Indigenous peoples (Section 9). Canada's northern territories have territorial level licensing boards with varying ethics requirements, to which we adapted our recruitment strategies. For example, the Yukon territory does not require a license to actively recruit respondents. However, the Northwest Territories requires individual community permissions to actively recruit residents, and accordingly we did not pursue such engagements given the general (as opposed to individual community-focused) nature of our survey. The survey was anonymous, and no data were collected on a respondent's location of residence, though the location(s) of their experience with professional risk assessment practice was asked (but not required).

The survey was designed based on the recommendations of Dillman et al. (2014) and drew influence from a survey of Canadian risk assessors (Vachon et al. 2017), and work on perceptions of NAMs in the ecotoxicology community (Mondou et al. 2020). A purposive (non-probability) sampling technique was used to identify respondents, which is common in exploratory survey research (Dillman et al., 2014). The recruitment list was drawn from past projects involving risk assessments in Indigenous communities across Canada, including the First Nations Food, Nutrition and Environment Study (FNFNES), First Nations Environmental Contaminants Program (FNECP), Northern Contaminants Program (NCP), studies included in a recent review of contaminated sites and Indigenous communities (Chong & Basu, 2023), and contacts within the authors' networks. The email addresses of potential respondents were collected from publicly available sources, including university, government, community, and organization websites and documents. The initial 'long list' included band council members, community researchers, industry professionals, consulting professionals, federal or provincial employees, and academics. A total of 311 email addresses were initially identified, of which 269 were successfully sent an invitation (Figure 4-1). To participate, respondents needed to self-identify as having experience with risk assessment (human health and/or ecological) in Indigenous communities in Canada.

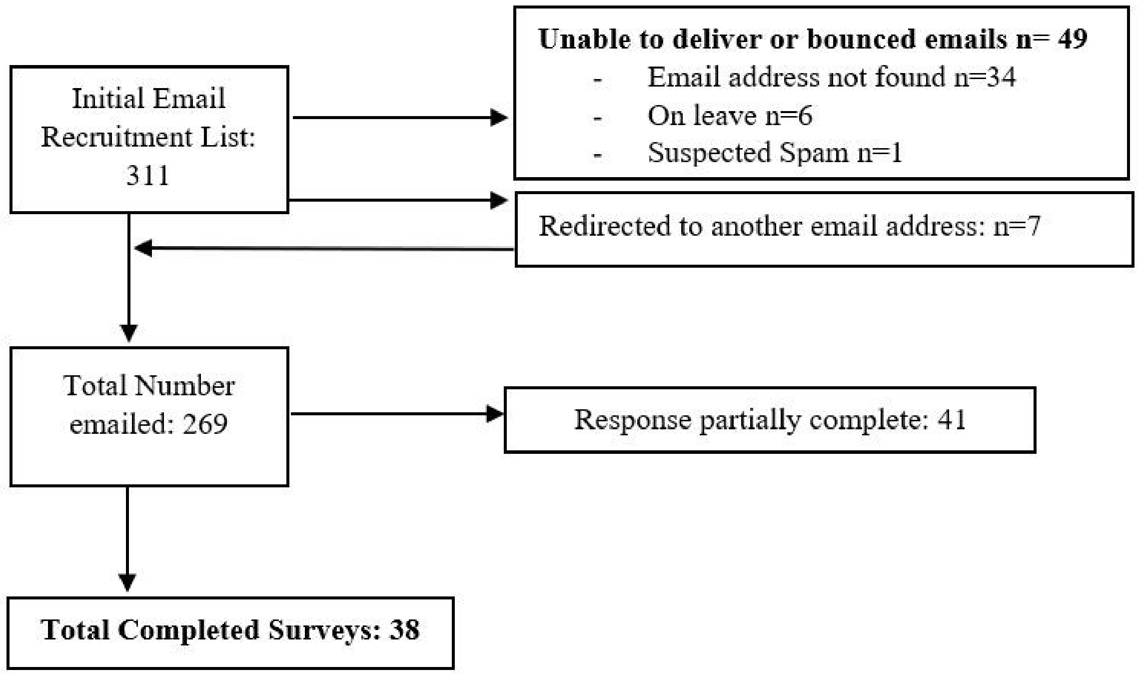

Figure 4-1: Respondent recruitment flowchart displaying the process from initial contact of potential respondents to final total of completed surveys.

The survey questions were designed and organized around the three study objectives, then informed by a literature review on risk assessment for environmental contaminants in Indigenous communities (Chong & Basu, 2023). An initial version of the survey instrument was pre-tested in March 2023 with 5 people involved in risk assessment in Indigenous communities, including community members, academics, and consultants, to ensure question clarity and consistency in interpretation. Based on feedback from the pre-test, the survey (Supplemental Materials Document A) was amended and then distributed between May and June 2023. The first section had 12 questions that focused on the respondent's profile and practice of risk assessments in the context of Indigenous communities. The second section had 17 questions about perspectives on the challenges with current risk assessment methods. The third section had three questions and asked respondents for ideas on how new risk assessment approaches may be designed to meet the needs of Indigenous communities. Several questions use a Likert scale, in which respondents choose from ordered, descriptive responses to indicate their attitudes or agreement towards a particular statement. An ordinal, typically bipolar scale such as a Likert scale is useful for assigning quantitative values to descriptive information and is commonly used in survey research to understand attitudes and feelings, and thus are applicable to the present work (Dillman et. al, 2014; Losby & Wetmore, 2012).

Data analysis methods were modeled after a study by Vachon et al. (2017) that surveyed Canadian risk assessors, which had a similarly small sample size of 29 respondents, and a study by Mondou et al. (2020), which compared perceptions of NAMs across sectors in the ecotoxicology community. Responses to the survey questions were exported through the Lime Survey software into a Microsoft Excel spreadsheet. Data analysis involved descriptive statistics performed through Microsoft Excel Functions (i.e.: averages and frequencies), goodness-of-fit statistical tests to explore relationships between demographic variables and responses, and open coding of data collected using open-ended questions (i.e., the codes and themes were developed and modified as we worked through the text) (Maguire & Delahunt, 2017; Vachon et al., 2017). Analyses focused particularly on the relationships between respondents' professional sector/experience level and their responses to questions, using Spearman's Rank Correlation and Maximum likelihood ratio Chi-Square to test these relationships. A Chi-Square test is used to test for a relationship between categorical variables (for example, professional sector and identified challenges with risk assessment), and Spearman's rank is used to test relationships between ordinal or nominal variables (for example, years of professional experience and perceived difficulty with risk assessment process). Maximum likelihood ratio Chi-Square (G-test) is used in situations where the sample size is too small to meet the assumptions of a standard Pearson's Chi-Square test (McHugh, 2013; MacDonald, 2014). Details of the analysis methods used, including test statistics and p-values, are found in supplemental materials (Tables S3-S5).

4.4 RESULTS

In total, 79 survey responses were initiated, 38 of which were completed and 41 of which were partially completed. The partially completed surveys were those which respondents initiated but did not finish. These surveys were discarded, and no data were used from them, as was outlined in the consent form. The 38 completed surveys represent a 14.1% response rate. There were no statistically significant relationships between participant sector and responses to survey questions, which is likely due to a small sample size. The data from sector subsamples are thus presented descriptively, and the patterns observed amongst them are discussed. The limitation of a small sample size is considered and discussed in the interpretation of our results.

4.4.1 Objective 1: Understand the practice of risk assessments in Indigenous communities

Characteristics of respondents. Table 4-1 outlines the characteristics of respondents. Briefly, the combined respondent experience with risk assessment covered every province and territory in Canada, expect Prince Edward Island (Figure S1). There were respondents from First Nations, Inuit, and Metis communities, as well as non-Indigenous respondents. While university/academic settings comprised the largest sector, survey respondents also reported working in Indigenous community-based environment offices and health centres, local Indigenous governments, and federal and provincial governments. Respondent experience with risk assessments in Indigenous communities ranged from less than a year to over 20 years, with near-even representation in all experience categories. Respondents reported a diversity of roles and tasks as part of their involvement in risk assessment. Most respondents had experience with both HHRA (69%) and ERA (75%). The respondents' levels of experience with the stages of the risk assessment process were highly variable. Overall, most had experience with risk characterization (78%) and communication (86%), with less having experience with toxicity/hazard assessment (69%) (Table S1).

Table 4-1: Demographic Characteristics of Respondents

Demographic Characteristics	n (%)
Location(s) of respondent experience in risk assessment*[a]	
Alberta	7 (18.4%)
British Colombia	8 (21.1%)
Manitoba	4 (10.5%)
New Brunswick	4 (10.5%)
Newfoundland and Labrador	5 (13.2%)
Northwest Territories	10 (26.3%)
Nova Scotia	4 (10.5%)
Nunavut	13 (34.2%)
Ontario	6 (15.8%)
Prince Edward Island	0
Quebec	11 (29%)
Saskatchewan	4 (10.5%)
Yukon	6 (15.8%)
Federal	4 (10.5%)
Other ("Inuit Nunangat"; "Nunavik")	2 (5.4%)
TOTAL	88
Sector	
Local Indigenous Government (Ex: Band Council)	3 (7.9%)
Indigenous Community-Based Environment Office	7 (18.4%)
Indigenous Community-Based Health Centre	1 (2.6%)
Federal or Provincial Government	8 (21.1%)
University/Academia	17 (44.7%)
Industry/Business	0
Consulting	1 (2.6%)
Non-Governmental Organization (NGO)	0
Other: "Nationally with Inuit"	1 (2.6%)
TOTAL	38
Role(s)/task(s) in risk assessment*[b]	
Researcher	27 (71.1%)
Project Manager	18 (47.4%)
Risk Assessor	8 (21.1%)
Community Health Professional	1 (2.6%)
Environmental Protection/Management Professional	8 (21.1%)
Education/Communication Professional	13 (34.2%)
Regulator/Policy-Maker	4 (10.5%)
Community Organizer	5 (13.2%)
Other: "International advocacy"; "Consultation"; "Monitoring committee"	3 (7.9%)
TOTAL	87
Years of Experience	
0-5 years	8 (21.1%)
6-10 years	7 (18.4%)
11-15 years	9 (23.7%)
16-20 years	5 (13.2%)
More than 20 years	9 (23.7%)
TOTAL	38

**Respondent had the option to select multiple responses;* [a] Multiple responses: 18 respondents reported one location; nine respondents reported two locations; four respondents reported three locations; two respondents reported four locations; and there was one respondent reporting five, seven, eight, and ten locations.; [b] Multiple responses: 12 respondents reported having one role; 11 respondents reported two roles; seven respondents reported three roles; six respondents reported four roles; and one respondent reported five roles.

Risk assessment work in Indigenous communities. Respondents were asked to list the top three human health risks, chemicals, and ecological risks of concern in the Indigenous communities where they conducted risk assessment work (Figure 4-2). In identifying the human health outcomes of concern, cancer was most often listed (37%), followed by neurological/cognitive developmental risks (29%) and diabetes (21%). Contaminants of concern listed by respondents was most frequently mercury (by 68% of respondents), with lead (29%), PCBs (26%) and PFAS (26%) also mentioned relatively frequently. A variety of ecological risks were identified by respondents, with the impacts on wildlife (58%) and traditional foods (50%) being most prominent, followed by water (24%). A complete list of the contaminants, ecological, and human health risks identified by respondents is available in supplemental materials (Table S2, a-c).

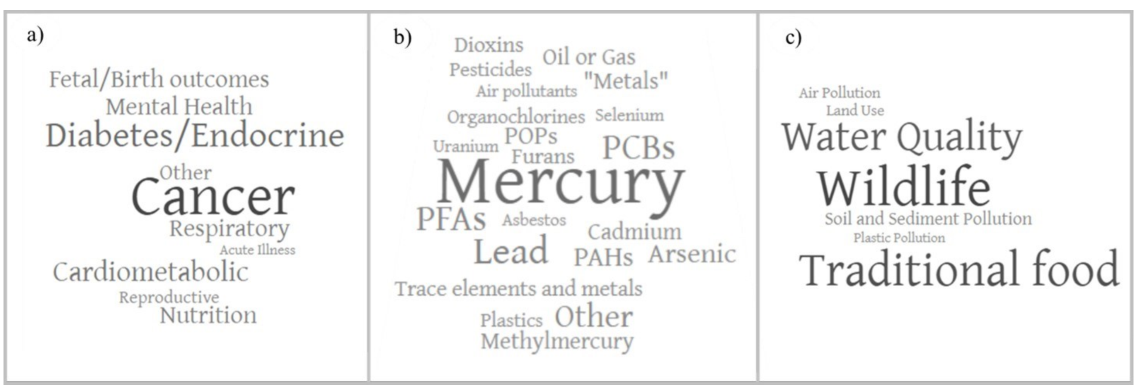

Figure 4-2: Word cloud representing coded responses to open-ended questions: *In your experience with risk assessments in Indigenous communities, what are the top three: a) Human health risks of concern? b) Chemicals of concern? c) Environmental/Ecological risk of concern? The size and darkness of color in the figure is relative to the number of responses. Word clouds were created using Worditout software (www.worditout.com).*

4.4.2 Objective 2: Challenges with risk assessments in Indigenous communities in Canada

Challenges with the steps of the risk assessment process. Respondents were asked to answer a Likert-scale style questionnaire on their level of difficulty with steps and aspects of the risk assessment process (Figure 4-3, Section A in blue). Most respondents indicated that all steps of the risk assessment process are either "difficult" or "very difficult" with risk communication (71%) being "difficult" to over two-thirds of respondents, followed by exposure assessment (66%), risk characterization (66%) and hazard assessment (58%). Alternatively, most respondents (58%) ranked problem formulation as "easy" or "very easy" on average. Notably, risk communication was perceived as "difficult" or "very difficult" by most federal and provincial government (88%) and academic (82%) respondents, and less so by Indigenous community environment and health office (38%) and Indigenous government (67%) respondents. Problem formulation was also perceived as more "difficult" on average by respondents from federal and provincial government agencies (63%) compared to respondents from all other sectors (Academia 12%; Indigenous government 33%; Environment and health office 38%). There were no significant correlations between the respondents' reported level of difficulty with risk assessment steps and their level of experience, except for the relationship between self-rated experience and perceived difficulty with problem formulation, for which there was a significant albeit weak negative correlation (correlation coefficient -0.37; p-value <0.05) (Table S3).

Resource challenges with risk assessment. Respondents were asked to rank how much of a problem various resource-level aspects of risk assessment are on a Likert scale (Figure 4-3, Section B in red). Community-level resource availability (86%), time (86%), and financial costs

(76%) were all considered to be "moderate" to "serious" problems for the majority of the 38 respondents. Interestingly, respondents from Indigenous governments and community-based environment and health offices considered on average for these resource factors to be more of a problem than federal/provincial government respondents, with the perspectives of academics falling between these two groups. For example, 50% of government employees perceived cost to be a "moderate" problem, while 82% of academics and 91% of those working at the community level ranked cost as a "moderate" to "serious" problem. Similarly, 100% of community-based respondents considered time and resource availability as "moderate" to "serious" problems, while fewer academics and federal/provincial employees ranked these factors as problematic (82% time and resources for academics, 88% time and 76% resources for federal/provincial government employees). However, there was not a significant relationship between sector of employment and responses to resource related questions (Table S4).

Challenges with conventional risk assessment work. Respondents were asked to rank the level of difficulty of various aspects of risk assessment work, including communicating results, context-specific use, and inclusion of Indigenous knowledge (Figure 4-3, Section C in green). Most ranked these aspects as "difficult" to "very difficult", with the assessment of cumulative risks (combined chemical and non-chemical stressors) being most often ranked as "difficult" or "very difficult" (87%), followed by communicating risk assessment results to community members (78%), adapting risk assessment methods to community-level priorities (61%), including Indigenous knowledge (61%), and involving Indigenous researchers and community members (60%). Responses were similar across sectors, however communicating risk assessment results to community members was perceived as "difficult" to 100% of federal or provincial employees, compared to 82% of academics, and 64% of community-based respondents. Also, involving Indigenous community members in risk assessments was rated most "difficult" by federal/provincial respondents (75%), and less so by academics (59%) and community-based respondents (55%). However, there was no statistically significant relationship between respondent sector and difficulty rankings (Supplemental table S4).

An open-ended section was provided for respondents to describe any additional challenges with risk assessments that were not addressed in the survey. The responses were coded using thematic analysis, yielding 4 main themes from 42 coded responses (Table 4-2, detailed code Table S6). Overall, many of the described challenges related to the epistemological differences between institutionalized risk assessment methods and practice, and an idealized assessment from the perspective of communities. For example, the most frequently cited challenge with risk assessments was a lack of focus on community-level priorities and community engagement (26% of respondents). The structure of risk assessment processes was also a challenge for four respondents in academia and from within communities (11%), who wrote that funding timelines are not aligned with the amount of time needed to establish trusting and collaborative relationships between Indigenous communities and other sectors such as researchers and governments. From a technical and methodological perspective, three respondents (8%) noted that the assumptions and worldviews embedded into western scientific risk assessment methods do not align with Indigenous epistemologies. The feasibility of measuring exposures, particularly through human biomonitoring, was described as a challenge due to the remoteness of communities, availability of equipment, and historical misuse of such samples from Indigenous communities which limits community trust.

Table 4-2: Thematic summary of responses to the open-ended question: *Are there other challenges with risk assessments in Indigenous communities that we have not asked about? Please describe them.* Complete coding table is available (Supplemental Materials, Table S6)

THEME	SUB THEME (% OF RESPONDENTS)
CAPACITY	• Limited community capacity to conduct risk assessment (competing priorities) (8%) • Staff capacity and availability of external experts (8%)
STRUCTURAL CHALLENGES	• Unrealistic time requirements (11%)
ENGAGEMENT/COLLABORATION	• Lack of focus on community priorities or engagement (26%) • Imposition of external research agendas and data control by external stakeholders (11%) • Other (5%)
METHODOLOGICAL/TECHNICAL	• Risk communication (balancing known benefits and potential risks of country food consumption) (8%) • Exposure measurement (8%) • Assumptions embedded in risk assessment do not align with Indigenous epistemologies (8%)

Question Section:	A: Difficulty with risk assessment steps					B: Resource related problems			C: Difficulty with aspects of risk assessment work					D: Level of agreement		
Legend:	0% % of responses "Difficult" or "Very difficult"					0% % of responses "moderate" or "serious"			0% % of responses “Difficult” or “Very difficult”					0% % of responses "Agree" or "Strongly agree"		
Question #:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SECTOR (n)																
Local Environment/ Health Dept. (8)	38	63	63	63	38	100	100	100	50	50	88	63	75	25	25	100
Indigenous Gov. (3)	33	100	67	67	67	67	100	100	67	67	100	67	67	33	33	100
Federal and Provincial Gov. (8)	63	75	63	63	88	50	88	76	50	75	88	100	75	38	75	50
Academia (17)	12	59	59	71	82	82	83	82	76	59	88	82	47	18	35	76
YEARS EXPERIENCE (n)																
0-10 years (15)	13	73	73	74	67	86	87	86	67	53	73	73	53	20	27	86
11-20 years (14)	57	71	57	71	93	64	86	78	50	57	86	85	64	42	64	65
More than 20 years (9)	22	44	33	44	44	78	88	100	66	78	78	78	66	11	33	78
HHRA EXPERTISE (n)																
No Experience (11)	0	63	36	55	36	91	91	91	45	46	82	72	27	9	36	75
Novice/Intermediate (22)	45	69	68	69	86	73	86	82	64	64	45	82	73	36	45	73
Advanced (5)	40	60	80	80	80	60	80	100	80	80	80	80	80	20	40	100
ERA EXPERTISE (n)																
No Experience (10)	0	50	40	50	60	80	70	90	50	50	70	90	40	20	30	70
Novice/Intermediate (24)	46	76	71	75	75	75	92	92	67	67	92	75	71	29	46	80
Advanced (4)	25	50	50	50	50	75	100	50	50	50	100	75	50	25	50	75
Total (n=38)	**32**	**66**	**58**	**66**	**71**	**76**	**86**	**86**	**61**	**61**	**87**	**79**	**61**	**26**	**42**	**76**

A (1-5): How difficult do you find each of the following aspects of risk assessments conducted in Indigenous communities? (Likert Scale: Very easy, Easy, Difficult, Very difficult, Don't know)	1: Problem Formulation 2: Exposure Assessment 3: Toxicity/Hazard Assessment 4: Risk Characterization 5: Risk Communication
B (6-8): In your experience with risk assessments in Indigenous communities, how much of a problem are the following aspects? (Scale: Not at all a problem, Minor problem, Moderate problem, Serious problem, Don't know)	6: The financial costs associated with risk assessments. 7: The amount of time needed to conduct a risk assessment. 8: The availability of resources within the community to conduct a risk assessment.
C (9-13): In your experience with risk assessments in indigenous communities, how difficult are the following aspects of the work? (Likert Scale: Very easy, Easy, Difficult, Very difficult, Don't know)	9: Including Indigenous knowledge in risk assessments. 10: Involving Indigenous researchers and community members in risk assessments. 11: Accounting for the cumulative effects of both chemical and non-chemical (ex: social) stressors. 12: Communicating risk assessment results to community members. 13: Adapting risk assessment methods to meet community-level priorities.
D (14-16): Please indicate your level of agreement with the following statements (Likert scale: Strongly disagree, Disagree, Agree, Strongly agree, Don't know)	14: In general, I am satisfied with the way that risk assessments are carried out for regulatory purposes in Indigenous communities. 15: In general, I am confident in the results of risk assessments to make decisions that affect Indigenous communities. 16: There is a need for new, improved approaches to risk assessments in Indigenous communities.

Figure 4-3: Heat map of respondent-identified challenges with risk assessments through Likert-scale questions compared to demographic variables. The heat map does not display “Don’t know” responses, or responses identifying an aspect of risk assessment as “easy”. An expanded heatmap that includes these responses can be found in the supplemental excel file S1.

4.4.3 Objective 3: Designing new approaches to risk assessment

Respondents were asked about their level of satisfaction with the risk assessment methods currently employed in Indigenous communities, and their confidence with the use of risk assessment results for decision-making (Figure 4-3, Section D in yellow, 14-15). Most federal and provincial government employees were confident with risk assessment results (i.e., 83% "agreed"), while respondents employed at the community level (i.e.: in Indigenous government and environment or health offices), were overall not confident (27% "agreed"), with academics sharing similar perspectives to those at the community level (40% "agreed"). Satisfaction with the way that risk assessments were conducted showed similar trends, with most respondents indicating dissatisfaction with risk assessment conduct (68%).

We also asked respondents about their level of agreement on the need for new and improved approaches to risk assessments in Indigenous communities (Figure 4-3, Column 16), to which 76% responded "agree" or "strongly agree", 11% "disagree" or "strongly disagree", and the remainder indicated "don't know". There was not a statistically significant difference in responses amongst sectors (Table S6). However, those working at the community level (i.e.: Indigenous government, local health centers and environment offices) unanimously agreed that there is a need for new risk assessment approaches (100%) while external sectors had a mixture of positive and negative responses (50% of provincial/federal employees and 76% of academics agreed). All respondents who "disagreed" or "strongly disagreed" were from the federal/provincial government or academia. While this is a small sample size, the findings indicate dissatisfaction and lack of confidence in current risk assessment approaches, and general agreement across sectors on the need for new, improved approaches.

Of the total respondents, relatively few (16%) had heard of New Approach Methodologies (NAMs). There was no relationship between the number of years of experience that respondents had in risk assessment and their familiarity with NAMs. Of the six respondents who had heard of NAMs, five had experience with the use of ERAs, three with HHRAs, and three with both. Only respondents who worked for the federal/provincial government or in academia had heard of NAMs. Respondents answered an open-ended question on what needs to be considered in the design and development of new risk assessment approaches, through which several themes were identified through thematic analysis and open coding (Table 4-3, detailed code Table S7). A total of 60 responses were coded. The most frequent response (37% of respondents) was that new risk assessment approaches must be Indigenous-led and community-engaged and based upon community-level priorities. Overall, respondents envisioned a variety of factors that would contribute to improved approaches to risk assessment in Indigenous community contexts, which included advancing structure/governance, data management, capacity building, communication, community engagement, and methodological considerations.

Table 4-3: Respondent ideas on what needs to be considered in the design and development of new risk assessment approaches in Indigenous communities. The complete coding table can be found in supplemental materials (table S7).

THEME	SUB-THEME (% of respondents)	Examples
Structure/Governance	• Improve regional governance (5)	A strong regional governance system provides a reporting body for research and facilitates health messaging.
	• Increase the role of local government (5)	Information shared directly with band council (For First Nations communities); reduce federal governance.
Data Management	• Community data control (5)	Community archives to track all information over time.
	• Improved monitoring (3)	Continuously updated representative data on exposures is needed.
Capacity Building	• Internal staff capacity (13)	Training researchers, healthcare practitioners and other internal members.
	• Technical/general (8)	Ability to conduct on-site analyses.
Communication	• Cultural relevance (5)	
	• Risk/benefit balance (13)	Traditional food advisories- health messaging should focus on benefits of traditional food consumption.
Methodological	• Cumulative risks (13)	Considering chemical mixtures and non-contaminant stressors and risk factors (cultural, social, economic, etc.); consider future land uses; holistic approaches.
	• Inclusion of local knowledge (24)	Appropriateness of current risk assessment assumptions must be based on local perceptions; Indigenous research methodologies and ways of knowing prioritized.
	• Traditional food exposure measurement (5)	Improve methods to account for unique traditional food uses.
Community Engagement	• Meet community priorities and engage community members (32) • Clear community benefits (5)	Risk assessment must be based on community-level priorities and leadership; Co-interpretation of data.

4.5 DISCUSSION

This research explored the use of human health and ecological risk assessment methods in Indigenous communities in Canada, including challenges with current practice and priorities for the development of new methods. While regulatory bodies are interested in modernizing risk assessment approaches, such methods have yet to be designed to address the challenges being faced in Indigenous community-level contexts. To our knowledge, this is the first survey on the topic. A diversity of professionals who have experience with risk assessments in Indigenous communities across Canada were surveyed, including community members working in local Indigenous government, environment, and health departments, and those who collaborate on the work, including academics, consultants, and federal and provincial employees. We aimed to recruit a diversity of respondents from different sectors; although the self-identified sector that the respondent belongs to may be different than those on our original recruitment list, we estimate that our invitation list was 37% Indigenous environment and health offices (7% response rate), 31% academia (18% response rate), 10% federal and provincial government (25% response rate), and 7% Indigenous government (13% response rate), with the remainder from consulting, organizations, and unknown sectors. As the total number of professionals involved with risk assessments in Indigenous communities across Canada is unknown, we cannot calculate the representativeness of our results. Our sample size is relatively small and is distributed in favor of academics (45%), while consultants (3%) are underrepresented. While we do not know the size and sector distribution of the total population, these sample attributes have the potential to bias the results. This limits our ability to extrapolate the results to risk assessment in general or in Indigenous communities across Canada, nor would it be appropriate to do so, given the uniqueness of each community. The relatively low response rates among the

Indigenous environment and health offices, and government may reflect the challenge of the lack of resources/time to participate in this type of questionnaire-based research. The situation was particularly exacerbated during or after the COVID pandemic (Spagnolo et al., 2020). However, our sample incorporates a diversity of voices known to be involved in risk assessment work in this context, especially those from Indigenous communities themselves. Future research or further consultations with Indigenous environment and health offices, and Indigenous governments will need to be designed to accommodate their needs.

4.5.1 Sectoral differences

This survey had a small sample size, which limits statistical inference. Further research is needed to verify the results presented here. Thus, differences in responses amongst professionals from different sectors are presented descriptively. Our results revealed some notable differences in responses amongst sector groups, particularly: those working within Indigenous communities (Indigenous government, community environment offices, and community health centres); those working in academia; and those working for the federal or provincial government. There were too few responses from other sectors to compare them similarly. Overall, we noted three key differences in responses between these sector groups. First, the sectors faced varied challenges related to the communication of and trust in risk assessment results. Both academics and federal and provincial employees perceived risk communication and community involvement to be more difficult than those working in communities themselves. Those working within Indigenous communities were the least confident in risk assessment results for their use in decision-making, followed by academia, with federal and provincial employees having the most confidence in the results. These challenges with trans-sectoral communication and overall confidence align with previous research findings that some communities experience mistrust in externally driven and institutionalized environmental assessment approaches, and this may be related to inadequate communication of results to communities (Arsenault et al., 2019; Sandlos & Keeling, 2016). Second, we found that financial resources, time, and community capacity were perceived as less of a barrier to federal and provincial government respondents than other sectors. This finding may be partially explained by previous research on contaminated sites, which describes that Canadian federal site management on First Nations reserve land is generally done within the established protocol and pre-defined budget, which may not address the specific requirements or concerns of some communities (Gailus, 2013). The findings from our survey give a clearer picture of the realities of risk assessment work at the community level compared to the perceptions of risk assessments at a federal level, however further research is required to understand the complexities. Third, all community-based respondents agreed on the need for a new approach to risk assessments, compared to majority agreement among academics and less (but still majority) agreement among federal and provincial employees. These findings align with recent research on factors affecting the perception of NAMs in the ecotoxicology community, which concluded there is a difference in the mean perceived viability of NAMs, particularly between academics versus non-academics (Mondou et al., 2020). Our survey varies from these findings in that there were differences in the perceptions on the need for new approaches not only between academics and non-academics, but between academics, community-based and government employees. Another recent study analysed public consultation submissions regarding environmental assessment reform and found sectoral differences in agreement on the need for science in reformed environmental assessment regimes in Canada, including around cumulative effects and decision-making (Jacob et al., 2018). Like our results, there was agreement amongst sectors on the need for improved approaches to cumulative effects assessment, and increased transparency in the assessment process, including through communication. Jacob et al. (2018) found that those working in industry perceived less of a need for scientific change in environmental assessment compared to other sectors, and our results can add to these findings by highlighting some potential differences in perspectives between academics, government employees, and Indigenous offices on the details of changes needed to risk assessment work.

While not addressed in our results, we also note that the overall purpose of conducting a risk assessment may differ amongst sectors. For example, government agencies have traditionally performed routine assessments for individual, physical health risks as a foundation for decision-making, management, and closing of contaminated sites (Arquette et al, 2001; Indigenous and Northern Affairs Canada, 2016), while community-led risk assessments often are aimed at contributing to a more holistic and community-engaged understanding of community health (Arquette et al., 2001; Eggers et al., 2018). These inherent differences in the motivation behind conducting a risk assessment may also contribute to the findings presented in this survey.

While previous studies have examined the perceptions of sector groups involved with environmental management, few have explored and compared perceptions concurrently. To our knowledge, there has not been a previous study comparing differences between sectors within and outside of Indigenous communities on the topic of risk assessment methods. While not an emergent theme in our survey, we note the importance of distinguishing between Indigenous rightsholders and non-Indigenous 'stakeholders' (Ettawageshik & Norman, 2020). Whereas federal and provincial employees, academics, and other collaborators have vested interests in this work, Indigenous community members have the right to self-determination, autonomy over their traditional territories, and free, prior, and informed consent in environmental risk assessment and management processes as outlined by UNDRIP (United Nations, 2007). Aligned with our study, Brock et al. (2021) conducted semi-structured interviews with Indigenous, industry, and government actors in environmental management, noting significant differences in the perceived definitions of engagement and consultation between Indigenous peoples and government employees, and the perceived roles of respondent groups in the environmental management process. Our findings add further insight into the varied perceptions amongst sectors, specifically on the topic of risk assessment challenges and priorities. Central to both Brock et al. (2021) and our study is the finding that improved communication between sectors may elevate collaboration, thus strengthening environmental management approaches. Improving communication and collaboration between sectors is challenging, and few evidence-based strategies have been developed on the topic (Chircop et al., 2015). While there are many studies examining relationships between researchers and communities, there are far fewer that examine multiple sectors. Suggestions have emerged from a variety of disciplines, especially the health sciences, and include identifying co-benefits, building long-term relationships as opposed to project-specific, and having team members that are specifically focused on the work of collaboration (Rudolph et al., 2013). Such methods may be applicable to improving collaboration in risk assessment work in Indigenous communities and are areas for further research.

4.5.2 Structural and bureaucratic elements of risk assessment

Overall, time, cost, and resource availability were considered “moderate” to “serious” problems when conducting risk assessment work in Indigenous communities in Canada, which is consistent with the available literature on the topic in the U.S. and internationally. For example, writings from the Akwesasne task force on the environment describe that Native governments face challenges accessing financial and other resources needed to address environmental concerns, and do not receive funding equitable to state and provincial governments (Arquette et al., 2002). Also consistent with our findings are previously cited challenges with unrealistic timelines and community capacity as barriers to trusted and effective environmental assessments in Canada (Arsenault et al., 2019). In Canada, many community risk assessment projects are through federally funded programs, including the First Nations Environmental Contaminants Program (FNECP), Northern Contaminants Program (NCP), and First Nations Baseline Assessment Program (Government of Canada, 2023b; Government of Canada, 2022c). Such programs emphasize local capacity building efforts and have provided many communities with funds to learn more about local contamination and provide a basis for risk mitigation. While these programs often contribute positively to community-based risk assessment work, this survey also highlights bureaucratic elements that present barriers to optimizing risk assessments. For example, the common requirement to outsource an external ‘expert’ (an “academically trained scientist” [Government of Canada, 2022c]) to collaborate on the project, and finite research timelines that are insufficient for establishing a trusting relationship between a community and a potential collaborator are considerable barriers. Brock et al. (2021) found that many Indigenous peoples inherently mistrust the processes of ‘engagement’ and ‘consultation’ employed by the federal government in environmental management, a relationship which is highly contextualized.

Improving communication and collaboration amongst these groups, which may be in part facilitated by deconstructing institutional barriers, may contribute to increased trust.

4.5.3 Epistemological differences, Traditional Knowledge, and inclusion of Indigenous peoples

Challenges with the adequate inclusion of Indigenous community perspectives and knowledge were evident in the survey, which is a well-documented issue in the literature on environmental assessment and management in Indigenous communities in Canada (Arsenault et al., 2019; Bowie, 2013) and globally (Wolfley, 1998). The inclusion of Traditional Knowledge and consultation with communities in risk assessment processes has become increasingly recognized as a key need in Canadian governmental reports and guidelines (Health Canada, 2010b, 2018). Discourse on the topic of Traditional Knowledge use in environmental management continues to push such policies beyond 'inclusion' to meaningful collaboration and recognition of Traditional Knowledge as a distinct knowledge system that should not be subsumed into the dominant 'western-scientific' body (Bowie, 2013; Ellis, 2005; Fernández-Llamazares et al., 2020; Assembly of First Nations, 2022; Zurba & Papadopoulos, 2023). The development of new risk assessment methods aligned with such policies must also consider the protection and confidentiality of Traditional Knowledge (Sinjela et al., 2005). The First Nations Principles of OCAP (Ownership, Control, Access, and Possession) asserts First Nations authority over how knowledge may be collected, used, and disseminated and supports data sovereignty (FNIGC, 2024). OCAP is an example of a tool that may support appropriate relationships with Traditional Knowledge systems in risk assessment research and work.

Many of the challenges identified in this survey were underpinned by epistemological differences between Indigenous communities themselves and the western-scientific methods applied to risk assessments. While recent updates to the *Canadian Environmental Protection Act 1999* through Bill S-5 highlight the need to uphold UNDRIP (Government of Canada, 2022b), the challenges that were identified through this study may undermine Indigenous peoples' right to self-determination by limiting their ability to lead risk assessment work in their communities. Respondents made several suggestions for the development of new risk assessment methods, including that they be community-based and led, moving beyond engagement and involvement of communities within largely non-Indigenous risk assessment frameworks. According to writings from First Nations leadership in Canada, this should include that governing bodies consult with and obtain free, prior, and informed consent from Indigenous peoples (Assembly of First Nations, 2022). The revitalization of self-governing capacities in Indigenous communities will ultimately contribute to improved environmental risk assessment processes (Bowie, 2013). In recent years, the First Nations Food, Nutrition, and Environment Study (FNFNES) was conducted, a Canada-wide environmental and health assessment purposefully led and designed by the Assembly of First Nations (Chan et al., 2021). Positively, the FNFNES represents a shift from conventional federally led and controlled assessments and promotes participatory research approaches. However, it uses generic and institutionalized risk assessment methods and a Western knowledge-based design, which limits the value of its results in terms of Indigenous ownership and sovereignty. The Principal Investigators of FNFNES acknowledged the limitation and called on decision-makers to support First Nations-led leadership and solutions to address systemic problems relating to food, nutrition and the environment affecting First Nations

(FNFNES, 2021). We also emphasize the importance of Indigenous community leadership in the design of new risk assessment methods and in future risk assessment implementation.

4.5.4 Technical and scientific aspects

The survey results highlight several technical and scientific challenges with the risk assessment process used in Indigenous communities, including the ability of risk assessment methods to account for cumulative risks and adapt to community-level priorities. The ability to account for the combined effects of chemical and non-chemical stressors was considered the most challenging by respondents. The growing development of cumulative risk assessment methods has largely focused on the quantitative assessment of risks related to exposure to multiple chemical stressors, and more recently, attention has been drawn to the inclusion of non-chemical, psychosocial stressors (ex: socio-economic strain, discrimination, housing insecurity) (Payne-Sturges et al., 2018). In the context of Indigenous communities, a few frameworks have been proposed for holistic risk assessment, including a variety of environmental indicators and socio-cultural factors, both quantitative and qualitative. For example, Harris and Harper’s (2000) work proposed an eco-cultural dependency web to better characterize risks to tribal health on the Umatilla Indian Reservation in the US. More recently, Arsenault et al. (2019) proposed a restructuring of environmental assessment processes with Indigenous Knowledge systems, which is applicable to risk assessment work. The need for more holistic assessment approaches has also been recommended by the Assembly of First Nations (2022). Such approaches, in combination with emergent CRA methodologies may aid in painting a more complete picture of the realities of health and ecological risks faced by Indigenous communities. The basis of cultural and spiritual beliefs for many Indigenous communities includes the interconnected nature of human and ecological health. However, these assessments are typically siloed in regulatory risk assessment work (Arsenault et al., 2019; Health Canada, 2019). Most respondents in this survey had experience with both human health and ecological risk assessments, and future research may seek to leverage these experiences and integrate these two risk assessment domains.

4.5.5 Risk communication

Challenges with risk communication that is locally relevant were a theme throughout this study, especially in balancing the risks and benefits of contaminated traditional food consumption. This challenge has been cited in previous publications related to risk communication in Indigenous communities, particularly in the Canadian Arctic, known as the 'Arctic Dilemma' (Krümmel & Gilman, 2016). A reduction in contaminant exposure is conventionally considered 'successful' management. However, there are complex losses associated with the diminished use of traditional food systems, and this effect is well documented, including in synthesis reports from the Arctic Monitoring and Assessment Program (Adlard et al., 2018). There are gaps in the literature on risk communication strategies for Indigenous communities (Boyd & Furgal, 2019), however, it has been evidenced that trust is an essential element of communication in practice (Boyd et al., 2019). Findings from this study suggest a general lack of trust, both in the results of risk assessments for decision-making, and between communities and external risk assessors. Future research may explore the trust levels in information sources included in risk assessments. Risk assessment approaches that are community designed and led, including in methods, implementation, and communication, may increase trust in the results.

4.5.6 New approaches to risk assessment in Indigenous communities

As 'New Approach Methodologies' (NAMs) for risk assessment are of regulatory interest at this moment, it is an opportune time to develop NAMs with the priorities of Indigenous communities at the forefront. However, few respondents had heard of 'NAMs', though nearly all respondents agreed that there is a need for new and improved approaches to risk assessment in Indigenous communities. Several themes emerged that provide a basis on which to further explore and develop such methods. The results of risk assessment work need to be locally relevant. This includes the ability to meet Indigenous community-level priorities, communicate results effectively, and incorporate Traditional Knowledge. Similar needs have been previously communicated in publications globally (Arsenault et al., 2019; Ellis 2005; Wolfley, 1998), and this survey adds a Canada-based perspective. The development of risk assessment methods that incorporate risk communication tools and strategies relevant to communities (i.e.: based upon Indigenous epistemologies) is an area for further research. According to respondents, risk assessment work should consider multiple chemical and non-chemical stressors, including social, cultural, and economic factors. In the context of Indigenous communities, this may go beyond the conventional use of the term 'cumulative risk' and its methodologies (largely quantitative to date (Sexton, 2012)) and include greater involvement of the social sciences. There is strong inertia for the development of NAMs in a variety of fields, and a recognition of the need for collaboration between disciplines in their development and application. To help overcome this, for example, social sciences literature on the use of toxicogenomics as a NAM has documented that innovation (researcher)-centric drivers to NAM development undermine adopter-centric drivers that focus instead on ease of use and integration with known practices (Pain et al., 2020), and as such NAMs development should be driven by the users. The findings of our survey support the need for collaborative efforts in developing NAMs in the field of risk assessment, and specifically ones that are driven by Indigenous community-based sectors. Future research may, therefore, include the development of new risk assessment methods, led by Indigenous communities and involving interdisciplinary collaboration. This may include adapting methods currently under development to meet community-level contexts.

4.5.7 Limitations

This survey received 38 completed responses, which is not representative of the population of professionals involved in risk assessment work in Indigenous communities across Canada, the total number of which is unknown. Thus, the presented results cannot be widely applied to all risk assessment work in all Indigenous communities in Canada. Further, each Indigenous community in Canada is unique, and thus, even with a larger sample size, the findings are not generalizable. Also, while we made some comparisons between responses from different professional sectors, these sub-groups are small and thus cannot represent the opinions of whole sectors. There were not statistically significant differences across sectors, likely due to the small sample size. Finally, an online survey format helps to eliminate power dynamics between respondent and researcher or amongst respondents (Dillman et al., 2014), but a limitation of this method is that it prevents the participation of those who do not have access to or ability to use a computer and does not allow for the flexibility to adapt questions based on responses as in an in-person interview. There were a limited number of open-ended questions in this survey, which intended to collect baseline information on the selected objectives and identify knowledge gaps, and this is common of online, anonymous surveys. However, this limits the depth of information received. Future research (ex: key informant interviews) may uncover further detail on the presented findings. Anonymous online survey results are limited by a non-response bias. The response rate of 14.1% is relatively low, though similar to studies on which we designed our methods and to which we compare our results. For example, a survey of Canadian risk assessors had a response rate of less than 15% (Vachon et al, 2017), and another survey of perceptions of NAMs in the ecotoxicology community had a response rate of 13% (Mondou et al., 2020). We followed a non-probability sampling method, which is commonly used for exploratory research, and of which a lower participation rate is common (Dillman et al., 2014). Factors contributing to a low response rate may include the length of the survey, lack of incentive, and recruitment strategy.

Despite these limitations, we surveyed a diversity of professionals who have conducted risk assessment work in many regions across Canada, with results showing an overall agreement on the limitations of current risk assessment methods and the need for new ones. These findings lay a groundwork for further exploring and developing risk assessment methods that better respond to the challenges identified here.

4.6 CONCLUSIONS

While regulatory bodies promote the development of new risk assessment approaches, such methods have yet to be designed to address the challenges being faced in Indigenous community-level contexts. To our knowledge, this is the first multi-sectoral survey on the challenges with and priorities for human health and ecological risk assessments in Indigenous communities across Canada. We surveyed a diverse group of professionals with varied experiences and roles in risk assessment practice in this context. Our results revealed notable differences in perspectives amongst sector groups, particularly those working within and outside of Indigenous communities. Improved communication and collaboration among sectors, which recognizes the Indigenous right to self-governance and prioritizes Indigenous leadership, may advance risk assessment practices and methods. This may facilitate a shared understanding of multi-sectorial goals, priorities, and challenges thus streamlining the development of more effective risk assessment methods that meet a variety of needs. New risk assessment approaches need to consider cumulative risks of multiple chemical and non-chemical stressors, adapt to community-level contexts, and integrate HHRA and ERA approaches. Recommendations for future research topics include optimizing communication of risk assessment results to communities, and developing community designed and lead HHRA and ERA approaches.

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4.8 References

Adlard B, Donaldson SG, Odland JO, Weihe P, Berner J, Carlsen A, Bonefeld-Jorgensen EC, Dudarev, AA, Gibson JC, Krümmel EM, Olafsdottir K, Abass K, Rautio A, Bergdahl I A, Mulvad G. (2018). Future directions for monitoring and human health research for the Arctic Monitoring and Assessment Programme. *Global Health Action, 11*(1), 1480084.

Arquette M, Cole M, Cook K, LaFrance B, Peters M, Ransom J, Sargent E, Smoke V, Stairs A. (2002). Holistic risk-based environmental decision making: A native perspective. *Environmental Health Perspectives, 110*, 259-264. doi: 10.1289/ehp.02110s2259

Arsenault R, Bourassa C, Diver S, McGregor D, Witham A. 2019. Including Indigenous knowledge systems in environmental assessments: restructuring the process. *Global Environmental Politics, 19*(3), 120-132. https://doi.org/10.1162/glep_a_00519

Assembly of First Nations. (2022). *Submission to the House of Commons Committee on Environment and Sustainable Development. Study on Bill S-5 An Act to amend the Canadian Environmental Protection Act, 1999, to make related amendments to the Food and Drugs Act and to repeal the Perfluorooctane Sulfonate Virtual Elimination Act.* Retrieved 18 December 2023 from https://www.ourcommons.ca/Content/Committee/441/ENVI/Brief/BR12143095/br-external/AssemblyOfFirstNations-e.pdf

Barton-Maclaren TS, Wade M, Basu N, Bayen S, Grundy J, Marlatt V, Moore R, Parent L, Parrott J, Grigorova P, Pinsonnault-Cooper J, Langlois VS. (2022). Innovation in regulatory approaches for endocrine disrupting chemicals: The journey to risk assessment modernization in Canada. *Environmental Research.* 204(Pt C):112225. https://doi.org/10.1016/j.envres.2021.112225

Bhuller Y, Ramsingh D, Beal M, Kulkarni S, Gagne M, Barton-Maclaren TS. (2021). Canadian Regulatory Perspective on Next Generation Risk Assessments for Pest Control Products and Industrial Chemicals. *Frontiers in Toxicology.* 3:748406. https://doi.org/10.3389/ftox.2021.748406

Bowie R. (2013). Indigenous self-governance and the deployment of knowledge in collaborative environmental management in Canada. *Journal of Canadian Studies, 47*(1), 91-121. http://dx.doi.org/10.3138/jcs.47.1.91

Boyd AD, Furgal CM. (2019). Communicating environmental health risks with Indigenous populations: A systematic literature review of current research and recommendations for future studies. *Health Communication, 34*(13), 1564-1574. https://doi.org/10.1080/10410236.2018.1507658

Boyd AD, Furgal CM, Mayeda AM, Jardine CG, Driedger SM. (2019). Exploring the role of trust in health risk communication in Nunavik, Canada. *Polar Record, 55*(4), 235-240. doi:10.1017/S003224741900010X

Brock T, Reed MG, Stewart KJ. (2021). Indigenous community participation in resource development decision-making: Practitioner perceptions of legal and voluntary arrangements. *Journal of Environmental Management, 283*, 111922. 10.1016/j.jenvman.2020.111922

Buell MC, Ritchie D, Ryan K, Metcalfe CD.(2020). Using Indigenous and Western knowledge systems for environmental risk assessment. *Ecological Applications, 30*(7), e02146. https://doi.org/10.1002/eap.2146

Burger J, Gochfeld M. (1996). Ecological and human health risk assessment: a comparison. Chapter 9. In: *Interconnections Between Human and Ecosystem Health.* Edited by Richard T. Di Giulio and Emily Monosson. London: Chapman & Hall. ISBN 0412 62400 I. Retrieved 2024 Mar 7. Available from https://link.springer.com/content/pdf/10.1007/978-94-009-1523-7_9.pdf

Burger J, Gochfeld M. (2011). Conceptual environmental justice model for evaluating chemical pathways of exposure in low-income, minority, Native American, and other unique exposure populations. *American Journal of Public Health, 101*(S1), S64-S73. https://doi.org/10.2105%2FAJPH.2010.300077

Chan, H. M., Fediuk, K., Batal, M., Sadik, T., Tikhonov, C., Ing, A., & Barwin, L. (2021). The First Nations Food, Nutrition and Environment Study (2008–2018)—rationale, design, methods and lessons learned. *Canadian Journal of Public Health, 112*, 8-19. https://doi.org/http://dx.doi.org/10.17269/s41997-021-00480-0

Chircop, A., Bassett, R., & Taylor, E. (2015). Evidence on how to practice intersectoral collaboration for health equity: a scoping review. *Critical Public Health*, 25(2), 178-191. https://doi.org/10.1080/09581596.2014.887831

Chong, K., & Basu, N. (2023). Contaminated sites and Indigenous peoples in Canada and the US: A scoping review. *Integrated Environmental Assessment and Management.* 23 November 2023. https://doi.org/10.1002/ieam.4869

Dillman, D. A., Smyth, J. D., & Christian, L. M. (2014). *Internet, Phone, Mail, and Mixed-Mode Surveys : The Tailored Design Method*. John Wiley & Sons, Incorporated. Retrieved January 2023 from http://ebookcentral.proquest.com/lib/mcgill/detail.action?docID=1762797

Doyle, J. R., Blais, J. M., Holmes, R. D., & White, P. A. (2012). A soil ingestion pilot study of a population following a traditional lifestyle typical of rural or wilderness areas. *Science of The Total Environment, 424*, 110-120. https://doi.org/10.1016/j.scitotenv.2012.02.043

Ellis, S. C. (2005). Meaningful consideration? A review of traditional knowledge in environmental decision making. *Arctic*, 66-77. https://www.jstor.org/stable/40512668

Eggers, M. J., Doyle, J. T., Lefthand, M. J., Young, S. L., Moore-Nall, A. L., Kindness, L., ... & Camper, A. K. (2018). *Community engaged cumulative risk assessment of exposure to inorganic well water contaminants, crow reservation, Montana*. International Journal of Environmental Research and Public Health, 15(1), 76. https://doi.org/10.3390/ijerph15010076

Ettawageshik, F., & Norman, E. S. (2020). From “stakeholder to rights-holder”: Re-examining the role of Indigenous peoples in the international joint commission as the third sovereign. *The First Century of the International Joint Commission*, 433-456. https://doi.org/10.1515/9781773851099-018

Fernández-Llamazares, Á., Garteizgogeascoa, M., Basu, N., Brondizio, E. S., Cabeza, M., Martínez-Alier, J., McElwee, P., & Reyes-García, V. (2020). A state-of-the-art review of Indigenous peoples and environmental pollution. *Integrated Environmental Assessment and Management, 16*(3), 324-341. https://doi.org/https://doi.org/10.1002/ieam.4239

First Nations Food, Nutrition, and Environment Study (FNFNES) (2021). *Key Findings and Recommendations for Decision-Makers.* University of Ottawa, Université de Montréal, and Assembly of First Nations. Retrieved February 2, 2024 from https://www.fnfnes.ca/docs/CRA/FNFNES_Final_Key_Findings_and_Recommendations_20_Oct_2021.pdf

First Nations Information Governance Center (FNIGC). (2024). Understanding OCAP. First Nations Principles of OCAP. Retrieved March 12, 2024 from https://fnigc.ca/ocap-training/

Gailus, J. (2013). *Management of Contaminated Sites on Indian Reserve Lands.* Site Remediation in British Colombia Conference, Vancouver, British Columbia, Canada. March 7, 2013. Retrieved March 2023 from https://www.dgwlaw.ca/wp-content/uploads/2014/12/Site_Remediation_Conference_Paper.pdf

Government of British Columbia. (2021). *Environmental Assessment Act*. Retrieved December 15 from https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/laws-rules/environmental-assessment-act

Government of British Columbia (2023). *Protocol 1 for contaminated sites- Detailed risk assessment.* Ministry of Environment and Climate Change Strategy. Retrieved December 15 2023 from https://www2.gov.bc.ca/assets/gov/environment/air-land-water/site-remediation/docs/protocols/p1_jan_2021_revisions_final_signed.pdf

Government of Canada. (2017). *Committee report- November 16-17, 2016.* Chemicals Management Plan Science Committee. Retrieved December 18 2023 from https://www.canada.ca/en/health-canada/services/chemical-substances/chemicals-management-plan/science-committee/meeting-records-reports/committee-report-november-16-17-2016.html

Government of Canada (2022a). *Federal Contaminated Sites Inventory*. Retrieved January 31, 2022 from https://www.tbs-sct.gc.ca/fcsi-rscf/home-accueil-eng.aspx

Government of Canada (2022b). *Bill S-5, Strengthening environmental protection for a healthier Canada act- Summary of amendments.* Retrieved December 18 2023 from https://www.canada.ca/en/services/environment/pollution-waste-management/strengthening-canadian-environmental-protection-act-1999/bill-c-28-strengthening-environmental-protection-healthier-canada-act-summary-amendments.html

Government of Canada (2022c). *First Nations Environmental Contaminants Program (FNECP)*. Retrieved December 10 2022 from https://www.sac-isc.gc.ca/eng/1583779185601/1583779243216

Government of Canada. (2023a). *Basics of Environmental Assessment under the Canadian Environmental Assessment Act, 2012*. Retrieved December 15 2023 from https://www.canada.ca/en/impact-assessment-agency/services/policy-guidance/basics-environmental-assessment.html

Government of Canada (2023b). *Indigenous climate and environmental funding*. Retrieved October 9 2023 from https://www.canada.ca/en/environment-climate-change/services/climate-change/indigenous-partnership/funding.html#indigenous-funding

Harper, B., Harding, A., Harris, S., & Berger, P. (2012). Subsistence exposure scenarios for Tribal applications. *Human and Ecological Risk Assessment, 18*(4), 810-831. https://doi.org/10.1080/10807039.2012.688706

Harris, S. G. (2000). Risk analysis: Changes needed from a Native American perspective. *Human and Ecological Risk Assessment, 6*(4), 529-535. http://dx.doi.org/10.1080/10807030008951325

Harris, S. G., & Harper, B. L. (1997). A Native American exposure scenario. *Risk Analysis, 17*(6), 789-795. https://doi.org/10.1111/j.1539-6924.1997.tb01284.x

Harris, S. G., & Harper, B. L. (2000). Using eco-cultural dependency webs in risk assessment and characterization of risks to tribal health and cultures. *Environmental Science and Pollution Research, 2*(2), 91-100.

Health Canada (2010a). *Supplemental Guidance on Human Health Risk Assessment for Country Foods (HHRAFoods).* Federal Contaminated Site Risk Assessment in Canada. Retrieved March 6 2024 from https://publications.gc.ca/collections/collection_2012/sc-hc/H128-1-11-641-eng.pdf

Health Canada. (2010b). *A Guide to Involving Aboriginal Peoples in Contaminated Sites Managament*. Retrieved January 10 2024 from https://publications.gc.ca/collections/collection_2011/sc-hc/H128-1-10-628-eng.pdf

Health Canada. (2018). *Guidance for evaluating human health impacts in environmental assessment: country foods*. Retrieved January 29 2024 from https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidance-evaluating-human-health-impacts-country-foods.html

Health Canada (2019). *Guidance of Evaluation Human Health Impacts in Environmental Assessment: Human Health Risk Assessment*. Retrieved December 18 2023 from https://publications.gc.ca/collections/collection_2019/sc-hc/H129-54-6-2019-eng.pdf

Krümmel, E.-M., & Gilman, A. (2016). An update on risk communication in the Arctic. *International Journal of Circumpolar Health, 75*(1), 33822. https://doi.org/10.3402%2Fijch.v75.33822

Losby, J.& Wetmore, A. (2012). CDC Coffee Break: Using Likert Scales in Evaluation Survey Work. National Center for Chronic Disease Prevention and Health Promotion. Retrieved March 7, 2024 from https://www.cdc.gov/dhdsp/pubs/docs/cb_february_14_2012.pdf

Maguire, M., & Delahunt, B. (2017). Doing a thematic analysis: A practical, step-by-step guide for learning and teaching scholars. *All Ireland Journal of Higher Education, 9*(3). http://ojs.aishe.org/index.php/aishe-j/article/view/335

McAuley, C., Dersch, A., Kates, L. N., Sowan, D. R., Koppe, B., & Ollson, C. A. (2016). Assessment of exposure to chlorinated organics through the ingestion of moose meat for a Canadian First Nation community. *Frontiers in Environmental Science*. 4, 78. https://doi.org/http://dx.doi.org/10.3389/fenvs.2016.00078

McAuley, C., Dersch, A., Mouille-Malbeuf, S., Koppe, B., & Sowan, D. (2018). Cadmium Tissue Concentrations in Kidney, Liver and Muscle in Moose (Alces alces) From First Nations Communities in Northern Alberta. *Frontiers in Sustainable Food Systems, 2*, 69. https://doi.org/10.3389/fsufs.2018.00069

Middleton, B. R., Talaugon, S., Young, T. M., Wong, L., Fluharty, S., Reed, K., Cosby, C., & Myers, R. (2019). Bi-Directional learning: Identifying contaminants on the Yurok Indian Reservation. *International journal of Environmental Research and Public Health, 16*(19). https://doi.org/10.3390/ijerph16193513

Mitchell, T. (2019). Colonial trauma: Complex, continuous, collective, cumulative and compounding effects on the health of Indigenous peoples in Canada and beyond. *International Journal of Indigenous Health, 14*(2), 74-94. https://doi.org/10.32799/ijih.v14i2.32251

Mondou, M., Hickey, G. M., Rahman, H. T., Maguire, S., Pain, G., Crump, D., Hecker, M., & Basu, N. (2020). Factors affecting the perception of New Approach Methodologies (NAMs) in the ecotoxicology community. *Integrated Environmental Assessment and Management, 16*(2), 269-281. https://doi.org/10.1002/ieam.4244

National Research Council. (2009). *Science and Decisions: Advancing Risk Assessment.* National Academies Press. Washington (DC). PMID: 25009905. DOI: 10.17226/12209

O'Neill, C. A. (2000). Variable justice: Environmental standards, contaminated fish, and acceptable risk to Native peoples. *Stanford Environmental Law Journal, 19*, 3. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2263492

OECD. (2020). *Linking Indigenous Communities with Regional Development in Canada.* Retrieved December 18 2023 from https://doi.org/doi:https://doi.org/10.1787/fa0f60c6-en

Pain, G., Hickey, G., Mondou, M., Crump, D., Hecker, M., Basu, N., & Maguire, S. (2020). Drivers of and Obstacles to the Adoption of Toxicogenomics for Chemical Risk Assessment: Insights from Social Science Perspectives. Environmental health perspectives, 128(10), 105002. https://doi.org/10.1289/EHP6500

Pastoor, T. P., Bachman, A. N., Bell, D. R., Cohen, S. M., Dellarco, M., Dewhurst, I. C., Doe, J. E., Doerrer, N. G., Embry, M. R., & Hines, R. N. (2014). A 21st century roadmap for human health risk assessment. *Critical reviews in toxicology, 44*(sup3), 1-5. 10.3109/10408444.2014.931923.

Payne-Sturges, D. C., Scammell, M. K., Levy, J. I., Cory-Slechta, D. A., Symanski, E., Carr Shmool, J. L., Laumbach, R., Linder, S., & Clougherty, J. E. (2018). Methods for evaluating the combined effects of chemical and nonchemical exposures for cumulative environmental health risk assessment. *International Journal of Environmental Research and Public Health, 15*(12), 2797. https://doi.org/10.3390%2Fijerph15122797

Redvers, N., Celidwen, Y., Schultz, C., Horn, O., Githaiga, C., Vera, M., ... & Rojas, J. N. (2022). The determinants of planetary health: an Indigenous consensus perspective. *The Lancet Planetary Health,* 6(2), e156-e163. https://doi.org/10.1016/S2542-5196(21)00354-5

Rudolph et al. (2013). *Health in All Policies: Improving Health Through Intersectoral Collaboration.* National Academy of Sciences. Retrieved March 7, 2024 from https://www.phi.org/wp-content/uploads/2013/01/q79jnmxq5krx9qiu5j6gzdnl6g9s41l65co2ir1kz0lvmx67to.pdf

Sandlos, J., & Keeling, A. (2016). Aboriginal communities, traditional knowledge, and the environmental legacies of extractive development in Canada. *Extractive Industries and Society- An International Journal, 3*(2), 278-287. https://doi.org/10.1016/j.exis.2015.06.005

Schmitt, C. J., Brumbaugh, W. G., Linder, G. L., & Hinck, J. E. (2006). A screening-level assessment of lead, cadmium, and zinc in fish and crayfish from Northeastern Oklahoma, USA. *Environmental Geochemistry and Health, 28*(5), 445-471. https://doi.org/10.1007/s10653-006-9050-4

Sexton, K. (2012). Cumulative risk assessment: an overview of methodological approaches for evaluating combined health effects from exposure to multiple environmental stressors. *International Journal of Environmental Research and Public Health, 9*(2), 370-390. https://doi.org/10.3390/ijerph9020370

Sinjela, Mpazi, & Ramcharan, Robin. (2005). Protecting traditional knowledge and traditional medicines of Indigenous peoples through intellectual property rights: issues, challenges and strategies. *International Journal on Minority and Group Rights*, 12(1), 1-24. Retrieved from https://heinonline.org/HOL/P?h=hein.journals/ijmgr12&i=15.

Spagnolo, J., Gautier, L., Seppey, M., & D'souza, N. A. (2020). Re-thinking global and public health projects during the COVID-19 pandemic context: Considerations and recommendations for early- and not-so-early-career researchers. *Social Sciences & Humanities Open,* 2(1), 100075. https://doi.org/10.1016/j.ssaho.2020.100075

Tong, R., Zhang, B. (2023). Cumulative risk assessment for combinations of environmental and psychosocial stressors: A systematic review. *Integrated Environmental Assessment and Management.* 20 (3), 602-615. https://doi.org/10.1002/ieam.4821

United Nations. (2007). *United Nations Declaration on the Rights of Indigenous Peoples*. Retrieved December 18 2023 from https://www.un.org/development/desa/indigenouspeoples/wp-content/uploads/sites/19/2018/11/UNDRIP_E_web.pdf

Vachon, J., Campagna, C., Rodriguez, M. J., Sirard, M.-A., & Levallois, P. (2017). Barriers to the use of toxicogenomics data in human health risk assessment: a survey of Canadian risk assessors. *Regulatory Toxicology and Pharmacology, 85*, 119-123. https://doi.org/10.1016/j.yrtph.2017.01.008

Wolf, D. C., Bhuller, Y., Cope, R., Corvaro, M., Currie, R., Doe, J., Doi, A., Hilton, G., Mehta, J., & Saltmiras, D. (2022). Transforming the evaluation of agrochemicals. *Pesticide Management Science*. https://doi.org/10.1002/ps.7148

Wolfley, J. (1998). Ecological risk assessment and management: Their failure to value Indigenous traditional ecological knowledge and protect tribal homelands. *American Indian Culture and Research Journal, 22*(2). DOI: 10.17953

Zurba, M., & Papadopoulos, A. (2023). Indigenous participation and the incorporation of indigenous knowledge and perspectives in global environmental governance forums: a systematic review. *Environmental Management, 72*(1), 84-99. https://doi.org/10.1007/s00267-021-01566-8

CONNECTING PARAGRAPHS

Chapter 4 detailed findings from a Canada-wide survey of those who work on risk assessments in Indigenous communities. The survey identified differences in perspectives between respondents from federal and provincial governments, academia, and within communities (i.e.: local government, community environment offices, health centers). Overall, risk assessments in Indigenous communities are challenged by a lack of cumulative risk assessment methods, communication, and resource availability, which provide priority areas for the improvement of conventional methods and the development of new methods, areas in which further research is needed. There was general agreement on the need for new risk assessment approaches for Indigenous community contexts.

With these findings in mind, and aligned with the 'prototype' and 'test' phases of the design thinking process, chapter 5 pilot-tests RISK21. RISK21 is a new HHRA approach developed by the Health and Environmental Sciences Institute, which has gained attention from regulators (Health Canada, US EPA). RISK has been tested in a variety of risk assessment contexts but has yet to be designed or tested for and by Indigenous communities. This study involved a collaboration with three communities (The Crow/Apsáalooke Nation, Cold Lake First Nation and Chipewyan Prairie Dene First Nation) who have experience with community-level risk assessment. We conducted case studies to test the use of RISK21 in these community contexts, compare it to conventional methods, and discuss its relevance. Fruitful discussions with the collaborating communities highlighted the need to consider both qualitative/descriptive as well as quantitative information in cumulative risk assessment approaches, and to further develop communication outputs that are widely accessible to communities.

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CHAPTER 5: Exploring the Use of the RISK21 Approach for Indigenous Community-Based Human Health Risk Assessments: Two Case Studies

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5.1 Abstract

Indigenous peoples in North America are disproportionately exposed to environmental contaminants and may face elevated health risks related to unique socio-cultural ties to the land. Conventional human health risk assessment (HHRA) methods do not account for these unique contexts. Regulators (i.e.: Health Canada, US EPA) have called for the development of more ethical and efficient HHRA approaches, but to our knowledge no such approaches have been designed in consideration of Indigenous community contexts. RISK21 is a new HHRA approach gaining regulatory attention. We present two case studies piloting RISK21's use in collaboration with three unique communities (Cold Lake First Nations, Chipewyan Prairie First Nation, Apsáalooke/Crow Nation). Our objectives are first, reflect upon the benefits and challenges of using RISK21 in these contexts; second, compare RISK21-based to conventional assessments; and third, ideate adaptations and improvements to the approach. The RISK21-based analyses had similar descriptive results to the original conventional assessments, including when using less information. We found RISK21 useful for rapid chemical assessment and visually representing data from multiple sources. We recommend areas where RISK21 (and other next-generation HHRA approaches) might be improved for Indigenous community contexts, including increasing the community-relevance of communication tools and incorporating holistic and non-conventional information.

KEY WORDS: Human health risk assessment; New approach methodologies (NAMs); Indigenous communities; RISK21; Cumulative risk assessment; traditional food

5.2 INTRODUCTION

Environmental pollution is a pervasive issue for Indigenous communities across Canada and the US. For example, approximately 4500 contaminated sites, largely driven by external industrial and mining activities, are located on First Nations reserve land in Canada (Government of Canada, 2021). In a recent report from the federally led Northern Contaminants Program, exposures to several persistent organic pollutants and heavy metals were up to eleven-fold higher among Inuit men and women from northern Canada compared to the general Canadian population in the South (Government of Canada, 2017). In the US, approximately 34% of Superfund sites are deemed “Native American Interest” sites (i.e.: they affect Native American peoples) (Chong and Basu, 2023), with an estimated 146 605 Native American people living within one mile of a Superfund site (US EPA, 2020). Many Indigenous communities face unique risks and impacts related to environmental pollution, including from contaminated sites, compared to the general population. This is not only due to disproportionate physical exposure, but also through impacts on culture, spirituality, language, the economy, and many other facets of life to which the land is a central element (Harris, 2000; O'Neill, 2000; Van Oostdam et al., 2005; Burger and Gochfeld, 2011; Eggers et al., 2018; Fernández-Llamazares et al., 2020). The contamination of traditional food systems has been particularly impactful, through chemical exposures and cultural losses associated with an inability to conduct traditional harvesting, fishing, hunting, and agricultural activities, and resulting in a transition to nutrient-poor market foods (Damman et al., 2008; Chan et al., 2021). It has also contributed to a breakdown of intergenerational knowledge transfer related to procuring, processing, and preparing traditional foods (Robin et al., 2021).

Human health risk assessment (HHRA) is a method used to estimate the "nature and probability of adverse health effects in humans who may be exposed to chemicals in contaminated environmental media" (US EPA, 2022). HHRAs are required by many governments globally prior to the initiation of industrial or development projects, and to make decisions about remediation and risk management at existing contaminated sites, including those that impact Indigenous communities (Health Canada, 2004). However, such generic and institutionalized HHRA methods have been described as inadequate for addressing the unique risk assessment needs of the Indigenous communities in which they are used. This includes, for example, that conventional HHRA methods may not adapt to community-specific needs or include Indigenous perspectives (OECD, 2020), are considered costly and time consuming (Pastoor et al., 2014), and often produce risk information that is not locally useful (Harris, 2000; Harper et al., 2012). Further, there is no well-established and agreed upon method for assessing combined risks of multiple chemical and non-chemical (socio-cultural) stressors (i.e.: cumulative risks) (Fox et al., 2017; Tong and Zhang, 2023). A recent systematic review concluded that while evidence continues to emerge on the harms associated with combined chemical and psychosocial stressors, there has been minimal progress on the integration of cumulative risk assessment into environmental management or public health policy decision-making (Tong and Zhang, 2023).

Within the past few decades, communities and governments in Canada and the US have called for a need to change the way that HHRAs are conducted, especially in regulatory contexts. There is increasing emphasis on the adoption of alternatives that are cheaper, more efficient, less resource intensive, and fit for purpose. This paradigm shift is marked by the U.S. National Research Council's "Science and Decision Report" of 2009 and the U.S. National Academy's book, "Exposure Science in the 21st Century" of 2012. Aligned with this shift, Canada's 2016

Chemicals Management Plan (CMP) Science Committee recommended that governing bodies, including Health Canada (HC) and Environment and Climate Change Canada (ECCC), must develop a roadmap for integrating alternative risk assessment approaches into regulatory decisions (CMP Science Committee, 2016). Most recently, in February of 2022, amendments to the Canadian Environmental Protection Act (CEPA) 1999 were proposed in Bill S-5, "Strengthening Environmental Protection for a Healthier Canada" Act. Bill S-5 specifically references honoring the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP), calls for improved risk communication, and ultimately developing new approaches to risk assessment for environmental contaminants. These amendments are particularly relevant to the many First Nations, Inuit, and Métis communities who are affected by environmental pollution and are subject to risk assessment results (United Nations, 2007; Government of Canada, 2022).

A variety of alternative tools and approaches to toxicity testing, exposure assessment, and risk assessment are currently under development. The desire is that modernized approaches will underpin the next generation of standards on which regulatory decisions will be based. One such approach is the Health and Environmental Sciences Institute's (HESI) RISK21, a HHRA approach that aims to optimize the use of existing information and testing resources (Embry et al., 2014). RISK21 was developed in response to recommended improvements to HHRA approaches, including by the National Academy of Sciences, to more efficiently, ethically, and transparently reach a risk or safety determination compared to conventional methods (Embry et al., 2014; risk21.org). RISK21's components include a conceptual framework for risk assessment and a visual exposure-toxicity matrix, which allows for exposure and hazard information to be evaluated and compared effectively (Embry et al., 2014). RISK21 also includes a framework for assessing cumulative risks and has a web-based risk communication tool (Moretto et al., 2017). RISK21 has been noted as a strategy for the integration of alternative risk assessment approaches in Canada's Chemicals Management Plan (CMP) committee report (CMP Science Committee, 2016) and publications from the US EPA (Turley et al., 2019). Institutional legitimacy of RISK21 is increasing, with eight government and regulatory agencies (including Health Canada), two academic institutions, five industries, and two consulting organizations involved (HESI, N.D.). A variety of case studies have been published using the RISK21 approach, for example, prioritizing chemicals in drinking water (Wolf et al., 2016; Dellarco et al., 2017) and assessing pyrethroid exposures in bed netting (Doe et al., 2016). However, RISK21 has not been used or validated in the context of Indigenous community-based risk assessments (M. Embry, personal communication, November 2022). In fact, to our knowledge, to date there has been no evidence of collaboration on the development of any next generation risk assessment tools with the Indigenous communities to which they may be ultimately applied.

Therefore, the objective of this paper is to explore and critically examine the use of the RISK21 tool in the context of Indigenous community-level HHRA data, through case studies. The expected outcomes are to first, reflect upon the use of the approach in these contexts, including its benefits and challenges; second, compare the approach (including results and conclusions) to conventional risk assessment methods; and third, to discuss and ideate adaptations or additions to the tool to improve its use in-context. This study is conducted in collaboration with three distinct communities: The Chipewyan Prairie First Nation, Cold Lake First Nations, and Apsáalooke/Crow Nation. The cases use data from risk assessments that have been previously conducted in these communities (Eggers et al., 2018; McAuley et al., 2018). The critical evaluation and discussion of RISK21's use in these contexts includes perspectives of the community members and their collaborators, who are co-authors of this work.

5.3 METHODS

5.3.1 The RISK21 approach

HESI describes RISK21 as ‘a flexible framework whereby both exposure and hazard are evaluated using all relevant sources of information, with a goal of reducing unnecessary resource utilization while providing sufficient precision and accuracy to make decisions protective of human health’ (Embry, 2018). The approach is centred on four principles: (1) focus on problem formulation; (2) utilize existing information; (3) start with exposure rather than toxicity; and (4) use a tiered approach to data development and decision-making. These principles are organized into a “roadmap”, which provides a basic framework for conducting risk assessments (supplemental materials S1) (Pastoor et al., 2014). Under this framework, risk assessments are conducted beginning at the lowest tier (tier 0) and progressing to higher tiers based on the assessment’s results and available information. Exposure tiers and toxicity tiers can be combined at various levels. For example, if there is a high level of toxicity data available for a chemical, but minimal exposure data available, the two can be used to characterize risk. The decision on what level of precision is required for assessment and decision-making is based upon the problem formulation stage (Pastoor et al., 2014). The case studies presented here will utilize various modalities of the RISK21 roadmap and matrix to explore its potential use in-context, which will be discussed in relation to the above objectives. The RISK21 approach followed in these case studies draws on publications from HESI, including methodology papers on the basic roadmap for HHRA (Embry et al., 2014; Pastoor et al., 2014), and its use demonstrated in a case study (Doe et al., 2016), and two methodology papers on problem formulation and use of the framework to conduct a cumulative risk assessment (Solomon et al., 2016; Moretto et al., 2017) (supplemental materials S2).

5.3.2 Case Studies

To respond to our objective, the case studies presented involve the collaboration of three Indigenous communities who have conducted risk assessment activities for environmental contaminants (Table 1). Members and partners of the communities of focus in the case studies are co-authors of this work and have experience with risk assessments, and thus the discussion stems from their critical consideration of the use of the RISK21 approach and ideas for its adaptation. The case studies represent a "pilot test" of RISK21's use in community contexts, with two distinct risk assessment scenarios: (1) to characterize human health risks from contaminant exposure; and (2) to assess cumulative risks (i.e.: the combined risks posed by multiple chemical and non-chemical stressors). All data used in the case studies are publicly available and published online. The risk assessment questions in these cases are those posed at the community level and capture a range of data contexts, through which we may identify the potential limitations and/or benefits of using RISK21 in this context. The results are not meant to be prescriptive, nor are they meant to be interpreted as actionable information on potential health risks.

Table 5-1: Summary table of case studies used to explore the use of RISK21 in context.

Case #	1	2
Community name(s) and location	**Chipewyan Prairie First Nation and Cold Lake First Nations, Alberta, Canada**	**Apsáalooke Nation (Crow Tribal community), Montana, USA**
Case Study Name	Assessing human health risks from Cadmium exposure through Moose tissues in the Chipewyan Prairie First Nation and Cold Lake First Nations	Cumulative risk assessment for contaminated well water and the Apsaálooke/Crow Nation, Montana
Risk Assessment Focus	Characterizing risk	Cumulative risk (chemical and non-chemical)
Exposure media of focus	Moose meat (kidney, liver, muscle)	Well water
Chemicals of interest	Cadmium	Arsenic, Manganese, Zinc, Uranium, Nitrate
Reference publications	McAuley et al., 2018. Cadmium Tissue Concentrations in Kidney, Liver and Muscle in Moose (Alces Alces) From First Nations Communities in Northern Alberta. Frontiers in Sustainable Food Systems. 2018; 2(69). https://doi.org/10.3389/fsufs.2018.00069 Chan et al., 2016. First Nations Food, Nutrition and Environment Study (FNFNES): Results from Alberta 2013. University of Ottawa, Ottawa, ON. 2016:155. Available from https://www.fnfnes.ca/docs/FNFNES_Alberta_Regional_Report_ENGLISH_2019-10-09.pdf	Eggers et al., 2018. Community Engaged Cumulative Risk Assessment of Exposure to Inorganic Well Water Contaminants, Crow Reservation, Montana. International Journal of Environmental Research and Public Health. 15(1). https://doi.org/10.3390/ijerph15010076

5.4 RESULTS

This section summarizes two case studies on human health risk assessments using the RISK21 approach, following a tiered exposure and/or toxicity assessment depending on the availability of data for each case. While we had access to all data at the outset, for demonstrative purposes we progressed from the use of less "precise" to more "precise" data following RISK21, where "precision" of exposure and toxicity values is defined as "the degree of accuracy in the data… proportional to the quality and quantity of data used to generate the estimate" (Embry et al., 2014). The case studies are organized as two separate results and discussion sections. The discussion sections detail our observations gleaned from each case in relation to the objectives outlined, specific to each community's perspective. The separation of the case discussions is intended to highlight the uniqueness of the two contexts. We discuss our third objective, ideating potential future adaptations and areas for research, in consideration of both cases.

5.4.1 Case Study 1- Assessing human health risks from Cadmium exposure through Moose tissues in the Chipewyan Prairie First Nation and Cold Lake First Nations

Step 1- 'Problem Formulation'

Scenario: The harvest and consumption of moose is essential to the dietary, social, and cultural well-being of many members of the Chipewyan Prairie First Nation (CPFN) and the Cold Lake First Nations (CLFN) in Alberta, Canada. CPFN and CLFN traditional territory is in Alberta's oil sands region, and there are concerns about the impacts on moose meat and subsequent human health concerns for consumers in these communities (McAuley et al., 2016;

McAuley et al., 2018). Of particular concern is the community's potential exposure to cadmium, a heavy metal that can accumulate in the tissues of moose, particularly in the kidneys and liver (McAuley et al., 2018). This case study will use the basic RISK21 framework and matrix to conduct an HHRA, utilizing data from an original community-based risk assessment published by McAuley et al. (2018).

Purpose: The purpose of this risk assessment is to characterize risks associated with the consumption of cadmium in moose tissues (muscle, kidney, and liver) by community members. The results will be compared to the original human health risk assessment conducted to estimate benchmark consumption quantities in CPFN and CLFN (McAuley et al., 2018).

Step 2- 'Assembly of Information'

Following the RISK21 framework, we first assemble information relevant to the risk assessment, including chemical properties, biological activity, adverse effects, and use and exposure information (Doe et al., 2016). Cadmium is a well-characterized heavy metal (US EPA, 2023a; US EPA, 2023b) with risk assessment information available through the US EPA's CompTox Database and Integrated Risk Information System (IRIS); and Health Canada (Health Canada, 1986; US EPA, 2023a; US EPA, 2023b). Evidence supporting the information on cadmium is considered the highest possible according to CompTox (Level 1: Expert curated, highest confidence in accuracy and consistency of unique chemical identifiers) (US EPA, 2023a). Cadmium's mechanism of action involves effects on cell proliferation, differentiation, and apoptosis. Adverse effects of cadmium include cancer and organ system toxicity (skeletal, urinary, reproductive, cardiovascular, central/peripheral nervous, reproductive) (Rahimzadeh et al., 2017).

The First Nations Food, Nutrition and Environment study (FNFNES) report from Alberta provides regional consumption rates (average and maximum) of moose meat, kidney, and liver for First Nations adults in Alberta (n=603) and cadmium concentrations (average and maximum) found in a sample of each tissue (moose meat n=9; kidney n=8; liver n=7) (Chan et al., 2016). Further, community-specific data is available on average and maximum cadmium concentrations from a 2018 study by the CLFN and CPFN, which involved the harvesting of 35 moose (26 from CPFN, 9 from CLFN) and analysis of cadmium concentrations in the tissues (muscle, liver, kidney) (McAuley et al., 2018).

Step 3- 'Tiered Risk Assessment'

While all the data were available at the outset of our case study, we conducted the assessment in two tiers, beginning with lower-tier exposure estimates (tier 0) based upon regional exposure data and progressing to more "precise" exposure estimates (tier 1) based on local community data, demonstrating the stepwise collection of data following the RISK21 approach (Pastoor et al., 2014). In this case study, both steps used the same level of toxicity information (i.e.: RfD from US EPA and Health Canada based on mode of action information, which is the highest tier/tier 3).

First assessment- Tier 0 exposure assessment (minimal information)

The first assessment involved the use of lower-tier data (i.e.: regional data from the FNFNES study as opposed to community-specific exposure information), simulating the initial availability of minimal data and demonstrating the stepwise use of the RISK21 framework.

a. **Exposure estimate:** Using the data from FNFNES on Moose consumption rates for First Nations in Alberta and mean and maximum cadmium concentrations in moose meat, we calculate average and maximum chronic daily intake (CDI) values, providing an exposure range (Table 5-2).

b. Toxicity estimate: The US EPA's CompTox dashboard catalogs cadmium toxicity values for oral exposures at the highest level of evidence (including mechanistic information). EPA's IRIS provides the No-Observed Adverse Effects Level (NOAEL) and reference doses (RfDs) for cadmium ingested via food. Thus, we will use a toxicity estimate range that spans from the NOAEL (10 ug/kg/day) to the RfD (1 ug/kg/day) (Health Canada, 1986; US EPA, 2023a).

c. Plotting exposure and toxicity data on the RISK21 matrix: Exposure and toxicity estimate ranges from the previous two steps are plotted using the RISK21 webtool (Figure 5-1a) (HESI, 2023).

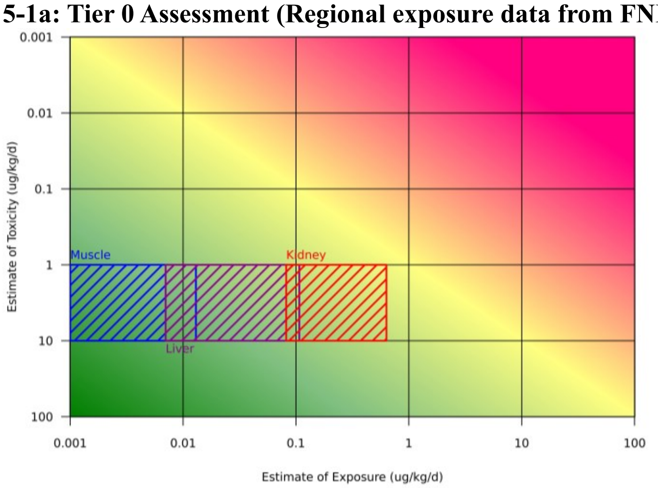
d. Assessment of safety: Examining the visual matrix (Figure 5-1a), maximum exposure estimates for cadmium in kidney tissue approach the yellow area, beyond which the risks are considered unacceptable to human health by US EPA standards. This assessment has a relatively high degree of uncertainty, as the exposure data used is regional as opposed to community-specific, and there was a small sample size of moose tissues in which cadmium concentrations were measured in the FNFNES study (moose meat n=9; kidney n=8; liver n=7). Also, the assessment does not account for background levels of cadmium (ex.: in other foods, soil, water, cigarette smoke). These limitations may prompt us to proceed to the next tier of the RISK21 approach, using community-specific exposure information.

Table 5-2: Chronic Daily Intake (CDI) Values for Total Population's Cadmium Consumption in Moose Tissues (meat, liver, kidney) (ug/kg/day). Daily moose meat consumption values are from the FNFNES report on Alberta (Chan et al., 2016). Tier 0 uses FNFNES exposure estimate values and regional moose meat contaminant measurements (Chan et al., 2016; McAuley et al., 2018). Tier 1 uses exposure estimates from moose harvested by the Chipewyan Prairie First Nation (CPFN) and Cold Lake First Nations (CLFN) (McAuley et al., 2018). The calculation of exposure estimates used standard human body weight (70.7 kg) measures for an average Canadian recommended by Health Canada (Health Canada, 2019), as used in the original risk assessment by McAuley et al. (2018).

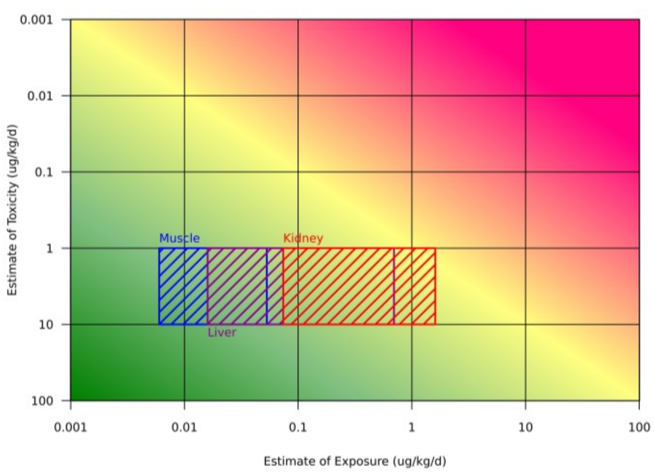
		Tier 0 Exposure Assessment (Minimal information)		**Tier 1 Exposure Assessment (Deterministic information)**			
		Regional Data (FNFNES)		**Chipewyan Prairie First Nation**		**Cold Lake First Nations**	
Tissue Type	Daily Moose meat consumption (g/kg/day)	Cadmium Concentration in Tissues (ug/g)	**Total CDI (ug/kg/day)**	Cadmium Concentration in Tissues (ug/g)	**Total CDI (ug/kg/day)**	Cadmium Concentration in Tissues (ug/g)	**Total CDI (ug/kg/day)**
Muscle (Avg)	0.165	0.009	**0.001**	0.039	**0.006**	0.004	**0.001**
Muscle (Max)	0.826	0.016	**0.013**	0.064	**0.053**	0.007	**0.006**
Liver (Avg)	0.006	1.161	**0.007**	2.582	**0.016**	0.860	**0.005**
Liver (Max)	0.028	3.78	**0.107**	24.5	**0.697**	1.900	**0.054**
Kidney (Avg)	0.006	13.17	**0.082**	11.948	**0.074**	4.600	**0.029**
Kidney (Max)	0.020	31.1	**0.633**	78.9	**1.607**	11.000	**0.224**

Figure 5-1: Plotting of exposure and toxicity information on the RISK21 Matrix. Plots created using the RISK21 Webtool (www.risk21.org). The Matrix presents a "red zone" and a "green zone" separated by a yellow margin. The green area indicates where exposure is below the considered 'safe' level for human health (i.e.: minimal risk) (Doe et al., 2016) Figure 5-1a uses regional exposure information from the FNFNES study (Chan et al., 2016) to estimate exposures (tier 0, minimal information). Tier 1 used community-specific exposure data from 26 harvested moose samples from CPFN (Figure 5-1b), and from 9 moose samples from CLFN (Figure 5-1c), as published by McAuley et al. (2018).

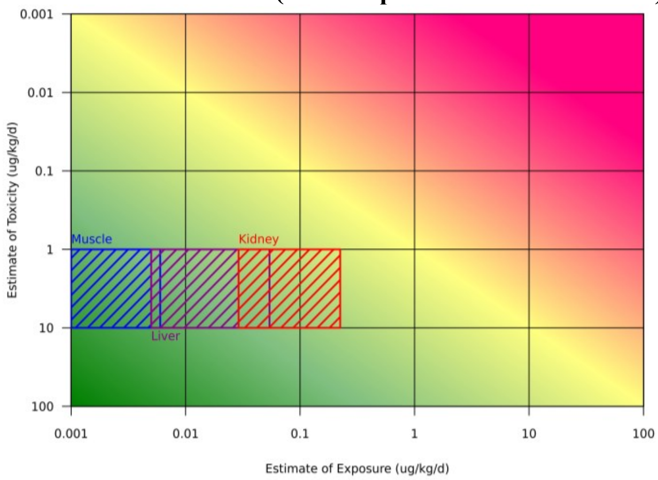
5-1a: Tier 0 Assessment (Regional exposure data from FNFNES)



5-1b: Tier 1 Assessment (Local exposure data from CPFN)



5-1c: Tier 1 Assessment (Local exposure data from CLFN)



Second Assessment- Tier 1 (Further investigation of exposure)

a. **Estimate of exposure:** The second-tier exposure estimate used community-specific data from CPFN and CLFN (i.e.: 35 locally harvested moose, 26 from CPFN and 9 from CLFN). Community-specific consumption data is unavailable, so the same consumption values from the FNFNES were used (Chan et al., 2016) to calculate the CDI values (Table 5-2).

b. **Estimate of toxicity:** As the toxicity information available for cadmium is at the highest level of evidence, the same values will be used as in the first assessment.

c. **Plotting exposure and toxicity data on the RISK21 matrix:** The RISK21 webtool was used to plot the exposure and toxicity estimates for both communities onto individual visual matrices (Figures 5-1b and 5-1c).

d. **Assessment of safety:** The community-level data provides a more accurate estimation of exposure and differentiates assessments between the two communities. Compared to the Tier 0 exposure assessment, exposure values for CPFN slightly exceed regional-level values, moving the assessment towards the 'red-zone' i.e.: the area of potential concern (Figure 5-1b). The exposure values for CLFN were slightly lower than values calculated using regional data, moving the assessment towards the 'green zone' (i.e.: safe level of exposure) (Figure 5-1c).

Step 4- Outcome and Conclusions

A conclusion that may stem from the assessment is that moose kidney and liver should be consumed with caution, especially in the context of CPFN. Certainty of this assessment may increase at higher exposure data tiers (ex: human biomonitoring data).

5.4.2 Case Study 2- Cumulative risk assessment for contaminated well water and the Apsaálooke/Crow Nation, Montana

The RISK21 approach includes a framework for conducting a cumulative risk assessment (CRA) (i.e.: assessing risks of combined exposure to multiple chemical and non-chemical stressors) (Moretto et al., 2017). This approach involves identifying common chemical assessment groups and non-chemical modulating factors. Unlike the first case, the framework for CRA includes a 'gatekeeper step' prior to problem formulation. This step assesses the evidence for co-exposure and common toxicity of the contaminants in question, which (under the RISK21 framework) determines the need for a CRA.

Scenario: The Crow Reservation in Montana is home to the Apsáalooke/Crow people, and is rich in water resources, including several mountain-fed rivers. Water quality began to visibly deteriorate in the 1960s with regional expansion of agriculture and mining. This resulted in the installation of costly well water infrastructure in homes, subsequently leading to metals contamination from the wells (Eggers et al., 2015; Eggers et al., 2018; Martin et al., 2021). Today, about half of the families on the Reservation rely on home well water for cooking and drinking, although quality remains poor (Eggers et al., 2018). Using a community-based participatory research approach, members from the Apsáalooke/Crow Tribal community and researchers from Montana State University conducted a CRA of exposure to inorganic contaminants (uranium, zinc, manganese, arsenic, and nitrate) in well water, integrating multiple knowledge sources (Eggers et al., 2018). The study involved the quantification of exposures to well water contaminants, a CRA for multiple chemicals, and a discussion of tribal members' knowledge of the contamination based on surveys and interviews, incorporating secondary health and economic data. Drawing data from the original CRA conducted by Eggers et al. (2018), this demonstrative case will explore the use of the RISK21 CRA framework in-context and compare it to the original assessment.

Step 1: Gatekeeper Step

For multi-chemical CRA to occur (prior to considering non-chemical stressors), the RISK21 framework requires evidence of both co-exposure of receptors to chemicals and common toxicity (i.e.: assuming dose additivity occurs when chemicals have a similar mode of action) (Moretto et al., 2017). However, RISK21 publications acknowledge a lack of methodological consensus on the criteria to determine when it is toxicologically appropriate to include chemicals in a CRA, consistent with literature on the topic (Callahan and Sexton, 2007; Moretto et al., 2017). Criteria for conducting a CRA may range from evidence of co-exposure only, to in-vitro and in-silico methods, to common apical effects or a common mechanism of action (US EPA, 2011; Moretto et al., 2017). The contaminants considered in this case have evidence of co-exposure (i.e.: are found in the same well water source), and some of them have potentially common endpoints (i.e.: diabetes has been found to be associated with U, Mn, and As). In addition, a CRA was justified, and conducted, in the original study by Eggers et al. (2018) (Table 5-1). Following US EPA and other relevant risk assessment guidance (US EPA, 2011; OECD, 2018), and aligned with the original community-based study, the present case study thus considers all chemicals within a common chemical assessment group.

Step 2: Problem Formulation

This risk assessment will aim to answer: 'What are the cumulative risks associated with Apsáalooke Tribal community members' exposures to inorganic well water contaminants?'. The contaminants of interest are uranium (U), manganese (Mn), arsenic (As), zinc (Zn), and nitrate (NO3-). The assessment will characterize non-cancer risks associated with contaminants (both cumulatively and independently), and subsequently consider the effects of modulating factors (i.e.: economic, cultural, social, legal, and physical factors).

Step 3: Assembly of Information (Exposure and Toxicity)

Exposure information (i.e.: contaminant measures of 164 wells, 197 participant surveys from 165 Tribal families) for well water at the community level is summarized (Table 5-3) (Eggers et al., 2018). This information represents a relatively high tier of exposure data (environmental monitoring data- Tier 2 of the RISK21 framework) and provides evidence of common exposure as the contaminants were found in the same well water samples.

Toxicity information available in the Integrated Risk Information System (IRIS) from the US EPA (Table 5-3) represents the highest level of evidence for chemical toxicity data used for regulatory decision making on human health risks in both the US and Canada (Health Canada, 2021; US EPA, 2023c; US EPA, 2023d). An evidence/concordance table was created to compare details of the toxicity information amongst the chemicals (supplemental materials S3). While it is established that As exposures are associated with carcinogenic risks (International Agency for Research on Cancer, 2012), for demonstrative and simplistic purposes, and as the case is not meant to be interpreted as real risk assessment results, the assessment here presented considers non-carcinogenic risks only.

Table 5- 3: Exposure and toxicity information and Hazard Quotients for contaminants found in well water on the Crow Reservation, Montana (Eggers et al. 2018). Exposure calculations assume a standard human body weight of 70kg, and an average well water consumption rate of 2L/day per the original assessment. The RfDs are from the US EPA IRIS database through US EPA CompTox (https://comptox.epa.gov/dashboard) The right column displays the Hazard Index (HI) method for CRA, which involves summing chemical hazard quotients (HQ). Given that the HI is >1, the combined exposure to the chemicals of concern is at a level that poses a human health risk greater than that of individual chemicals. IRIS, Integrated Risk Information System; RfDs, reference doses; CRA, cumulative risk assessment.

Chemical Name	**Average exposure (ug/kg/day)**	**Reference dose (ug/kg/day)**	**Hazard quotients (HQ)**
Arsenic (As)	0.034	0.3	0.114
Manganese (Mn)	2.914	46	0.063
Zinc (Zn)	3.143	300	0.01
Nitrate (Ni)	46	1600	0.029
Uranium (U)	0.229	0.2	1.143
SUM (Hazard Index)			**1.356**

Step 4: Using the RISK21 Matrix to Assess Risk

a. **Plotting information on the RISK21 matrix:** The exposure and toxicity information were plotted on the RISK21 matrix (Figure 5-2). Lines on the matrix define three areas: area of potential concern for individual compounds (right of the solid black line), area in which chemicals are considered for a CRA (between solid and dashed black lines), and area of no concern (left of the dashed black line). The lines represent cut-off points for exposure/toxicity ratios, which may be determined by policy or the scenario in question (for demonstrative purposes we use 1:1 and 1:1000 margins of exposure for the lower and higher thresholds, respectively). The matrix shows that U exposures alone are at a level which may pose a risk to human health. Depending on the priorities outlined in the problem formulation stage, the risk assessment may stop here until the risks posed by U are addressed. The remaining chemicals lie between the dashed and solid black lines, so do not pose human health risks independently, but we may assess them as a chemical group (Moretto et al., 2017). Notably, as this plot used average exposure estimates, it may not represent 'high consumers' (ex.: those exceeding 2L of water consumption per day or using highly contaminated wells) and does not account for background exposures (ex.: water used in food preparation). Furthermore, oral reference doses (RfDs) are used to estimate toxicity in this assessment, which produces different results than would the use of other reference values. For example, Maximum Contaminant Level Goals (MCLGs) for drinking water as defined by the US EPA are set at a value of zero for both As and U (US EPA, 2024). Thus, the risks as calculated from RfDs identify U alone as being at a level of concern, but if the EPA MCLGs for drinking water were applied, As would also be identified. The determination of which guidelines should be used in an assessment would be community-specific and dependent upon the problem formulation stage.

b. **Applying CRA method:** Based on the above assessment of the RISK21 matrix, we conduct a multi-chemical CRA using an existing methodology. Aligned with the original assessment by Eggers et al. (2018), we used a Hazard Index (HI) method, which involves summing the Hazard Quotients (HQ) (i.e. the ratios between the exposure and toxicity values of each chemical) (Table 5-3). An HI >1.0 indicates that there are non-carcinogenic health risks for well water consumption over a lifetime (Eggers et al. 2018). The five chemicals in this case study produce an HQ of 1.36, indicating an increased risk to human health compared to exposure to each individual chemical. According to Moretto et al. (2017), the HQ cannot be accurately visualized on the RISK21 matrix due to the application of safety factors to reference doses prior to comparing them to exposure estimates. Thus, this assessment will consider individual chemicals and how non-chemical stressors may impact their exposure and toxicity.

c. **Consideration of modulating factors:** In the study by Eggers et al. (2018), 30 key informant interviews described economic, cultural, and behavioral factors within the community that may be important when assessing the contaminant data. Several other papers authored by members of the Crow Environmental Health Steering Committee and Tribal Research Group further highlight factors that may modulate contaminant exposure and/or toxicity (Table 5-4). For example, a study that conducted 97 well water tests and homeowner surveys described physical health (inability to seek out and transport clean water home), location (proximity to U sources), spirituality, and adequacy of health services as factors potentially contributing to contaminant exposure (Eggers et al., 2015). A survey of community members described that the lack of access to education and information about contamination, minimal financial and technical resources, and no routine testing or communication of results, contributed to perceived contaminant-related risks (Martin et al., 2021). Finally, complex jurisdictional and legal issues prevent the Apsáalooke/Crow Tribal community from controlling and owning contaminant monitoring, challenging their efforts to repair and replace water infrastructure and potentially contributing to ongoing exposure (Doyle et al., 2018).

Under RISK21's framework, modulating factors are understood quantitatively (i.e.: effects on biological processes and key events within a mode of action for a given chemical), falling into the categories of host, lifestyle, and environment factors (Simon et al., 2014). However, many of the factors considered in the original community-based assessment (Eggers et al., 2018) are qualitative descriptive measures of importance to the community, including survey information and local knowledge from key informants. Thus, we adapted the evidence table as proposed in the RISK21 framework to display hypothesized relationships between modulating factors and exposure/toxicity. While the magnitude of these factors cannot be precisely determined, their directional effect on either exposure or toxicity were estimated, which was based on qualitative descriptions of their effects observed in the Apsáalooke/Crow Tribal community population (Table 5-4).

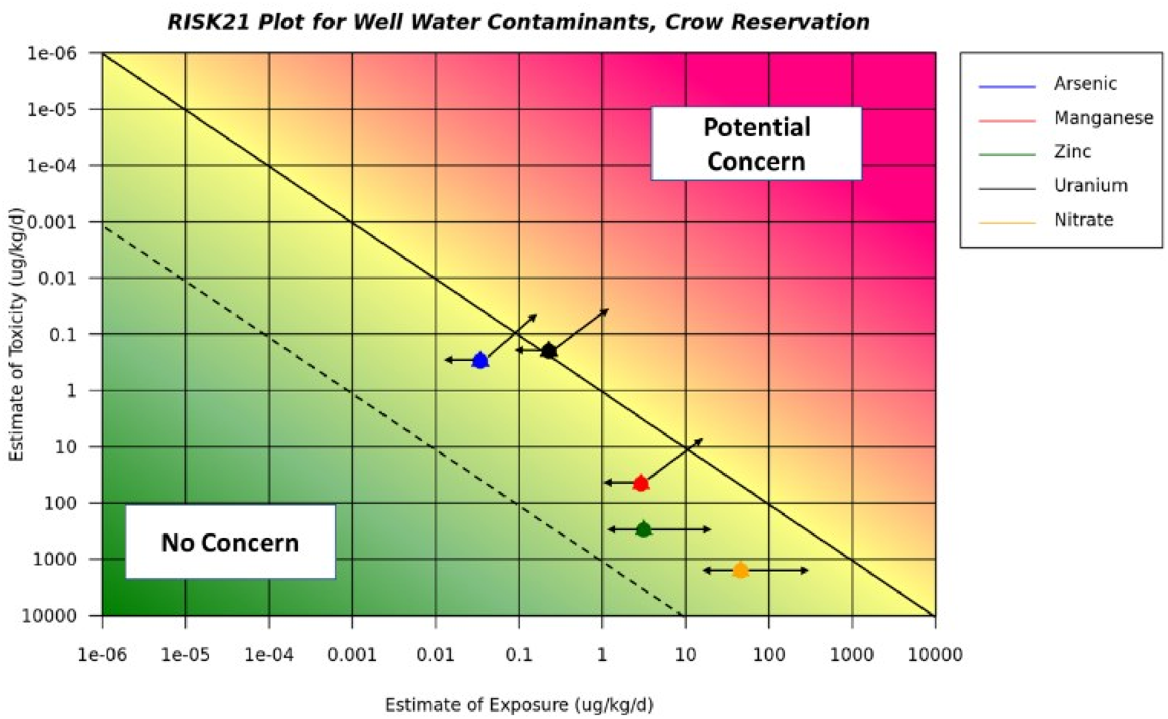
Table 5-4: Summary of modulating factors for well water contaminants on the Crow Reservation, Montana, describing hypothesized relationships between modulating factors and exposure, toxicity, or both.

Modulating Factor	**EXP or TOX**	**Description**	**Direction/ Magnitude (increase or decrease)**
Income	EXP and TOX	Purchasing bottled water and water treatment is an economic hardship for lower-income families; those that can afford bottled water use it for cooking/drinking (Eggers et al., 2018; Eggers et al,. 2015). Lower socio-economic status families have decreased access to healthcare services, increasing toxicity risks (Mitchell, 2019).	Increase and decrease (all contaminants)
Access to and adequacy of health services	TOX (?)	Lack of adequate health care services leads to inadequate treatment of potential toxic effects of exposures to chemicals in well water (Eggers et al. ,2015).	Increase (all)
Physical health	EXP	Poor physical health decreases one's ability to seek out and transport clean water home, reliance on contaminated well water increases (Eggers et al., 2015; Martin et al., 2021).	Increase (all)
Environmental health literacy	EXP	21% of community members surveyed felt confident they understood well stewardship measures to protect well water from contamination (Eggers et al., 2018). No significant difference in exposure for 'Environmentally literate" participants (Eggers et al., 2018). This has been noted in other studies in Indigenous communities (Dellinger et al., 2022).	Unknown
Access to information and education	EXP	Reservation members feel they lack access to information about water quality concerns (Martin et al., 2021). No community-based opportunities for homeowners to learn how to take care of wells or plumbing (Martin et al., 2021).	Increase (all)
Environmental regulation	EXP	Inadequate environmental enforcement and complex legal and regulatory issues contribute to drinking water disparities (Eggers et al., 2018). Delay in addressing contamination and establishing clean water infrastructure- under-recognition of Local Knowledge as water quality data needed to secure funding, institutionalization of funding boards, intersecting legal responsibilities (state vs. federal), poor environmental enforcement, lack of tribal authority (Doyle et al., 2018).	Increase (all)
Diabetes prevalence rates	TOX	Diabetes prevalence double the statewide average. Diabetes increases vulnerability to nephrotoxic effects of U (Eggers et al., 2018; Menke, 2016). U in urine increases likelihood of diabetes (Menke, 2016) Physicians in the community health center have noticed that people with diabetes are losing kidney function more rapidly (Eggers et al., 2018). Diabetes has also been associated with both Mn (Shan, 2016) and As exposures (Liu, 2016; Rahman, 1998; Tseng and Chen, 2000)	Increase (U, Mn, As)

Plotting modulating factors on the RISK21 matrix: Based on the above information on modulating factors, we add directional arrows to the RISK21 matrix to represent hypothesized changes to exposure and/or toxicity that these factors may precipitate (Figure 5-2). While there is evidence from the literature to support a potential relationship between modulating factors on exposure to and toxicity of the metals found in well water (both as a group and individually), the effects of these factors (socio-cultural and socio-economic) are variable and often qualitative, and thus it is not possible to accurately estimate the magnitude of increased or decreased risk. Rather, the figure presents a visual representation of the hypothesized potential relationship of these factors to exposure and toxicity.

d. **Conclusions from plotting of modulating factors:** Based on the visual representation of modulating factors in relation to individual chemical exposure and toxicity, it is apparent that these factors have the potential to bring some chemicals (i.e.: As and Mn) from an area of “no expected risk” to an area of “potential human health risk”, while also magnifying the “potential human health risk” of U.

Figure 5-2: RISK21 plot displaying estimates of toxicity and exposure data for chemicals of concern in well water on the Crow Reservation, Montana. Plot created using the RISK21 Webtool (www.risk21.org). The solid line defines the area of potential concern for individual compounds (cut-off set at a 1:1 margin of exposure). The dashed line represents the level above which chemicals may be considered for a CRA, or below which the exposure is low enough to indicate no concern for interaction (set at ratio of exposure/toxicity of 1:1000). The arrows represent modulating factors on the matrix from the second-tier assessment. Note there are some chemicals (Arsenic, Manganese, and Zinc) with evidence of modulating factors potentially increasing both exposure and toxicity (for example, diabetes and uranium exposure both as risk factors for poor kidney health), and thus a diagonal arrow is placed to represent this. Note that the arrow sizes are not proportional to the magnitude of an estimated effect.



Step 5: Outcomes and Conclusions

Conclusions that come from the above assessment may be that exposures to well-water contaminants, in combination with one another and in the context of non-chemical modulating factors, potentially pose health risks to Apsáalooke/Crow Tribal community members. Variations amongst individual community members' physical and social factors may be either protective or further increase contaminant-related risks. We may also use the above assessment to prioritize specific chemicals of concern (i.e.: U) that exceed regulatory limits on their own.

5.5 DISCUSSION

5.5.1 Objective 1: Conventional versus RISK21-based HHRA

Case Study 1

The first case study pilots the use of the RISK21 approach for dietary risk characterization of cadmium in moose muscle, kidney, and liver in the CLFN and CPFN. The case used a tiered exposure assessment, initially using regional-level data to estimate exposure values and progressing to the use of community-specific information. We compare the original community-based assessment (McAuley et al., 2018), which examined exposures to cadmium and determined benchmark consumption quantities, to the RISK21-based assessment (tier 0, regional-level exposure estimates, and tier 1, community-level exposure estimates), both quantitatively and descriptively. First, from a quantitative perspective, the original assessment indicates that the risk value (HQ) for high consumers of moose kidney is equal to one. In the RISK21-based assessment, we calculated HQ < 1 for high consumers of cadmium in the tier 0 assessment (regional data). In the tier 1 assessment using community-specific data, in CLFN we also calculated HQ < 1, though in CPFN we calculated HQ > 1 (supplemental materials S4). Notably, the original assessment considered background exposures, with an assumption of a background cadmium exposure of 0.22 ug/kg-bw/day, and thus used an “allowable cadmium exposure” of 0.78 ug/kg-bw/day (2018), while the RISK21-based HQ calculations used a reference dose of 1 mg/kg-bw/day, which does not account for background exposures. Furthermore, the original assessment combined data across three communities, while the RISK21-based assessments were community-specific in tier 1. Lastly, the original assessment determined benchmark consumption quantities, while the RISK21-based assessment did not. From a descriptive or decision-making perspective, the original risk assessment published by

McAuley et al. (2018) concluded that moose muscle was safe, while kidney and liver consumption should be limited. In comparison, the results of our RISK21 case study here concluded that kidney should be consumed with caution (i.e.: high consumers land in the “red zone” on the matrix). Muscle tissues were in the “green zone” (i.e.: no concern), while liver was plotted in the “yellow zone” (i.e.: potential concern) for CPFN for the second-tier assessment, while all tissues fell into the “green zone” for CLFN. The use of this information would be at the discretion of decision-makers. In the context of RISK21, the less “precise”, lower-tier estimates (i.e.: generated from regional-level data) might be used for preliminary decisions when community-level data are unavailable.

Case Study 2

The second case study used the RISK21 CRA framework to demonstrate a quantitative CRA of multiple chemical stressors, and subsequently visualize potential relationships between non-chemical modulating factors and contaminant exposure and toxicity in the context of quantitative exposure and toxicity data, survey data, and secondary demographic information from the Apsáalooke/Crow Tribal community. The assessment may be used to highlight the need for measures to directly reduce exposure (i.e.: through environmental health education, remediation, and legal and policy action) and reduce the impact of modulating factors that potentially contribute to disproportionate exposure and toxicity (i.e.: addressing social determinants of health linked to socioeconomic status such as housing and water security, better access to primary and tertiary healthcare, etc.).

We compare the assessment conducted on the Crow Reservation by Eggers et al. (2018) to the presented RISK21-based case. Quantitatively, both the original study and RISK21-based assessment used the same CRA methodology (Hazard Index), and thus the results were comparable. Descriptively, conclusions stemming from the RISK21 case study here (i.e.: that multiple chemical exposures, and other contextual factors, may increase health risks related to well water contamination for Apsáalooke/Crow Tribal community members) is aligned with those reported in the original assessment by Eggers et al. (2018). Methodologically, a notable difference was the requirement of a "gatekeeper step" in RISK21 for chemicals to have both evidence of common toxicity and co-exposure (Moretto et al., 2017), while in contrast, there is a general lack of agreement from the scientific community on when it is toxicologically appropriate to group chemicals for CRA (Callahan and Sexton, 2007; Moretto et al., 2017), and criteria can range from co-exposure only to a variety of toxicity information. US EPA published guidelines and current literatures on CRA were followed in the original community-based case and in the present case study (US EPA, 2011; Stoiber et al., 2019). Another key difference was that the RISK21 framework favors quantitative information input on modulating factors, while the information of importance to the original community assessment is largely qualitative and descriptive. Despite these differences, we were able to plot the information on the RISK21 matrix. In this sense, we found the tool to be flexible for a range of data availability contexts and found the matrix useful for integrating and visualizing multiple information sources.

5.5.2 Objective 2: Challenges and benefits

Case Study 1

In the first case study, there were several data limitations to consider in the interpretation of the RISK21 assessment results. First, cadmium concentrations in moose organ tissues are related to age (Arnold et al., 2006), and the assessment does not account for this. The animals harvested by CLFN were juveniles, therefore the cadmium organ concentrations were much lower than those in animals harvested by CPFN (i.e.: average liver cadmium concentrations were 2.582 ug/g in CPFN harvested moose versus 0.860 ug/g in CLFN harvested moose; and similarly, 11.948 versus 4.6 ug/g for kidney and 0.039 versus 0.004 ug/g for muscle, respectively). A second limitation was the use of standardized assumptions to calculate exposure. For example, the use of standard human body weight and regional-level exposure data may miss important outliers related to country food consumption at the community level (ex: children and older adults). While the lower-tier exposure estimates may be useful for an initial assessment, the variations between the first and second assessments' RISK21 matrices demonstrates that obtaining community-level exposure information can assist with understanding variations between exposures in individual communities. Finally, the RISK21-based case studies presented here did not account for background exposures, potentially leading to an underestimate of exposure values.

We note some challenges with the use of the RISK21 approach in this context. First, the matrix was limited in its application to community-level risk communication. The authors of the original risk assessment did not foresee the tool to be able to help communities to understand risk in a different way. While the matrix is likely simple to use for those with experience in risk assessment and provides a risk visualization tool that can facilitate discussion between risk assessment professionals, it may not be interpretable by the general community or easy to communicate, which is a priority for the CLFN and CPFN. This perspective is consistent with literature on the persistent challenges with risk communication in many other Indigenous communities globally (Boyd and Furgal, 2019; Boyd and Furgal, 2022; Fernández-Llamazares et al., 2020). The original publication by McAuley et al. (2018) aimed to estimate benchmark consumption quantities associated with minimal health risks for community members (i.e.: amounts that can be safely consumed, in servings per month). While the tool can assist with these estimations, the matrix itself is not widely accessible as a risk communication tool.

Furthermore, an important element of risk communication for CPFN and CLFN is the ability to account for potential food insecurity (for example, through the loss of confidence in traditional food systems resulting from consumption advisories) (McAuley and Knopper, 2011), which is not inherent to this approach. Previous writings on risk communication in Indigenous communities evidences the potentially negative impacts of miscommunicating or misunderstanding risks related to country foods. For example, an assessment of traditional food alternatives for coastal First Nations communities in BC found that switching to market foods may pose greater health risks than continuing to eat potentially contaminated traditional food (Wiseman and Gobas, 2002). Incorporating different units of measure into the RISK21 matrix, such as servings per month as opposed to mg/kg/day, may be more appropriate for community-wide risk communication. Consumption guidance regarding reducing the size of meals from older animals may help to reduce exposure. The National Research Council (1996) writes that decision-making must recognize uncertainties in risk assessments, including both the magnitude and its sources, as well as fundamental biases. RISK21's visual output may also be made more transparent as a decision-making tool by including a component indicating the precision of the assessment, data tiers used, and uncertainties.

The regional data from the recent FNFNES study was helpful for estimating exposures in the absence of community-specific consumption data and was used in both the RISK21-based and original community HHRAs. In combination with other databases (ex.: US EPA CompTox dashboard), the FNFNES exposure data (i.e. consumption information and average regional concentrations of contaminants found in a variety of traditional foods) can be used for preliminary risk assessment. It is important to emphasize that the use of regional data (when available) would be based upon the community-level risk assessment needs and may not be appropriate to address all risk assessment goals, and thus detailed problem formulation is an essential first step (Pastoor et al., 2014). In the context of a community-based assessment, initial problem formulation needs to be community-led and community perspectives on the data needed for decision-making should be prioritized.

Case Study 2

There were several potential challenges with the RISK21 approach in the context of cumulative risk assessment for well water contamination in the Apsaálooke/Crow Nation. First, within-community variations in exposures and modulating factors are difficult to communicate through the visual matrix (for example, socio-economic status and spatial variations in U concentrations) (Eggers et al., 2015). The integration of this information into the visual output may be an area for adaptation. Second, as mentioned above, RISK21's framework favors quantitative information to estimate the effects of modulating factors on exposure and toxicity

(Solomon et al., 2016), though this does not well-capture the historical nature (i.e.: over several decades, and in a format that is descriptive and observational) of how water contamination has affected community members (Doyle et al., 2018). For example, Apsáalooke/Crow Tribal community members have noted that the loss of water security has contributed to poor physical health outcomes, deterioration of ecosystems and species vital to spiritual and cultural practices (Doyle et al., 2018), and a loss of connection to the land (Eggers et al., 2015). This is consistent with writings from other communities and Indigenous scholars on the importance of cumulative and holistic risk assessment that includes qualitative information. For example, the Mohawk community of Akwesasne writes that a holistic risk assessment approach must consider multi-disciplinary and qualitative information sources (Arquette et al., 2002). Harris and Harper's (2000) work on eco-cultural dependency webs in tribal health risk assessment describes that elements of health (ecological, human, socio-cultural, and socio-economic) interact in complex ways and must be factored into assessments. These and other "non-conventional" information sources need to be considered in a CRA. Though there is minimal consensus to date on how this might be achieved (Callahan and Sexton, 2007; Sexton 2012; Sexton, 2015), writings on CRA methods have defined that qualitative assessments are possible, depending on the circumstances, and in some cases may be the only way to understand complex cumulative risks (ex.: sociocultural stressors accompanying the known presence of contaminants in traditional foods) (Callahan and Sexton, 2007). In this case study, we adapted the RISK21 approach to visualize hypothesized relationships between qualitative data and exposure and toxicity estimates. Development and adaptation of methods to account for qualitative information in risk assessment is an area for further research. Lastly, RISK21 is a human health (as opposed to ecological) risk assessment tool, which is consistent with regulatory standards in which these are conventionally considered as separate assessments. Considering both human and ecological risks, as well as interacting components, is important to include in modernized risk assessments, especially in Indigenous communities. This need was recently highlighted in a statement from the Assembly of First Nations in response to proposed amendments to the Canadian Environmental Protection Act (CEPA) through Bill S-5 (AFN, 2022). Further adaptations to the RISK21 tool might consider adding an integrated ecological risk assessment step that is factored into an overall improved understanding of cumulative risk. The need for a shift from single-chemical risk assessment approaches to CRA is recognized in Bill S-5 and globally (National Research Council, 2009; WHO, 2009; Government of Canada, 2022). This case study supports that new CRA methods, such as RISK21 be developed for a variety of data contexts, including in situations with disparate evidence on modes of action for chemicals (which is not readily available for the tens of thousands of chemicals available on the global market), and for a diversity of non-chemical information of importance to communities.

5.5.3 Objective 3: Potential adaptations and areas for further research

Conventional risk assessment work in Indigenous communities faces several inherent challenges (Harris, 2000; Arquette et al., 2002; Harper et al., 2012; Chong and Basu, 2023), and as we consider modernizing risk assessment practices, these challenges must be accounted for. In the current study, we piloted the use of the RISK21 approach in the context of two case studies involving three Indigenous communities and discussed the cases amongst co-authors from the communities of focus. In doing so, we uncovered some considerations for the improvement of next-generation risk assessment approaches such as RISK21.

First, the RISK21 approach follows a “hierarchy” of evidence, in which certain sources of evidence and knowledge are privileged over others through the tiering of information. This approach prioritizes the initial chemical assessment over non-chemical stressors and does not well incorporate non-quantitative (i.e.: qualitative, descriptive) information. Similarly, for communities who engage in risk assessment work, the privileging of western-scientific information over Indigenous knowledge systems is an ongoing challenge, as cited in a recent systematic review on the braiding of Indigenous knowledge systems and western sciences in the Alberta oil sands region (Wilcox et al., 2023). These findings and ours highlight the need for a better understanding of biases towards the value of certain evidence sources within risk assessment approaches, and adaptations that best meet community-specific contexts. The US National Research Council (NRC) recommends that cumulative risk assessment should be included in regulatory decision-making, instead of as a part of a general background description of context (NRC, 2009; Sexton, 2015). Further, writings on Indigenous processes of decision-making emphasize that Traditional Knowledge and political systems must be considered in addition to conventional risk assessment findings to make well-informed environmental management decisions, such as in the Inuvialuit Final Agreement (Indian and Northern Affairs Canada, 2005). Similarly, we found that non-quantitative evidence of importance to communities should be considered as primary as opposed to secondary, contextual information. This may include the consideration of non-conventional information sources (ex., local and traditional knowledge, descriptive and qualitative information). The meaningful use of such information in risk assessment, and its potential incorporation into the RISK21 tool is an area for further research.

Second, while the definition of 'health' in conventional risk assessment guidance tends to focus on physical health risks related to chemical exposures (Health Canada, 2019; US EPA, 2022), Indigenous communities and leaders have called for a more holistic perspective (Chong and Basu, 2023). For example, the Mohawk community of Akwesasne (Arquette et al., 2002) and the Confederated Tribes of the Umatilla Indian Reservation (Harris and Harper, 2000) have published papers with approaches to risk assessment that consider interconnected economic, environmental, political and social factors. The RISK21 CRA framework may assist in providing a way to visualize and incorporate multiple sources of information related to physical health risks, and we recommend that new approaches such as RISK21 continue to be adapted to consider diverse definitions of 'health' and a holistic understanding of health risks. This may include re-defining and increasing the parameters of key terminology used in RISK21 to facilitate its adaptation to specific contexts.

Third, we recommend that risk assessment approaches such as RISK21 continue to strive to improve the communication of results to communities in ways that are meaningful and relevant. In our case studies, it was deemed that the visual communication output (i.e.: RISK21 matrix) remained most accessible to those with an expertise with conventional risk assessment work, but less so for community members. For example, axes labeled with exposure and toxicity estimates in ug/kg/day are not readily interpretable into tangible applications for risk management at the community or individual level. The risk communication matrix presented here may be most helpful within a 'western-scientific' understanding of risk but may still not be suitable for communities themselves. This is consistent with previous writings on the limitations of conventional risk communication in Indigenous community contexts, especially related to traditional foods (McAuley and Knopper, 2011; Robin et al., 2021). Further research may explore how to bridge this gap, including through the consideration of community-level communication from the beginning of risk assessment processes that are led by communities themselves. One idea is to use social media and new technology, which has been evidenced to improve health risk messaging in the Arctic, notably by replacing traditional top-down approaches with two-way communication that in turn can be used to better understand the perceptions and interpretations of messages from the community at large (Krummel and Gilman, 2016; Basu et al., 2022). We also note that the communities of focus in the presented case studies, and many others who conduct community-based risk assessment work, have strong communication strategies and ongoing efforts to make risk assessment results relevant to community members. We recommend that newly designed risk assessment approaches consider ways in which their outputs could be made more harmonious with community-level communication efforts.

Finally, and fourth, for many Indigenous communities, risk assessment work requires holistic, community-specific approaches, as well as time to establish trusting relationships between communities and external risk assessors. '21^{st} Century Risk Assessment' of increasing interest to regulatory bodies prioritizes efficiency in decision-making, time, and resource use (National Research Council, 2009; Embry et al., 2014; CMP Science Committee, 2016; Stucki et al., 2022), which is a needed response to the current paucity of information on contaminants and contaminated sites globally. We recommend that community-based cases such as ours that explore the use of RISK21 and other new approaches may help to gather a diversity of experiences and perspectives and ensure the harmonization of community and regulatory priorities in next-generation risk assessments, and there is a need for more research in this area.

Leveraging transdisciplinary approaches such as user experience and design thinking may assist in ideating further improvements to next-generation risk assessments.

5.6 CONCLUSIONS

Two case studies were conducted to explore the use of the RISK21 HHRA framework and matrix in the context of three Indigenous communities. The first case study involved risk characterization for cadmium exposures through moose tissues consumed by the Cold Lake First Nations and the Chipewyan Prairie First Nation in Alberta. The second case was a cumulative risk assessment (i.e.: assessed multiple chemical and non-chemical factors) for exposures to well water contaminants for the Apsáalooke/Crow Tribal community in Montana. Overall, the descriptive results from the RISK21-based analysis performed here were similar to results from the original assessments. This similarity held when we performed RISK21-based analysis with lower data tiers (i.e.: using less information than a conventional assessment). We also found RISK21 potentially useful in these contexts for rapid assessment of chemicals, and for visually representing data from multiple sources. However, overall we found that the current RISK21 approach may require adaptations to adequately address the HHRA needs of the Indigenous community contexts presented here. Thus, within the two cases, we identified and discussed several areas in which the RISK21 approach may be adapted for improved relevance and utility within the specific Indigenous community contexts studied here, and these ideas may be utilized by other communities who wish to conduct similar work. These include: (1) dismantling hierarchies of evidence that favor quantitative information; (2) broadening to more holistic definitions of health in HHRAs; (3) improving community-level risk communication outputs; and (4) producing more context-specific case studies to understand the use and adaptation of the tool in a variety of contexts.

5.6.1 Limitations

The two case studies presented represent unique risk assessment situations in three Indigenous communities across North America. However, as is the nature of case studies, the findings reflect a snapshot in time in the communities of focus. In addition, they were purposefully selected here for demonstrative purposes. There is a wide diversity of communities and purposes for which risk assessments are used, as demonstrated in the FNFNES study which reported large differences in exposure estimates according to seasonal, agricultural, and traditional food patterns and use among First Nations communities across Canada (Chan et al., 2021). This diversity extends internationally as described in a recent review of Indigenous peoples and pollution (Fernandez-Llamazares et al., 2020). Thus, the presented cases using RISK21 here may not be widely generalizable. Further, assumptions inherent to risk assessment increase uncertainty in the context of Indigenous communities. For example, the standard body weight from Health Canada is derived from the general population, although it is well-known that nutrition and food security in Indigenous communities contributes to differences in average weight. Finally, though the data collection methods used in the originally cited assessments were rigorous, and every effort was made to minimize biases, researcher bias is inherent to case study methodology, and is present in our reported results and interpretations.

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Data generated or analyzed during this case study are provided within the article. The original published articles are referenced and publicly available online.

Competing interests: The authors declare there are no competing interests.

5.8 References

Arnold SM, Zarnke RL, Lynn TV, Chimonas M-AR, and Frank A. (2006). Public health evaluation of cadmium concentrations in liver and kidney of moose (Alces alces) from four areas of Alaska. *Science of the Total Environment,* 357(1-3), 103-111. https://doi.org/10.1016/j.scitotenv.2005.02.040

Arquette M, Cole M, Cook K, LaFrance B, Peters M, Ransom J, Sargent E, Smoke V, and Stairs A. (2002). Holistic risk-based environmental decision making: A native perspective. *Environmental Health Perspectives,* 110, 259-264. https://doi.org/10.1289/ehp.02110s2259

Assembly of First Nations. (2022). *Submission to the House of Commons Committee on Environment and Sustainable Development. Study on Bill S-5 An Act to Amend the Canadian Environmental Protection Act, 1999, to make related amendments to the Food and Drugs Act and to repeal the Perfluorooctance Sulfonate Virtual Elimination Act*. Retrieved December 29, 2023 from https://www.ourcommons.ca/Content/Committee/441/ENVI/Brief/BR12143095/br-external/AssemblyOfFirstNations-e.pdf

Boyd AD, and Furgal CM. (2019). Communicating environmental health risks with Indigenous populations: A systematic literature review of current research and recommendations for future studies. *Health Communication,* 34(13), 1564-1574. https://doi.org/10.1080/10410236.2018.1507658

Boyd AD and Furgal CM. (2022). Towards a participatory approach to risk communication: the case of contaminants and Inuit health. *Journal of Risk Research*, 25(7), 892-910. https://doi.org/10.1080/13669877.2022.2061035

Burger J and Gochfeld M. (2011). Conceptual environmental justice model for evaluating chemical pathways of exposure in low-income, minority, Native American, and other unique exposure populations. *American Journal of Public Health,* 101(S1), S64-S73. https://doi.org/10.2105%2FAJPH.2010.300077

Callahan MA, and Sexton K. (2007). If cumulative risk assessment is the answer, what is the question? *Environmental Health Perspectives,* 115(5), 799-806. https://doi.org/10.1289/ehp.9330

Chan HM, Fediuk K, Batal M, Sadik T, Tikhonov C, Ing A, and Barwin L. (2021). The First Nations Food, Nutrition and Environment Study (2008–2018)—rationale, design, methods and lessons learned. *Canadian Journal of Public Health,* 112, 8-19. https://doi.org/http://dx.doi.org/10.17269/s41997-021-00480-0

Chan L, Receveur O, Batal M, David W, Schwartz H, Ing A, Fediuk K and Tikhonov C. (2016). First Nations Food, Nutrition and Environment Study (FNFNES): Results from Alberta 2013. University of Ottawa, Ottawa, ON, 155. Retrieved November 17 2023 from https://www.fnfnes.ca/docs/FNFNES_Alberta_Regional_Report_ENGLISH_2019-10-09.pdf

Chong K and Basu N. (2023). Contaminated Sites and Indigenous Peoples in Canada and the US: A Scoping Review. *Integrated Environmental Assessment and Management, 00*. https://doi.org/10.1002/ieam.4869

CMP Science Committee. (2016). Meeting no.5: 16-17 November 2016 Integrating New Approach Methodologies within the CMP: Identifying Priorities for Risk Assessment, Existing Substances Risk Assessment Program. Retrieved November 17 2023 from https://www.ec.gc.ca/ese-ees/default.asp?lang=En&n=172614CE-1

Damman S, Eide WB and Kuhnlein HV. (2008). Indigenous peoples' nutrition transition in a right to food perspective. *Food Policy*, 33(2), 135-155. https://doi.org/https://doi.org/10.1016/j.foodpol.2007.08.002

Dellarco M, Zaleski R, Gaborek B, Qian H, Bellin C, Egeghy P, Heard N, Jolliet O, Lander D and Sunger N. (2017). Using exposure bands for rapid decision making in the RISK21 tiered exposure assessment. *Critical Reviews in Toxicology*, 47(4), 317-341. https://doi.org/10.1080/10408444.2016.1270255

Dellinger MJ, Pingatore N, Chelius T, Visotcky A, Sparapani R and Ripley M. (2022). Environmental health literacy for Anishinaabe (Great Lakes Native American) fish consumers: A randomized control trial. *Environmental Research,* 212, 113335. https://doi.org/https://doi.org/10.1016/j.envres.2022.113335

Doe JE, Lander DR, Doerrer NG, Heard N, Hines RN, Lowit AB, Pastoor T, Phillips RD, Sargent D, Sherman JH, Young Tanir J and Embry MR. (2016). Use of the RISK21 roadmap and matrix: human health risk assessment of the use of a pyrethroid in bed netting. *Critical Reviews in Toxicology,* 46(1), 54-73. https://doi.org/10.3109/10408444.2015.1082974

Doyle JT, Kindness L, Realbird J, Eggers MJ and Camper AK. (2018). Challenges and opportunities for tribal waters: Addressing disparities in safe public drinking water on the Crow Reservation in Montana, USA. *International Journal of Environmental Research and Public Health,* 15(4), 567. https://doi.org/10.3390/ijerph15040567

Eggers MJ, Doyle JT, Lefthand MJ, Young SL, Moore-Nall AL, Kindness L, Medicine RO, Ford TE, Dietrich E, Parker AE, Hoover JH, and Camper AK. (2018). Community Engaged Cumulative Risk Assessment of Exposure to Inorganic Well Water Contaminants, Crow Reservation, Montana. *International Journal of Environmental Research and Public Health*, 15(1), Article 76. https://doi.org/10.3390/ijerph15010076

Eggers MJ, Moore-Nall AL, Doyle JT, Lefthand MJ, Young SL, Bends AL, Crow Environmental Health Steering Committee and Camper AK. (2015). Potential health risks from uranium in home well water: An investigation by the Apsaalooke (Crow) tribal research group. *Geosciences,* 5(1), 67-94. https://doi.org/10.3390/geosciences5010067

Embry MR, Bachman AN, Bell DR, Boobis AR, Cohen SM, Dellarco M, Dewhurst IC, Doerrer NG, Hines RN, Moretto A, Pastoor TP, Phillips RD, Rowlands JC, Tanir JY, Wolf DC, Doe JE. (2014). Risk assessment in the 21st century: Roadmap and matrix. Critical Reviews in Toxicology, 44:6-16. doi: 10.3109/10408444.2014.931924.

Embry MR. 2018. HESI's Risk Assessment in the 21st Century (RISK21) Framework: Overview and Applications Online, ACS. Retrieved November 17 (2023) from https://www.agrodiv.org/webinars/hesis-risk-assessment-in-the-21st-century-risk21-framework-overview-and-applications/

Fernández-Llamazares Á, Garteizgogeascoa M, Basu N, Brondizio ES, Cabeza M, Martínez-Alier J, McElwee P and Reyes-García V. (2020). A State-of-the-art review of Indigenous peoples and environmental pollution. *Integrated Environmental Assessment and Management*, 16(3), 324-341. https://doi.org/https://doi.org/10.1002/ieam.4239

Fox MA, Brewer LE and Martin L. (2017). An overview of literature topics related to current concepts, methods, tools, and applications for cumulative risk assessment (2007–2016). *International Journal of Environmental Research and Public Health,* 14(4), 389. DOI: 10.3390/ijerph14040389

Government of Canada. (2017). Canadian Arctic Contaminants Assessment Report- Human Health Assessment. Retrieved November 20 2023 from https://pubs.aina.ucalgary.ca/ncp/84294.pdf

Government of Canada. (2021). Federal Contaminated Sites Inventory. Retrieved April 2022 from https://www.tbs-sct.gc.ca/fcsi-rscf/home-accueil-eng.aspx

Government of Canada. (2022). *Bill S-5, Strengthening Environmental Protection for a Healthier Canada Act- Summary of Amendments*. Ottawa, Ontario. Retrieved November 17 2023 from https://www.canada.ca/en/services/environment/pollution-waste-management/strengthening-canadian-environmental-protection-act-1999/bill-c-28-strengthening-environmental-protection-healthier-canada-act-summary-amendments.html

Harper B, Harding A, Harris S, and Berger P. (2012). Subsistence exposure scenarios for Tribal applications. Human and Ecological Risk Assessment, 18(4), 810-831. https://doi.org/10.1080/10807039.2012.688706

Harris SG. (2000). Risk analysis: Changes needed from a Native American perspective. Human and Ecological Risk Assessment, 6(4), 529-535. https://doi.org/10.1080/10807030008951325

Harris SG and Harper BL. (2000). Using eco-cultural dependency webs in risk assessment and characterization of risks to tribal health and cultures. Environmental Science and Pollution Research, 2(2), 91-100.

Health Canada. (1986). Cadmium. Retrieved November 17 2023 from https://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/cadmium/index-eng.php

Health Canada. (2004). Federal Contaminated Site Risk Assessment in Canada. Retrieved November 17 2023 from https://publications.gc.ca/collections/Collection/H46-2-04-367E.pdf

Health Canada. (2019). Selection of Body Weights Values for Use in Human Health Risk Assessment (HHRA) Conducted by Health Canada. Task Force on Scientific Risk

Assessment. Retrieved November 17 2023 from https://www.canada.ca/content/dam/hc-sc/documents/services/health/publications/science-research-data/selection-body-weights-values-human-health-risk-assessment/27-16-1696_Body-Weight-Use-HHRA-ENG.pdf

Health Canada. (2021). Federal Contaminated Site Risk Assessment in Canada: Toxicological Reference Values (TRVs). Government of Canada. Retrieved December 18 2023 from https://publications.gc.ca/collections/collection_2021/sc-hc/H129-108-2021-eng.pdf

HESI (Health and Environmental Sciences Institute). (2023). RISK 21 Webtool. Retrieved October 27 2023 from https://risk21.org/

HESI (Health and Environmental Sciences Institute). (N.D.). Fact Sheet: Risk Assessment in the 21st Century (RISK21). Health and Environmental Sciences Institute. Retrieved November 17 2023 from https://hesiglobal.org/wp-content/uploads/2022/01/RISK21-2021-v2.pdf

Indian and Northern Affairs Canada. (2005). Inuvialuit Final Agreement. Retrieved November 17 2023 from https://irc.inuvialuit.com/sites/default/files/Inuvialuit%20Final%20Agreement%202005.pdf

International Agency for Research on Cancer. (2012). *Arsenic, metals, fibres and dusts.* IARC monographs on the evaluation of carcinogenic risks to humans. Retrieved March 8 2024 from https://publications.iarc.fr/Book-And-Report-Series/Iarc-Monographs-On-The-Identification-Of-Carcinogenic-Hazards-To-Humans/Arsenic-Metals-Fibres-And-Dusts-2012

Krummel EM, Gilman A. (2016). An update on risk communication in the Arctic. *International Journal of Circumpolar Health* 75: 33822. https://doi.org/10.3402/ijch.v75.33822

Liu BF, Wang J, Li Y, Han X, Hu H, Guo H, Zhang X. (2016). Association of urinary metals levels with type 2 diabetes risk in coke oven workers. *Environmental Pollution,* 210, 1-8. https://doi.org/10.1016/j.envpol.2015.11.046

Martin C, Simonds VW, Young SL, Doyle J, Lefthand M and Eggers MJ. (2021). Our relationship to water and experience of water insecurity among Apsáalooke (Crow Indian) people, Montana. *International Journal of Environmental Research and Public Health*, 18(2), 582. https://doi.org/10.3390/ijerph18020582

McAuley C and Knopper LD. (2011). Impacts of traditional food consumption advisories: compliance, changes in diet and loss of confidence in traditional foods. *Environmental Health.* 2011 Jun 8;10:55. doi: 10.1186/1476-069X-10-55. PMID: 21651789; PMCID: PMC3127975.

McAuley C, Dersch A, Kates LN, Sowan DR, Koppe B and Ollson CA. (2016). Assessment of exposure to chlorinated organics through the ingestion of moose meat for a Canadian First Nation Community. *Frontiers in Environmental Science*. 4 (78) https://doi.org/http://dx.doi.org/10.3389/fenvs.2016.00078

McAuley C, Dersch A, Mouille-Malbeuf S, Koppe B, and Sowan D. (2018). Cadmium tissue concentrations in kidney, liver and muscle in moose (Alces Alces) from First Nations communities in Northern Alberta. *Frontiers in Sustainable Food Systems*, 2 (69). https://doi.org/10.3389/fsufs.2018.00069

Menke A, Guallar E and Cowie CC. (2016). Metals in Urine and Diabetes in U.S. Adults. Diabetes, 65, 164-171. https://doi.org/10.2337/db15-0316

Mitchell F. (2019). Water (in) security and American Indian health: Social and environmental justice implications for policy, practice, and research. *Public Health,* 176, 98-105. https://doi.org/10.1016/j.puhe.2018.10.010

Moretto A, Bachman A, Boobis A, Solomon KR, Pastoor TP, Wilks MF and Embry MR. (2017). A framework for cumulative risk assessment in the 21st century. *Critical Reviews in Toxicology,* 47(2), 85-97. https://doi.org/10.1080/10408444.2016.1211618

National Research Council. (1996). Understanding risk: Informing decisions in a democratic society. National Academies Press. Retrieved November 17 2023 from https://nap.nationalacademies.org/read/5138/chapter/1

National Research Council. (2009). *Science and Decisions: Advancing Risk Assessment.* Washington, DC: The National Academies Press. Retrieved March 6, 2024 from https://pubmed.ncbi.nlm.nih.gov/25009905/O'Neill CA. (2000). Variable justice: Environmental standards, contaminated fish, and "acceptable" risk to Native peoples. *Stanford Environmental Law Journal,* 19, 3. Retrieved from https://digitalcommons.law.seattleu.edu/faculty/633?utm_source=digitalcommons.law.seattleu.edu%2Ffaculty%2F633&utm_medium=PDF&utm_campaign=PDFCoverPages

OECD. (2018). Considerations for Assessing the Risks of Combined Exposure to Multiple Chemicals, Series on Testing and Assessment No. 296, Environment, Health and Safety Division, Environment Directorate. Retrieved November 17 2023 from https://www.oecd.org/chemicalsafety/risk-assessment/considerations-for-assessing-the-risks-of-combined-exposure-to-multiple-chemicals.pdf

OECD. (2020). Linking Indigenous Communities with Regional Development in Canada. Retrieved November 17 2023 from https://doi.org/doi:https://doi.org/10.1787/fa0f60c6-en

Pastoor TP, Bachman AN, Bell DR, Cohen SM, Dellarco M, Dewhurst IC, Doe JE, Doerrer NG, Embry MR and Hines RN. (2014). A 21st century roadmap for human health risk assessment. *Critical Reviews in Toxicology,* 44 (Suppl 3), 1-5. https://doi.org/10.3109/10408444.2014.931923

Rahimzadeh M, Rahimzadeh M and Kazemi S. (2017). Cadmium toxicity and treatment: an update. *Caspian Journal of Internal Medecine*, 8(3), 135. https://doi.org/10.22088%2Fcjim.8.3.135

Rahman MT, Ahmad SA. Axelson O. (1998). Diabetes mellitus associated with arsenic exposure in Bangladesh. *American Journal of Epidemiology, 148*, 198-203. https://doi.org/10.1093/oxfordjournals.aje.a009624

Robin T, Burnett K, Parker B and Skinner K. (2021). Safe food, dangerous lands? Traditional foods and Indigenous peoples in Canada. *Frontiers in Communication,* 6, 749944. https://doi.org/10.3389/fcomm.2021.749944

Sexton K. (2012). Cumulative risk assessment: an overview of methodological approaches for evaluating combined health effects from exposure to multiple environmental stressors. *International Journal of Environmental Research and Public Health,* 9(2), 370-390. https://doi.org/10.3390/ijerph9020370

Sexton K. (2015). Cumulative health risk assessment: Finding new ideas and escaping from the old ones. *Human and Ecological Risk Assessment: An International Journal,* 21(4), 934-951. http://dx.doi.org/10.1080/10807039.2014.946346

Shan ZC, Sun T, Luo C, Guo Y, Yu X, Yang W, Hu FB, Liu L. (2016). U-Shaped association between plasma manganese levels and type 2 diabetes. *Environmental Health Perspectives,* 124, 1876-1881. https://doi.org/10.1289/ehp176

Simon T.W., Simons S.S., Preston R.J., Boobis A.R., Doerrer N.G., Fenner-Crisp P.A., McMullin T.S., McQueen C.A., Rowlands J.C. 2014. The use of mode of action information in risk assessment: Quantitative key events/dose-response framework for modeling the dose-response for key events. Critical Reviews in Toxicology 44: 17–43. https://doi.org/10.3109/10408444.2014.931925

Solomon KR, Wilks MF, Bachman A, Boobis A, Moretto A, Pastoor TP, Phillips R and Embry MR. (2016). Problem formulation for risk assessment of combined exposures to chemicals and other stressors in humans. *Critical Reviews in Toxicology*, 46(10), 835-844. https://doi.org/10.1080/10408444.2016.1211617

Stoiber, T., Temkin, A., Andrews, D. et al. (2019). Applying a cumulative risk framework to drinking water assessment: a commentary. Environmental Health 18, 37. https://doi.org/10.1186/s12940-019-0475-5

Stucki AO, Barton-Maclaren TS, Bhuller Y, Henriquez JE, Henry TR, Nagy EG, Hirn C, Miller-Holt J, Perron M and Ratzlaff D. (2022). Use of new approach methodologies (NAMs) to meet regulatory requirements for the assessment of industrial chemicals and pesticides for effects on human health. *Frontiers in Toxicology,* 98. https://doi.org/10.3389/ftox.2022.964553

Tong R and Zhang B. (2023). Cumulative risk assessment for combinations of environmental and psychosocial stressors: A systematic review. *Integrated Environmental Assessment and Management,* 00, 1-14. https://doi.org/10.1002/ieam.4821.

Tseng, CH, Tai, TY, Chong CK, Tseng CP, Lai MS, Lin BJ, Chiou HY, Hsueh YM, Hsu KH and Chen CJ. (2000). Long-term arsenic exposure and incidence of non-insulin-dependent diabetes mellitus: A cohort study in arseniasis-hyperendemic villages in Taiwan. *Environmental Health Perspectives,* 108, 847-851. http://ehpnet1.niehs.nih.gov/docs/2000/108p847-851tseng/abstract.html

Turley AE, Isaacs KK, Wetmore BA, Karmaus AL, Embry MR, and Krishan M. (2019). Incorporating new approach methodologies in toxicity testing and exposure assessment for tiered risk assessment using the RISK21 approach: Case studies on food contact chemicals. Food and Chemical Toxicology, 134, 110819. https://doi.org/https://doi.org/10.1016/j.fct.2019.110819

United Nations. (2007). United Nations Declaration on the Rights of Indigenous Peoples. https://www.un.org/development/desa/indigenouspeoples/wp-content/uploads/sites/19/2018/11/UNDRIP_E_web.pdf

US EPA. (2011). *Technical Support Document- EPA's 2011 National-Scale Air Toxics Assessment*. Office of Air Quality, Planning and Standards. Retrieved February 29, 2024 from https://www.epa.gov/sites/default/files/2015-12/documents/2011-nata-tsd.pdf

US EPA. (2020). Population Surrounding 1,857 Superfund Remedial Sites. Retrieved November 17 2023 from https://www.epa.gov/sites/default/files/2015-09/documents/webpopulationrsuperfundsites9.28.15.pdf

US EPA. (2022). Human Health Risk Assessment. Retrieved April 6 2023 from https://www.epa.gov/risk/human-health-risk-assessment

US EPA. (2023a). Cadmium. Comptox Chemicals Dashboard. U.S. Environmental Protection Agency. Retrieved March 1 2023 from https://comptox.epa.gov/dashboard/chemical/details/DTXSID1023940

US EPA. (2023b). Cadmium. Interated Risk Information System (IRIS). Retrieved March 1 2023 from https://iris.epa.gov/ChemicalLanding/&substance_nmbr=141

US EPA. (2023c). Basic Information about the Integrated Risk Information System. Retrieved March 20 2023 from https://www.epa.gov/iris/basic-information-about-integrated-risk-information-system

US EPA. (2023d). Manganese. Integrated Risk Information System. Retrieved March 10 2023 from https://iris.epa.gov/ChemicalLanding/&substance_nmbr=373

US EPA. (2024). National Primary Drinking Water Regulations. *Ground Water and Drinking Water.* Retrieved March 8 2024 from https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations#Inorganic

United Nations. 2007. United Nations declaration on the rights of indigenous peoples. Available from https://www.un.org/development/desa/indigenouspeoples/wp-content/uploads/sites/19/2018/11/UNDRIP_E_web.pdf.

Van Oostdam J, Donaldson SG, Feeley M, Arnold D, Ayotte P, Bondy G, Chan L, Dewaily E, Furgal C and Kuhnlein H. (2005). Human health implications of environmental contaminants in Arctic Canada: a review. *Science of the Total Environment*, 351, 165-246. https://doi.org/10.1016/j.scitotenv.2005.03.034

Wilcox AA, Provencher JF, Henri DA, Alexander SM, Taylor JJ, Cooke SJ, Thomas PJ and Johnson LR. (2023). Braiding Indigenous knowledge systems and Western-based sciences in the Alberta oil sands region: A systematic review. *Facets,* 8(1), 1-32. http://dx.doi.org/10.1139/facets-2022-0052

Wiseman CLS and Gobas FAPC. (2002). Balancing risks in the management of contaminated First Nations fisheries. *International Journal of Environmental Health Research,* 12(4), 331-342. https://doi.org/10.1080/0960312021000056438

Wolf D, Bachman,A, Barrett G, Bellin C, Goodman JI, Jensen E, Moretto A, McMullin T, Pastoor TP and Schoeny R. (2016). Illustrative case using the RISK21 roadmap and matrix: prioritization for evaluation of chemicals found in drinking water. *Critical Reviews in Toxicology*, 46(1), 43-53. https://doi.org/10.3109/10408444.2015.1082973

World Health Organization (WHO). (2009). *International Programme on Chemical Safety & Inter-Organization Programme for the Sound Management of Chemicals, Assessment of combined exposures to multiple chemicals : report of a WHO/IPCS international workshop on aggregate/cumulative risk assessment*. Retrieved March 6 2024 from https://www.who.int/publications/i/item/9789241563833

CONNECTING PARAGRAPHS

Chapter 5 detailed two case studies conducted in collaboration with three unique Indigenous communities in the US and Canada, testing the use of the RISK21 approach to HHRA on existing data and comparing it to conventional approaches. RISK21's visual input was an interesting way to display the data (particularly in the cumulative risk assessment case), and it produced similar results to conventional methods while using less precise data. However, one of the key learnings from these cases was that the involved communities have a variety of qualitative and quantitative non-chemical information of relevance to the assessment that is not meaningfully included or communicated in the tested approach.

Chapter 6 explores the use of methods that identify and measure Indigenous Health Indicators (IHIs) of community relevance, which are community-defined and measured factors that can be assessed alongside an HHRA towards a more holistic and contextualized assessment. Here, we pilot-test existing IHI approaches published by two communities to consider their application at a regional scale using existing data from the First Nations Food, Nutrition, and Environment Study (FNFNES). Following the design thinking process, this chapter is part of 'ideation' and 'prototyping' towards the development of Indigenous Health Indicators approaches. Key findings from this initial ideation phase were shared with members of the Environment Department in the Kanien:keha'ka community of Kanesatake, towards the development of an IHI approach in this community-specific context as detailed in chapter 7. This chapter was not submitted as a peer-reviewed publication but is included here as a part of the design process which can be referenced by others who wish to conduct similar work in designing and testing new risk assessment tools. I am the first author of this chapter, and it is additionally co-authored by Dr. Niladri Basu.

CHAPTER 6: Indigenous Health Indicators (IHIs) as a New Approach to Human Health Risk Assessments for Contaminants- Pilot Testing IHI Operationalization on a Regional Scale

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6.1 Abstract

Human health risk assessment (HHRA) approaches for environmental contaminants are used to make environmental management decisions in Indigenous communities but often fail to adequately assess 'health' as defined by communities themselves. There are few case studies and a lack of methodological consensus on how to meaningfully include community-relevant health information in HHRAs. Two communities (The Swinomish Tribal Community and Amskapi Piikani Blackfoot Nation) have published methods for the development and use of 'health indicators' (termed *Indigenous Health Indicators* or IHI in this work), which are community-defined and measured factors that can be used in parallel to risk assessments to understand and communicate potential health impacts (6 Swinomish health indices and 9 Piikani well-being indices). A growing body of regional health indicator information is available through recent initiatives to address the gap in knowledge on Indigenous health, such as the Canada-wide First Nations Food, Nutrition, and Environment Study (FNFNES), but the possibility of using the IHI approaches on these datasets has not been tested. Thus, we aim to pilot test the use of these two published approaches to organizing IHI (Piikani Well-being Index and Swinomish IHI) on a regional set of indicators and contaminant information. Our objectives are to first, pilot the use of selected IHI methods in a new context; second, explore the feasibility of scaling IHI methods for

regional indicator datasets; third, consider both qualitative/descriptive and quantitative indicator measurement methodologies; and fourth, ideate how IHI approaches may be considered in the development of new risk assessment approaches. The resultant case study utilizes 10 attributes in three existing indicator categories from the FNFNES to ideate how IHI tools may be included in the development of new approaches to HHRA of relevance to Indigenous communities. The results highlight several inherent challenges with scaling a ‘values-based’ approach. If, and how, regional IHI values may be operationalized in HHRA methods or used to screen for potential health ‘risks’ remains in question. Future work may seek to address some of these challenges and explore other existing regional datasets.

6.2 BACKGROUND

Human Health Risk Assessment (HHRA) approaches are used to make decisions about the management of environmental contaminants, by quantifying potential health risks based on chemical exposure and hazard information. Of those most affected by HHRAs in Canada are Indigenous Peoples and communities, who often face unique contaminant related risks by both disproportionate exposure (Government of Canada, 2022) and unique impacts on land-based cultural, spiritual, and food systems different from the general population (Fernández-Llamazares et al., 2020). Despite these disproportionate and unique health impacts, conventional HHRA approaches do not effectively define or evaluate health from the perspectives of Indigenous communities themselves, which leads to health risk assessment results that lack relevance to Indigenous Peoples (Gregory, 2016; O'Rourke, 2024).

Recent literature and reports from the Assembly of First Nations (AFN) highlights that the development of risk assessment methods that are more context-specific, including the consideration of both multiple chemical and non-chemical factors (for example, social, cultural, and economic), is important in the development of community-relevant approaches (Assembly of First Nations, 2022; Chong et al., 2024a; Eggers et al., 2018; Hoover et al., 2015). There are a range of approaches for conducting more context-specific assessments, including cumulative risk assessment methods that consider biomarkers of stress (i.e.: allostatic load) (Lewis et al., 2011; Sexton & Linder, 2011), to GIS-based screening methods using epidemiologic and demographic data (i.e.: EJ Screen, CalEnviroScreen) (Lievanos, 2018; Min et al., 2019). The importance of gathering descriptive information about health risks and local knowledge related to contamination has been increasingly recognized in regulatory risk assessment guidance (Health

Canada, 2018, 2019). However, current risk assessment approaches are critiqued as inadequate in their consideration of these information types, and focused too narrowly on western science defined, physiological aspects of health (Gregory et al., 2001; Gregory, 2016; Mullen et al., 2023). Several Indigenous communities have conducted studies aiming to more meaningfully bring forth non-chemical information in their assessments (Eggers et al., 2018; M. K. Gislason & H. K. Andersen, 2016), have developed models for more holistic assessment approaches (Arquette et al., 2002; Harper et al., 2012; Harris & Harper, 2000), and have sought to identify values that can be used to increase the relevance of environmental assessments (Failing et al., 2013; Reid et al., 2014). However, the number of available community-based cases is small, and there remains a lack of methodological consensus on how to consider community-relevant information on 'non-chemical' health risks in risk assessments (Callahan & Sexton, 2007; Sexton, 2012; Sexton, 2015).

A US EPA workshop identified the use of health indicators from the health and social sciences as a potential avenue for better characterizing health risks related to contamination (Sanchez et al., 2010). Health indicators are measures of health that can be either quantitative (ex: socioeconomic status, chronic disease rates, percentage of food secure households) or descriptive (ex: cooperation within a community network, access to traditional medicines), with the former being the focus of most studies to date on the topic (Donatuto et al., 2020). While many studies based in Indigenous communities utilize health indicators generally to define health risks and impacts (Arquette et al., 2002; Bouche, 2022; Maya K Gislason & Holly K Andersen, 2016; Hackett et al., 2018; Harris & Harper, 2000; Kryzanowski & McIntyre, 2011), the use of this approach presents several challenges. First, generic western-scientific indicators often lack community-relevance and may miss aspects of 'health' of importance to Indigenous Peoples as previously described. Second, at a regulatory level, there is ambiguity as to how health indicators can be meaningfully applied to risk assessment. For example, Health Impact Assessment guidance published by Health Canada mentions Aboriginal health and Traditional Knowledge but does not include a method by which these can be incorporated into an assessment in a way that is legitimate to both regulators and community members (Gregory, 2016), often resulting in their subsumption into the dominant western framework. In addition to the lack of methodological guidance on how to measure health in a relevant and meaningful way in Indigenous community contexts (Satterfield et al., 2013), there is minimal information on how health indicators can be operationalized for health risk assessments and decision making. In general, there is a paucity of information on health indicators of concern for Indigenous Peoples in Canada (Chan et al., 2021; Donatuto et al., 2016), though recent initiatives begin to address this gap. In Canada, there is a growing body of Indigenous led and defined health data, including through the First Nations Information Governance Center's (FNIGCs) regional health survey (RHS) and community health survey, and the First Nations Food, Nutrition, and Environment Study (FNFNES). Both are led by First Nations organizations and utilize First Nations definitions of health as the basis for collecting health indicator information.

Responding to some of these challenges, methods for community-defined and measured Indigenous Health Indicators (IHI) have emerged over the last decade and a half. A leader in the development of IHI approaches is the Swinomish Tribal Community, who have published numerous papers since 2011 which outline methods for the identification and testing of a suite of IHI. IHI can be used in parallel to risk assessment methods and to holistically assess Indigenous health, including 'intangible' aspects (ex: relations to the natural environment, importance of ceremonies) (Donatuto et al., 2016; Donatuto et al., 2011; Donatuto et al., 2020). These methods involve the ranking and weighting of IHI in the context of environmental changes (such as contamination), to prioritize potential health outcomes of concern. These include the use of a descriptive ranking approach, which assigns numerical value to descriptive information, presenting a way to consider community defined and measured health indicators in environmental assessments. Following the development of these methods, a few other communities have trialed the use of IHIs in various contexts, including the Squaxin Island Tribe, Tsleil-Waututh First Nation, and Coast Salish communities (Donatuto et al., 2016; Donatuto et al., 2014). The results of these trials have been positive, demonstrating the potential for the Swinomish IHI methods to be applicable in other settings (Donatuto et al., 2016). More quantitative in nature, the Amskapi Piikani Blackfeet Nation have also recently (in 2023) published their methodology for developing a suite of community-specific indicators for community-defined health assessment. These “Piikani Well-Being Indices” (PWI) are quantitative and often demographic in nature, while their parameters (i.e.: values indicating good or poor health) are community-defined (Paul et al., 2023).

While there are numerous approaches available for the identification of health indicators, the IHI approach was chosen due to its intended application in the context of environmental assessments, including through the inclusion of a ‘threshold approach’ (i.e.: identifying when a health indicator level is unacceptable, as defined by community members), and the PWI approach provides a similar method for community-based risk identification and definition, in a quantitative context (Donatuto et al., 2016; Paul et al., 2023). The ‘threshold’ approach is similar to that used in conventional HHRA methods for identifying health risks and thus is particularly relevant to this demonstrative case.

Canada is undergoing a paradigm shift in the way that HHRAs for environmental contaminants are conducted. New approach methodologies (NAMs) are tools, technologies, and approaches that respond to the need for more resource efficient, time-saving, and ethical risk assessment (National Academies of Sciences & Medicine, 2022). There is increasing regulatory interest in the development of NAMs for decision-making, including as a part of Canada's Chemicals Management Plan and most recently, written into '*Bill S-5'*, which outlines proposed amendments to the '*Canadian Environmental Protection Act'* (CEPA) (Government of Canada, 2022). Bill S-5 also marks the first consideration of the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) in the CEPA. UNDRIP includes the right to a 'healthy' environment and to self-determination for Indigenous Peoples, however, the operationalization of these rights in the CEPA remains unclear (Assembly of First Nations, 2022). While NAMs for 'next generation' HHRA are being designed and tested, this development has yet to include Indigenous Peoples or consider the specific priorities of Indigenous communities. There is a need to develop new risk assessment approaches that are relevant for the Indigenous communities in which they will ultimately be applied.

As the development of NAMs for risk assessment is underway, Indigenous Health Indicators are an emergent and promising tool for improving the relevance of risk assessments for Indigenous communities and capturing important definitions of health from community perspectives. They are valuable organization and communication tools for health information of importance to communities and have been successfully tested and used in a handful of community-led contexts. Here we mention two methods that are published and publicly available, the Swinomish IHI and PWI. Simultaneously, recent initiatives to address the gap in knowledge on Indigenous defined and measured health status are underway, with Canada-wide information emerging from studies such as the FNFNES and FNIGC RHS. These regional assessments, while Indigenous led, continue to use conventional methods, while the possibility of using the IHI approaches on these datasets have not been tested. Further, while the PWI and IHI examine different types of information (descriptive versus quantitative), there is a lack of consensus on how a diversity of semi-quantitative, descriptive, and quantitative indicator information might be considered cumulatively in the context of contamination (Sexton, 2012; Sexton, 2015), and further, whether it is appropriate to do so (Donatuto et al., 2016; Gregory, 2016). There is no information on if and how such methods might be scaled to understand their broader applicability.

6.3 OBJECTIVES

We aim to pilot test the use of an existing Indigenous Health Indicators (IHI) approach on a regional set of indicators and contaminant risk assessment information. Our objectives in doing so are to:

1. Pilot the use of selected IHI methods in a new context, producing a regional assessment case study.
2. Explore the feasibility of scaling existing IHI methods for regional indicator datasets.
3. Consider how both qualitative/descriptive and quantitative indicator measurement methodologies may be integrated.
4. Ideate how the methods might be considered as part of newly developed human health risk assessment approaches.

We propose that using a ‘health indicators’ approach is one way in which risk assessment practice can be developed to include greater consideration for and relevance to Indigenous communities. Here, we explore the potential role of existing IHI methods in the development of more holistic and relevant risk assessment approaches. To do so, we pilot test the PWI and IHI methods on existing regional-level First Nations’ health indicators data. This case study uses a publicly available regional dataset (FNFNES) to first, organize and visualize both ‘quantitative’ and ‘qualitative/descriptive’ health indicators of potential relevance; and second, consider this ‘non-chemical’ health indicator information in the context of contaminant risk assessment information, towards a more ‘holistic’ risk assessment approach.

6.4 METHODS

6.4.1 Positionality Statement

The authors of this case study are non-Indigenous academics from McGill University's Center for Indigenous Peoples' Nutrition and Environment. This work is part of a project co-lead by the Kanien'kehà:ka community of Kanesatake and McGill University, which aims to understand how NAMs for contaminant risk assessment can be designed to meet the priorities of Indigenous communities. This study was conducted to learn about the IHI methods, lessons from which may then be applied to it's use in Kanesatake. Members of the Ratishontsanonhstats Kanesatake Environment team provided inspiration and support for this work. Despite all efforts to conduct research with this positionality in mind, the authors acknowledge that the biases and worldviews that arise from their identities place limitations on this work.

6.4.2 Data Source

The First Nations Food, Nutrition, and Environment Study (FNFNES) was a 10-year, Canada-wide study co-led by the Assembly of First Nations (AFN), University of Ottawa, and Université de Montréal, involving 92 participating First Nations communities (Chan, 2019). The FNFNES collected a range of information on contaminant concentrations in food and water, as well as consumption, nutrition, food security, health and lifestyle survey data. We chose this dataset based on its public availability online, the leadership of the study by the AFN, and the categorization of the information geographically, with which we were able to conduct an assessment that compares data amongst regions. The FNFNES survey data (i.e.: food security, health and lifestyle information) are used to determine the 'IHI' values in this case study. These data were collected in the locations where a conventional HHRA for contaminants in traditional foods and water was conducted (i.e.: measuring contaminant exposures and comparing these to a reference toxicity value to calculate health risk) as part of the FNFNES. The FNFNES food security, health, and lifestyle survey data are organized in this case study as in the referenced IHI and PWI approaches. This provides an opportunity to more broadly consider qualitative, 'non-chemical' and descriptive information on potential health risks (i.e.: the IHIs in this case study), in the context of conventional HHRA data which captures quantitative health risks from contaminant exposure and toxicity information.

6.4.3 Organizing Health Indicators

We draw upon several methods for organizing and measuring health indicators (summarized in Table 6-1). Both the Swinomish Tribal Community and Piikani Nation's methods use broad indicator categories, and then sub-categories or 'attributes' of each indicator, which detail it's meaning as defined by the community (Donatuto et al., 2016; Paul et al., 2023). The FNFNES categorizes data in their report under several sub-headings, and thus we use these headings here as indicator 'categories', with specific measures as 'attributes'. We attempted to align these categories with the existing methodologies by comparing available indicators in the FNFNES data to the Swinomish IHI and PWI categories (Table 6-1).

Table 6-1: Summary of referenced Methodologies for organizing and measuring Indigenous Health Indicators. *Indicates an indicator category that FNFNES data used in the current case study matched. See supporting information for a table of FNFNES data organized by indicator.

Name	Community	Indicator Categories	Types of information (Input)	Output
Swinomish Indigenous Health Indicators (IHI)	Swinomish Tribal Community	Community Connection Natural Resources Security* Cultural Use* Education Self-Determination Resilience*	Descriptive Scale Ranking Weighting and prioritization of indicators	Numerical Index (Scale of 1-4)
Piikani Wellbeing Index (PWI)	Amskapi Piikani Blackfeet Nation	*Our Health** *Our Lands and Stewardship* *Our Food Sovereignty** *Institutional Capacity and Traditional Governance* *Our Culture* *Social and Educational, Lifeway** *Our Business, Affairs, and* *Economics** *Our Land Tenure*	Quantitative metrics	Numerical Index (Scale of 0-1)

6.4.4 Determining Indicator Values

This case study draws upon two methodologies developed by members and collaborators of the Swinomish Tribal Community (Donatuto et al., 2016; Donatuto et al., 2020; Donatuto et al., 2014; Donatuto et al., 2011) and the Amskapi Piikani Blackfoot Nation (Paul et al., 2023). In these approaches, values-based measurement of health indicators requires community input to determine what is considered an indicator value representing "good" or "poor" health. In the case of the Swinomish Indigenous Health Indicators (IHI), Donatuto et al. describe a participatory method for ranking and weighting indicators using descriptive scales, which assign values to indicator attributes on a number of dimensions- including for example ranking the current health status of an indicator (Donatuto et al., 2016), predicted changes to an indicator status over time, and the relative importance of indicators in scenarios such as resource change and contamination (Donatuto et al., 2020; Donatuto et al., 2011). The descriptive scale rankings assign numerical values- for example, the health status of an indicator could be ranked on a scale of 1-4 (i.e.: 1=doing poorly; 2=doing okay; 3=doing pretty good; 4=doing great), and average rankings amongst community members determine the indicator value. These rankings could also be used to prioritize indicators, for example, those which fall into an average ranking of 'doing poorly' or below may be considered for further evaluation and management. Lastly, an indicator that is consistently weighted with no or little importance may be reconsidered in an indicator list for that specific scenario (Donatuto et al., 2016; Donatuto et al., 2014). In the case of regional data from FNFNES, we do not have information on the relative importance of the various indicators used, and thus we weigh them equally in this evaluation. However, the data are available publicly online in regional reports from the FNFNES (Chan, 2019) and thus can be repurposed in subsequent works.

In contrast to the descriptive measurement of Swinomish IHI, the Piikani Well Being Index uses quantitative measures (for example, demographic information or disease prevalence). However, the determination of whether a value is indicative of good or poor health also relies on a value judgement. In the PWI study by Paul et al., the community sets 'goalposts' for each indicator, (i.e.: maximum and minimum values for the indicator, set on a 0-1 scale, with a value of 1 indicating optimal health) (Paul et al., 2023).

As mentioned above, both the Swinomish IHI and PWI studies organize *indicators* by broad category, with *attributes* precisely defining each indicator. The value of each attribute contributes to an overall indicator score. In the Swinomish IHI method, the attributes of each indicator are also ranked and weighted relative to one another to determine the importance of each to the indicator score. For the purposes of this demonstrative case, while we assumed equal weights, we avoided including indicator measures that were too similar in the FNFNES report (for example, '# of years of education' and '% of population having completed high school').

In this example, using regional-level data from FNFNES, we cannot make value judgements about what values would be indicative of 'good' or 'poor' health as defined by communities. This definition likely varies between communities, as it will be based on community-specific experiences and expectations and may change over time (Donatuto et al., 2020, Goodman et al., 2014). We also cannot make judgements about the relative importance of attributes of each indicator in comparison to others. Thus, for demonstrative purposes we apply here a percentile ranking methodology, which is used in the US EPA's EJScreen (Environmental Justice Screening tool) to assess and prioritize sociodemographic indicators of concern. The US EPA developed EJScreen's tool for environmental justice screening, which involves a suite of indicators that aim to assess priority socio-demographic concerns in relation to environmental contamination. EJScreen is used by the US EPA to screen and prioritize environmental justice community health risks using large regional datasets (US EPA, 2024). While not an Indigenous community-specific approach, some methodological considerations from EJScreen are useful when evaluating regional data, and the approach is designed for the prioritization of population groups who face environmental justice concerns. The use of a percentile ranking approach allows us to compare indicator scores across regions, and ultimately to identify priority geographic regions of concern for each indicator area.

While we used an EJScreen approach, we chose not to compare each value for First Nations health indicators to the general Canadian population as EJ Screen does for the US- doing so upholds an assumption that the general average is the standard to which First Nations communities should aspire, when in fact, many communities have their own ideals and standards for health which are not necessarily in line with the non-Indigenous population. Overall, it is important to maintain that the use of percentile rankings is generally used for screening, which is a first step in identifying locations, contaminants, and/or health concerns where further focus may be needed. However, screening level assessments are not risk assessments and do not determine the presence or absence of a 'health risk' in a given location (US EPA, 2024).

Quantitative indicator data from FNFNES was used per region and a percentile rank was calculated. For data that involves a descriptive scale (for example, self-reported health status ranging from poor to excellent), we followed Donatuto et al.'s (2016) methodology for determining an average rank value, and then compared regionally by assigning a percentile ranking. We then took the percentile rank for each and averaged them to get an overall value for the indicator group. The combination of indicator attributes to get a total indicator value is consistent with the referenced IHI methods (Donatuto et al, 2016; Donatuto et al., 2020; Paul et al., 2023).

Some data represent 'positive' indicators of health, that is, the higher the value, the 'better' (for example, level of physical activity), while others are the inverse (for example, rate of chronic disease). To average percentile rankings into a single ranking per attribute, we converted all ‘negative’ values into positive ones. For example, ‘diabetes rate’ can be inversely converted to ‘percent of population with absence of diabetes’. Some of these assumptions, however, are subject to bias. For example, the perspective that a higher level of education is ‘better’ is one which may not be universally shared. Acknowledging this, for demonstrative purposes we assigned positive or negative value to the data used and convert all data to ‘positive indices’ from which we can draw an overall health indicator value in each category.

6.4.5 Contaminant Information

We also took regional-level FNFNES data on contaminant exposure and ‘hazard quotient’ method for HHRA and compared these results across regions. We applied color-coded conditional formatting to highlight areas with the highest ‘risk’ (i.e.: a hazard quotient greater than 1.0), which follows a similar format as IHI methods in studies by Donatuto et al. (2016). This format allows us to visualize, and potentially prioritize, areas which may be of highest concern for both contaminant exposure and health indicator status. For example, if the results reveal both contaminant-related risks and increased health indicator vulnerabilities for a region, management may target both areas. Further consideration for contaminant-related risks may be given to areas whose hazard quotient do not exceed the ‘risk’ threshold, but who have increased vulnerabilities in health indicator categories.

6.5 RESULTS

6.5.1 Overview of health indicators

The following results demonstrate the organization and visualization of existing regional health indicator information following the IHI approaches outlined above (Table 6-2). The FNFNES health indicator categories chosen for this case were based on the FNFNES' available data and previously identified IHIs from the referenced studies (Table 6-1), leading to the identification of three indicator categories with ten total attributes: sociodemographic information (2 attributes), food sovereignty and security (4 attributes), and health and lifestyle factors (4 attributes). Attributes were drawn from the FNFNES regional reports and organized by indicator categories, for a total of 7 quantitative and 3 descriptive attributes identified and used for this case (Table 6-2a). The indicator categories and attributes were differentiated into descriptive (shaded grey) and quantitative indicator information and displayed as percentile rankings (Table 6-2b). Finally, the attributes (both descriptive and quantitative) were summed into a single indicator 'value', which is visually represented as 'better' (green) or 'worse' (red) health compared to the other indicators and regions, using conditional formatting (Table 6-2c).

The final, consolidated table (6-2c) of indicators provides a simplified visual comparison of the indicators across regions, integrating both qualitative and quantitative data. We note that these two data 'types' are not equally weighted in each indicator category. For example, for the indicator category 'food security and sovereignty', there are three quantitative and one descriptive attribute, though all four are weighted equally. Comparing indicator values across regions in Table 6-2c, we can see that there are regions with amongst the highest values in some indicator categories, but the lowest in others. For example, Alberta has one of the lowest percentile rankings for 'sociodemographic information' (0.17), but it has the second highest percentile ranking for the 'health and lifestyle' category (0.75). Results can similarly be compared within and between regions, however limitations to their interpretation and use are further discussed below.

6.5.2 Overview of HHRA data visualization

Contaminant information was conditionally formatted so that red represents a hazard quotient greater than one (i.e. a potential 'risk'), as reported by the FNFNES (Table 6-3). Using this format, one can 'narrow-in' on contaminants and regions of greatest concern. For example, this format highlights that mean Arsenic contamination was above the referenced hazard values in British Colombia, indicated by a red-colored box (Table 6-3), which may flag this region and contaminant for further evaluation and management. The color-coded and side-by-side format also shows comparisons between regions and produces a visual representation of the data, which can further be compared in relation to the health indicators table (Table 6-2). Notably, as the hazard quotient data are color-coded in relation to a hazard value, as opposed to in relation to each other as in the case of the indicator information, viewing the tables together requires a detailed understanding of the differences between these two classifications and color schemes to interpret their meaning.

Table 6-2 (a-c): FNFNES 'Indigenous Health Indicators' Assessment tables, demonstrating the process for calculating indicator values in the present case study, following methodologies by Donatuto et. al (2018), Paul et al., (2023), and the US EPA (2004).

Table 6-2a: Initial Raw Data. Grey indicator attributes are those evaluated using descriptive scale rankings.

Indicator Category	Indicator Attributes (% rank)	BC	AB	SK	MB	ON	QC	AT
Sociodemographic Information	% Highschool Education or greater	65 (0.83)	50 (0)	58 (0.33)	61 (0.50)	64 (0.67)	51 (0.17)	76 (1.00)
	% Main source of income is wages * (used as a proxy for employment)	59 (1.00)	49 (0.33)	46 (0.17)	44 (0.00)	56 (0.67)	57 (0.83)	52 (0.50)
Food Sovereignty and Food Security	% reporting household Traditional food harvesting and production practices	75 (0.83)	56 (0)	62 (0.33)	56 (0)	70 (0.67)	79 (1.00)	62 (0.33)
	mean traditional food intake days per year	190 (1.00)	116 (0.67)	139 (0.83)	107 (0.33)	70 (0.17)	109 (0.50)	68 (0.00)
	% of adults who did not report wanting more traditional foods in their household (i.e.: not missing traditional foods)	9 (0.00)	22 (0.33)	22 (0.33)	34 (0.83)	27 (0.67)	16 (0.17)	40 (1.00)
	Food security scale (scale of 1-4; severe, moderate, marginal, none)	3.02 (0.17)	2.8 (0.00)	3.05 (0.33)	3.09 (0.67)	3.24 (1.00)	3.08 (0.50)	3.20 (0.83)
Health and Lifestyle	% absence of obesity	58 (1.00)	56 (0.83)	52 (0.50)	46 (0.17)	49 (0.33)	34 (0.00)	52 (0.50)
	% absence of Diabetes	90 (1.00)	83 (0.83)	81 (0.67)	75 (0.17)	74 (0)	75 (0.17)	80 (0.50)
	Self-reported health status (Average scale ranking from 1-5; poor, fair, good; very good; excellent)	2.98 (0.83)	2.96 (0.33)	2.96 (0.33)	2.79 (0)	2.91 (0.17)	2.97 (0.67)	2.99 (1.00)
	Self-reported activity level (Average scale ranking from 1-4; sedentary, somewhat active, moderately active, highly active)	2.34 (0.83)	2.45 (1.00)	2.28 (0.33)	2.15 (0.17)	2.32 (0.67)	2.12 (0)	2.28 (0.33)

Table 6-2b: Conditional formatting per percentile rank. In the Indicator Attributes column, grey indicates a qualitative/descriptive indicator, while white indicates a quantitative indicator.

Indicator Category	Indicator Attributes	BC	AB	SK	MB	ON	QC	AT
Socio-demographic Information	Highschool Education or greater (%)	0.83	0	0.33	0.5	0.67	0.17	1
	Main source of income is wages * (*used as a proxy for employment)	1	0.33	0.17	0	0.67	0.83	0.5
Traditional Food Systems and Security	Traditional food harvesting and production practices reported at the household level (% of households)	0.83	0	0.33	0	0.67	1	0.33
	Mean traditional food intake days per year	1	0.67	0.83	0.33	0.17	0.5	0
	% of adults who did not report wanting more traditional foods in their household (i.e.: not missing traditional foods)	0	0.33	0.33	0.83	0.67	0.17	1
	Food security scale (scale of 1-4; severe, moderate, marginal, none)	0.17	0	0.33	0.67	1	0.5	0.83
Health and Lifestyle Measures	Absence of obesity (%)	1	0.83	0.5	0.17	0.33	0	0.5
	Absence of Diabetes (%)	1	0.83	0.67	0.17	0	0.17	0.5
	Self-reported health status (Average scale ranking from 1-5; poor, fair, good; very good; excellent)	0.83	0.33	0.33	0	0.17	0.67	1
	Self-reported activity level (Average scale ranking from 1-4; sedentary, somewhat active, moderately active, highly active)	0.83	1	0.33	0.17	0.67	0	0.33

Table 6-2c: Summary of Totaled Indicator Values

	Indicator Value Percentile Rank						
Indicator Category	**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**AT**
Sociodemographic Information	0.92	0.17	0.25	0.25	0.67	0.50	0.75
Traditional Food Systems and Security	0.50	0.25	0.46	0.46	0.62	0.54	0.54
Health and Lifestyle Measures	0.92	0.75	0.46	0.12	0.29	0.21	0.58

Table 6-3: FNFNES regional contaminant risk assessment for heavy metals and organic contaminants. Values taken from the FNFNES regional report (Chan et al., 2019) and conditionally formatted to display hazard quotient values of higher concern (red) and no concern (green).

		Hazard Quotients (Mean)						
Contaminant		**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**AT**
METALS								
Arsenic	Mean	1.1	0.004	0.01	0.02	0.02	0.03	0.41
	Maximum	1.55	0.01	0.02	0.02	0.03	0.04	0.76
Cadmium	Mean	0.26	0.11	0.04	0.04	0.08	0.18	0.02
	Maximum	0.54	0.11	0.05	0.05	0.08	0.19	0.05
Lead	Mean	0.06	0.06	0.01	0.04	0.09	0.06	0.01
	Maximum	0.13	0.11	0.02	0.05	0.1	0.06	0.07
Mercury	Mean	0.06	0.03	0.07	0.38	0.08	0.08	0.02
	Maximum	0.47	0.03	0.07	0.49	0.09	0.2	0.05
ORGANIC CONTAMINANTS								
HCBs	Mean	0.0018	0.00003	0.0003	0.0001	0.00045	0.0004	0.0002
DDE	Mean	0.0001	0	0.00001	0.0001	0.00004	0.00003	0.00001
PCB	Mean	0.0003	0.00001	0.0005	0.00011	0.00261	0.003	0.0003
Chlordane	Mean	0.0029	0.00007	0.001	0.00024	0.00318	0.001	0.001
Toxaphene	Mean	0.0018	0.00001	0.0001	0.00009	0.00222	0.0002	0.0002
PAH	Mean	0.00001	0.00001	0.00004	0.00001	0.00056	0	0
PFCs	Mean	0.0059	0.00072	0.02	0.00566	0.0312	0.01	0.01
PBDE	Mean	0.0075	0.00018	0.001	0.00654	0.0078	0.02	0.0005
Dioxan and Furan	Mean	0.00004	0	0.002	0.00001	0.0001	0.01	0

6.6 DISCUSSION

Health information of relevance to communities is an important consideration in the development of accurate and ethical next-generation human health risk assessment approaches. Here, we used two existing community-based IHI approaches (the Swinomish IHI and Piikani Well-being Index) and piloted these methods on a regional scale, leveraging existing data from a large regional dataset (the FNFNES). We sought to explore the feasibility of scaling the IHI approach and the integration of both quantitative and descriptive or qualitative health indicator information, and further, to ideate how IHI approaches may be used in the context of HHRA for contaminants. Overall, in response to our objectives, this case study highlights limitations to the operationalization of the IHI approaches at a regional scale as presented here, primarily due to a lack of community-specific information on values and priorities, which is essential to these approaches. The scaling of the approach in a data organization and visualization sense, as displayed here, is potentially feasible and this requires further research. Qualitative/descriptive and quantitative information may be sorted and presented alongside each other for an overview of the differences between attributes amongst and within regions, though combining these into a single indicator value results in a loss of potentially important meaning and could lead to misrepresentation of the information. The color-coded, visual representation and organization of both IHI and conventional HHRA information has potential to be useful for representing and prioritizing the socio-demographic and socio-cultural contexts of contaminant-related risks.

Pilot testing the IHI approaches in a new context may help us to move towards mutually recognized methods that can be adapted for a variety of contexts and be understood and valued by both communities and regulators alike. It also helps us to identify challenges and knowledge gaps with the transferability of the approach, as we further discuss below. Novel to this paper was regional scaling of the IHI methodologies, the combination of methods to consider both quantitative and descriptive information, and the visual organization of survey data in relation to contaminant risk assessment information.

6.6.1 Applying the IHI approach on a regional scale

The need for Indigenous definitions of ‘health’ in ‘health risk assessment’ has been previously identified (Arquette et al., 2002; Gregory, 2016; Harris & Harper, 2000), and the use of an Indigenous Health Indicators (IHI) approach may help to address this gap. Of central importance to the IHI approaches, as published by the communities leading their development, is the involvement of community members in the process (Donatuto et al., 2016; Paul et al., 2023). While the considered regional health indicators are Indigenous defined, as the FNFNES is co-led by the Assembly of First Nations, a major limitation to this case study was a lack of community involvement. Ultimately, a key finding was the inability to conduct a ‘values-based’ assessment on a regional scale, which is essential to the methodology. This was not possible as the definitions of and priorities for health vary between communities within a region. Despite this difference, organizing and visualizing the data using a ‘health indicators’ approach that identifies areas of ‘better’ and ‘worse’ health has potential as a helpful tool. The uses of this tool may include further mobilizing the use of large regional datasets to prioritize regional health concerns and to contextualize contaminant risk assessments. Thus, ‘scaling’ the IHI approach to a regional level in this case study was potentially feasible for the data organization and visualization components, but not necessarily for values-based assessment.

Unique to this case study in comparison to the published IHI methods (Donatuto et al., 2016; Paul et al., 2023) was the use of percentile rankings to 'scale' the approach (i.e.: to compare, synthesize, and communicate the data amongst regions). This adaptation was adopted from the US EPA's EJ Screen. We note that Indigenous communities and leaders have critiqued EJ Screen for its lack of relevance to community contexts, due to the use of generic health indicators that are applied to the general population (Mullen et al., 2023). Applying an IHI approach to tools such as EJ Screen, where the methodology involves Indigenous defined and measured indicators as opposed to generic ones, may begin to address this challenge. However, the integration of a percentile ranking approach into the IHI methods presented several notable limitations. First, the percentile ranking method did not capture the 'values-based' measurement essential to the IHI and PWI methods, as described above (Donatuto et al., 2020; Gregory, 2016; Paul et al., 2023). Second, the percentile ranking approach may produce "false negatives". For example, results from the FNFNES in Ontario shows the lowest food insecurity rates amongst regions (29% of all households), and the highest average food security ranking (3.24/4, with 4 indicating no food security) and thus the 'best' percentile ranking (1.00) for this indicator attribute compared to the other regions (Table 6-2) (Chan et al., 2018). However, compared to the general Canadian food insecurity average (18% of Canadians in 2021) (Uppal, 2023), a food insecurity rate of 29% is still relatively high. In this example, while using percentile rankings may be useful for identifying regions of the highest concern, improving food security may be a priority everywhere, which a percentile ranking method could underrepresent. Overall, further research is needed to understand the application of an IHI approach at a regional scale, which may include leveraging regional prioritization tools such as EJ Screen.

6.6.2 Qualitative/descriptive and quantitative values

Using a combination of two methods, we pilot-tested a way to consider both qualitative and quantitative non-chemical information as part of the same indicator value. This is opposed to a hierarchy that favors quantitative information, which is an identified limitation in literature on cumulative risk assessment for contaminants (Sexton, 2015). This integration of qualitative and quantitative non-chemical information is unique to this case study compared to the referenced methodologies. A key challenge identified through this case study is that the scaling of the approach to a regional level may lead to an over-simplification of the data, especially qualitative and descriptive information. The final visual summary (Table 6-2c) does not represent many of the nuances of the diverse dataset used to create it, which is better represented in Tables 6-2a and 6-2b. Some of the data was categorized as 'qualitative/descriptive' and organized using ranking scales, following a methodology by Donatuto et al. (2016) (though we acknowledge that this method was designed for community-level assessment). Throughout the steps of the process (through results Tables 6-2a to 6-2c), the data is distilled, which loses some of the distinct meanings of each of the indicator attributes. While there is a desire to better and more meaningfully represent qualitative and descriptive information in risk assessments, this method represents the information similarly to quantitative data by including it in the same summed calculation, which may diminish or subsume it's meaning. This finding is consistent with writings on mixed methods research, which cites a potential for loss of meaning when 'converting' qualitative to quantitative data, which is challenged by minimal guidance for researchers on the topic (Hochwald et al., 2023). While quantitative indices are more straightforward to assess on a regional scale, they may miss some of the nuances and 'intangibles' of health risks of importance to communities that qualitative/descriptive data elicits

(Gregory, 2016). Furthermore, there are an unequal number of attributes per indicator, and thus attributes in larger groups have less weight. In this case study, the assumption of equal weight across attributes of an indicator is likely inaccurate, though it is unclear how data on the relative importance of each attribute (variable to context) may be applied at a regional scale, and this is an area for further research. The data used and organized in this case study is openly provided for others to repurpose and reorganize, as the approach continues to be developed and iterated.

Despite these limitations, the organization of both qualitative and quantitative information on health indicators into indicator categories is one potential component of addressing the commonly cited problem of an over-reliance on quantitative information as the 'core' risk assessment, while qualitative and descriptive information is often seen as supplemental (Burger and Gochfeld, 2011). Furthermore, we note through this case study that the use of descriptive scale rankings in a health indicators approach is a way in which such information may be considered, prioritized, and compared to contaminant risk assessment information. While this approach may not capture the nuances of descriptive and qualitative information, exploring it's use at this regional scale is a potentially important, and to our knowledge novel, way to integrate qualitative, descriptive and community-defined aspects of health into conventional risk assessment approaches. Transferring this approach to other settings and scales, as we have done here, is a step towards improving our understanding of its applicability to next generation risk assessment approaches.

6.6.3 Visualizing and Interpreting Indigenous health indicators in the context of HHRA data

Applying an IHI approach to survey data from the FNFNES provides a novel way to organize, visualize and categorize health information alongside contaminant information, which may be useful for prioritization of both chemical and non-chemical risks; it may also be used to 'narrow in' on chemical and non-chemical stressors of concern for inclusion in a cumulative risk assessment. Further developing the visual 'heatmap' style presentation here for greater community-level accessibility may be an area for further work.

Led by federal and provincial governmental organizations, the United States has several environmental justice screening and mapping tools (i.e.: EJScreen, CalEnviroScreen, EnviroAtlas, etc.), which assist with the identification of priority geographic areas of concern in relation to health indicators and contaminant-related risks (Lievanos, 2018; Min et al., 2019; US EPA, 2024). However, such tools are lacking in Canada, with only one existing application of the EnviroScreen method in British Columbia (Buse et al., 2022). While the use of these population-level tools in the context of Indigenous communities for decision-making has several limitations (Mullen et al., 2023), they may be useful as a component of regional level prioritization and decision-making. Further research in Canada may investigate how to utilize Indigenous-defined health indicator approaches in context-relevant environmental justice tools. This is an especially relevant research need given that royal assent was recently received for Canada's *Bill C-226, An Act respecting the development of a national strategy to assess, prevent and address environmental racism and to advance environmental justice.* Bill C-226 specifically references the meaningful involvement of Indigenous and racialized communities in strategies to address harms posed by environmental racism (Parliament of Canada, 2023). The development of tools that can assess and address environmental contamination in ways that are meaningful and relevant to Indigenous communities, as this approach may begin to realize, is one component of upholding this commitment.

Another potential limitation to this approach is that presentation of data as ‘positive’ versus ‘negative’ indicators is somewhat visually confusing (for example, measuring the number of respondents who do not have diabetes, as opposed to the prevalence of diabetes), and manipulating the data to fit this structure has the potential to precipitate misinterpretations or misrepresentations. Thus, a person viewing the data would require a clear understanding of its meanings to accurately interpret the findings. Relevant and clear communication is a priority for improving Indigenous community-level risk assessment approaches (Chong et al., 2024a). Strategies for communication and engagement are discussed in detail in the IHI and PWI methodologies referenced here. Such strategies include using local language in communications and providing traditional foods and activities at community events where information is presented (Donatuto et al., 2016; Donatuto et al., 2011; Paul et al., 2023). While not tested here, the operationalization of this method at local levels necessitates the consideration of such strategies.

Organizing and visualizing indicator information on a regional scale, and exploring how it may be considered in the context of contaminant risk assessment, may aid in the development of next-generation risk assessment approaches. New approach methodologies (NAMs) aim to be more efficient and predictive, and less resource intensive than conventional methods. Exploring how an indicators approach may be considered in the design of NAMs-based tools is important. For example, RISK21 is a NAMs-based risk assessment tool that produces a visual matrix and provides a framework for cumulative risk assessment but does not have an avenue for including qualitative and descriptive information as part of the core assessment (Chong et al., 2024b;

Moretto et al., 2017). Considering how an IHI approach may be complemented by such tools, and vice versa, is an area for further research.

Furthermore, this case study compared the regionally available data from FNFNES to the indicator categories identified, however there are several other databases with information on Indigenous health. These include the FNIGC regional health survey data (of which there are over 60 listed indicators and 466 data available online) (First Nations Information Governance Centre, 2024), and studies lead by Inuit and Metis communities and governments, such as the *Qanuippitaa? Inuit health survey* (Ayotte et al., 2024), although these surveys are not explicitly focused on health indicators in the context of contamination. Future work might, if desired by Indigenous governing bodies and leadership, look at establishing a consistent and harmonized database of regional Indigenous health information for use in assessments where local data is lacking.

In considering the utility of using an IHI approach in the context of an HHRA for contaminants, several limitations are evident. While the IHI approach may offer a different way to prioritize contaminant and health information together, we acknowledge that there is usually no causal link between these data. The interactions between health indicators and contaminant exposure are complex and not represented by this method. This method's utility may lie in aiding us in identifying contaminants and health indicators of greatest concern, which could then be prioritized for further evaluation. However, we maintain that the case presented here is not a risk assessment, but rather a data organization and visualization tool which may be used to better understand the contexts of communities who face potential harms from contamination, beyond conventional hazard and exposure data.

Thus, a next step may be to explore how these indicators can be used to interpret contaminants information and further how they can be interpreted in relation to one another. Some indicators may represent vulnerabilities that precipitate increased ‘risks’ related to contaminant exposure, and some represent impacts of contaminant exposure on health. Many likely fall into both categories. Compared to conventional methods, an IHI approach considers health indicators information in parallel to contaminant information (as opposed to supplemental to the ‘core’ risk assessment). However, the question of the appropriate level of ‘integration’ of IHI into HHRA methods remains. Hazard Quotient values for contaminant risk assessments are calculated by comparing exposure to hazard values. If exposure exceeds the hazard value (i.e.: a Hazard Quotient >1), this is considered a potential ‘risk’. One way in which to further operationalize the IHI in risk assessment contexts is to identify ‘thresholds’ that are standards for health risks as defined by communities, and to use these thresholds in a similar way that a hazard value (for example, a ‘tolerable daily intake’ value) would be used to assess contaminant-related risks. Somewhat similarly, studies that use the Swinomish IHI consider the relative importance of indicators to dealing with resource change compared to the perceived impact (Donatuto et al., 2020; Donatuto et al., 2014; Donatuto et al., 2011). Donatuto et. al (2016) also suggest that an IHI ‘ranking’ approach may be used to establish a threshold (i.e.: a value at which negative impacts would occur) (Donatuto et al., 2016). To do this on a regional level, however, would require further data gathering and value judgements on indicator values of ‘risk’, which may be challenged by variations amongst communities, and further, by the conventional definition of risk itself. While the use of the Hazard Quotient method presents risks in black and white, qualitative and descriptive health information is more nuanced, and may require an entirely different approach, while recognizing that an assessment method itself cannot fully capture the realities of contaminant-related 'risks' and impacts faced by Indigenous communities. Future research on such approaches should proceed cautiously, noting that the IHI are not meant to be subsumed within generic methods (Donatuto et al., 2016).

6.6.5 Data Sovereignty

Finally, we note that in the development of any large-scale, regional, or screening-level tools, the principles of Indigenous data sovereignty and self-determination must be upheld. Here, we used a publicly available regional dataset from the FNFNES, the collection and reporting of which was co-led by the Assembly of First Nations following the First Nations Data Sovereignty Principles of Ownership, Control, Access, and Possession (OCAP) (Chan et al., 2021; First Nations Information Governance Centre, 2022; Schnarch, 2004). However, the operationalization of the approach proposed here, and any approach leveraging Indigenous data, requires ongoing collaboration. Developing and applying western-scientific approaches, including the use of screening and prioritization tools, should be done only with the consent and under the leadership of Indigenous communities. Doing so will help to ensure their relevance and applicability to contexts and ultimately produce methods that are beneficial to communities themselves (Mullen, 2022; Mullen et al., 2023). The use of IHI approaches designed by and for communities is one tool that may assist with decision-making and assessment reflective of the environmental health issues specific to and prioritized by Indigenous Peoples.

6.7 CONCLUSIONS

A consistent and agreed upon methodological approach for including community-relevant health information in risk assessments has yet to be established. Methods for developing and using Indigenous Health Indicators (IHI) by two communities (The Swinomish Tribal Community and Piikani Blackfoot Nation) present promising ways forward and have been tested in a handful of settings to date. This paper aimed to explore the operationalization of these two methodologies in the context of regional survey data that was collected alongside a regional HHRA for environmental contaminants. The resultant demonstrative case represents an ideation of how IHI tools may be used in the development of new approaches to risk assessment that are more relevant to Indigenous community contexts than conventional methods. To capture the diversity of available data (both qualitative and quantitative), we attempted to use the two communities' established methods in combination and compare them alongside conventional HHRA data, producing a visual organization of the data that may be used as a component of an approach for prioritizing HHRA information and health indicator information in parallel. While the indicator information does not produce a 'risk assessment', the comparison of indicator values amongst regions is an approach that may be used to better understand the contexts of contaminant-related risks. Alongside health indicator information, contaminant HQs may be further contextualized and potential vulnerabilities or protective factors in relation to contamination may be recognized. This information may be used to identify areas for further research, allocation, and management. The organization of information in this case study may also provide an ideation of the approach in the design of a visual communication tool for health risk assessment information, both 'chemical' and 'non-chemical'. Overall, however, this case highlights several inherent challenges with scaling a 'values-based' approach. If, and how, IHI values may be further operationalized in new HHRA methods or used to determine health 'risks' remains in question. Future work may seek to address some of these challenges, as well as consider and leverage other existing regional datasets.

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6.9 References

Arquette, M., Cole, M., Cook, K., LaFrance, B., Peters, M., Ransom, J., Sargent, E., Smoke, V., & Stairs, A. (2002). Holistic risk-based environmental decision making: A native perspective. *Environmental Health Perspectives, 110*, 259-264. https://doi.org/10.1289/ehp.02110s2259

Assembly of First Nations. (2022). *Submission to the Senate Standing Committee on Energy, the Environment and Natural Resources (ENEV) Study on An Act to amend the Canadian Environmental Protection Act, 1999, to make related amendments to the Food and Drugs Act and to repeal the Perfluorooctane Sulfonate Virtual Elimination Act (Bill S-5).* Retrieved June 27 2024 from https://sencanada.ca/Content/Sen/Committee/441/ENEV/briefs/Brief_AFN_VictorOdele_e.pdf

Ayotte P, Gagnon S, Riva M, Muckle G, Hamel D, Bélanger RE, Fletcher C, Furgal C, Dawson A, Galarneau C, Lemire M. The Qanuilirpitaa? 2017 Nunavik Health Survey: design, methods, and lessons learned. *Canadian Journal of Public Health.* 2024 Jan;115(Suppl 1):7-19. https://doi.org/10.17269/s41997-023-00846-6

Bouche, C. (2022). Developing Indigenous health indicators for cumulative effects management. Simon Fraser University. Resource and Environment Management Theses. Retrieved June 27 2024 from https://summit.sfu.ca/item/34920

Buse, C. G., Bezzola, A., Brubacher, J., Takaro, T. K., Fredeen, A. L., & Parkes, M. W. (2022). Cumulative impacts of diverse land uses in British Columbia, Canada: Application of the "EnviroScreen" method. *International Journal of Environmental Research and Public Health, 19*(18), 11171. https://doi.org/10.3390/ijerph191811171

Callahan, M. A., & Sexton, K. (2007). If cumulative risk assessment is the answer, what is the question? *Environment Health Perspectives. 115*(5), 799-806. https://doi.org/10.1289/ehp.9330

Goodman, R. A., Bunnell, R., & Posner, S. F. (2014). What is "community health"? Examining the meaning of an evolving field in public health. *Preventive medicine,* 67 Suppl 1(Suppl 1), S58–S61. https://doi.org/10.1016/j.ypmed.2014.07.028

Government of Canada (2022). *Federal Contaminated Sites Inventory*. Retrieved January 31 2022 from https://www.tbs-sct.gc.ca/fcsi-rscf/home-accueil-eng.aspx

Chan, H. M., Fediuk, K., Batal, M., Sadik, T., Tikhonov, C., Ing, A., & Barwin, L. (2021). The First Nations Food, Nutrition and Environment Study (2008–2018)—rationale, design, methods and lessons learned. *Canadian Journal of Public Health, 112*, 8-19. https://doi.org/http://dx.doi.org/10.17269/s41997-021-00480-0

Chan, L., Batal, M., Sadik, T., Tikhonov, C., Schwartz, H., Fediuk, K., Ing, A., Marushka, L., Lindhorst, K., Barwin, L., Berti, P., Singh, K., & Receveur, O. (2019). *FNFNES Final Report for Eight Assembly of First Nations Regions: Draft Comprehensive Technical Report.* Retrieved June 27 2024 from https://www.fnfnes.ca/docs/FNFNES_draft_technical_report_Nov_2__2019.pdf

Chong, K., Hickey, G. M., Chan, H. M., & Basu, N. (2024a). Exploring practices, challenges, and priorities for human health and ecological risk assessments in Indigenous communities in Canada. *Integrated Environmental Assessment and Management*. [Online ahead of print]. https://doi.org/10.1002/ieam.4927

Chong K., Chavez M, Dersch A, Doyle J, Eggers M, LaFrance J, Lefthand M, MacDermid F, McAuley C, Simonds V, Young S, and Basu, N. (2024b). Exploring the use of the RISK21 approach for Indigenous community-based human health risk assessments: Two case studies. *FACETs.* [In Print]. DOI: 10.1139/facets-2024-0085

Donatuto, J., Campbell, L., & Gregory, R. (2016). Developing responsive indicators of Indigenous community health. *International Journal of Environmental Research and Public Health, 13*(9), Article 899. https://doi.org/10.3390/ijerph13090899

Donatuto, J., Campbell, L., & Trousdale, W. (2020). The "value" of values-driven data in identifying Indigenous health and climate change priorities. *Climatic Change, 158*(2), 161-180. https://doi.org/10.1007/s10584-019-02596-2

Donatuto, J., Grossman, E. E., Konovsky, J., Grossman, S., & Campbell, L. W. (2014). Indigenous community health and climate change: Integrating biophysical and social science indicators. *Coastal Management, 42*(4), 355-373. https://doi.org/10.1080/08920753.2014.923140

Donatuto, J. L., Satterfield, T. A., & Gregory, R. (2011). Poisoning the body to nourish the soul: Prioritising health risks and impacts in a Native American community. *Health, Risk & Society, 13*(2), 103-127. https://doi.org/10.1080/13698575.2011.556186

Eggers, M. J., Doyle, J. T., Lefthand, M. J., Young, S. L., Moore-Nall, A. L., Kindness, L., Medicine, R. O., Ford, T. E., Dietrich, E., Parker, A. E., Hoover, J. H., & Camper, A. K. (2018). Community engaged cumulative risk assessment of exposure to inorganic well water contaminants, Crow Reservation, Montana. *International Journal of Environmental Research And Public Health, 15*(1), Article 76. https://doi.org/10.3390/ijerph15010076

Failing, L., Gregory, R., & Higgins, P. (2013). Science, uncertainty, and values in ecological restoration: A case study in structured decision-making and adaptive management. *Restoration Ecology, 21*(4), 422-430. https://doi.org/https://doi.org/10.1111/j.1526-100X.2012.00919.x

Fernández-Llamazares, Á., Garteizgogeascoa, M., Basu, N., Brondizio, E. S., Cabeza, M., Martínez-Alier, J., McElwee, P., & Reyes-García, V. (2020). A state-of-the-art review of Indigenous peoples and environmental pollution. *Integrated Environmental Assessment and Management, 16*(3), 324-341. https://doi.org/https://doi.org/10.1002/ieam.4239

First Nations information Governance Centre. (2024). *FNIGC Knowledge Lodge.* Retrieved July 17 2024 from https://fnigc.ca/first-nations-data-centre/data-online/

First Nations Information Governance Centre. (2022). *Understanding OCAP*. Retrieved November 20 2023 from https://fnigc.ca/ocap-training/

Gislason, M. K., & Andersen, H. K. (2016). The interacting axes of environmental, health, and social justice cumulative impacts: A case study of the blueberry river first nations. *Healthcare (Switzerland), 4*(4), Article 78. https://doi.org/10.3390/healthcare4040078

Government of Canada (2022). *Bill S-5, Strengthening environmental protection for a healthier Canada act- Summary of Amendments.* Ottawa, Ontario 2022. Retrieved from June 27 2024 from https://www.canada.ca/en/environment-climate-change/news/2023/06/bill-s-5-strengthening-environmental-protection-for-a-healthier-canada-act.html

Gregory, R., McDaniels, T., & Fields, D. (2001). Decision aiding, not dispute resolution: Creating insights through structured environmental decisions. *Journal of Policy Analysis and Management, 20*(3), 415-432. https://doi.org/http://dx.doi.org/10.1002/pam.1001

Gregory, R., Doug, E., Kaechele, N., Trousdale, W. (2016). Values-based measures of impacts to Indigenous health [Perspective]. *Risk Analysis, 36*(8), 1581-1588. https://doi.org/10.1111/risa.12533

Hackett, P., Liu, J., & Noble, B. (2018). Human health, development legacies, and cumulative effects: environmental assessments of hydroelectric projects in the Nelson River watershed, Canada. *Impact Assessment and Project Appraisal, 36*(5), 413-424. https://doi.org/10.1080/14615517.2018.1487504

Harper, B., Harding, A., Harris, S., & Berger, P. (2012). Subsistence exposure scenarios for Tribal applications. *Human and Ecological Risk Assessment. 18*(4), 810-831. https://doi.org/10.1080/10807039.2012.688706

Harris, S. G., & Harper, B. L. (2000). Using eco-cultural dependency webs in risk assessment and characterization of risks to tribal health and cultures. *Environmental Science and Pollution Research, 2*(2), 91-100. Retrieved from https://superfund.oregonstate.edu/sites/superfund.oregonstate.edu/files/harris_harper_2000_eco-cultural_dependency_webs_espr.pdf

Health Canada. (2018). *Guidance for evaluating human health impacts in environmental assessment: country foods*. Health Canada. Ottawa, Ontario. Retrieved June 27 2024 from https://publications.gc.ca/site/eng/9.855584/publication.html

Health Canada. (2019). *Guidance for Evaluating Human Health Impacts in Environmental Assessment: Human Health Risk Assessment.* Health Canada. Ottawa, Ontario. Retrieved June 27 2024 from: https://publications.gc.ca/site/eng/9.870475/publication.html

Halevi Hochwald, I., Green, G., Sela, Y., Radomyslsky, Z., Nissanholtz-Gannot, R., & Hochwald, O. (2023). Converting qualitative data into quantitative values using a matched mixed-methods design: A new methodological approach. *Journal of Advanced Nursing*, *79*(11), 4398-4410. https://doi.org/10.1111/jan.15649

Hoover, E., Renauld, M., Edelstein, M. R., & Brown, P. (2015). Social science collaboration with environmental health. *Environmental Health Perspectives, 123*(11), 1100-1106. https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.1409283

Kryzanowski, J. A., & McIntyre, L. (2011). A holistic model for the selection of environmental assessment indicators to assess the impact of industrialization on Indigenous health.

Canadian Journal of Public Health, 102(2), 112-117. https://doi.org/10.1007/BF03404158

Lewis, A. S., Sax, S. N., Wason, S. C., & Campleman, S. L. (2011). Non-chemical stressors and cumulative risk assessment: an overview of current initiatives and potential air pollutant interactions. *International Journal of Environmental Research and Public Health, 8*(6), 2020-2073. https://doi.org/10.3390%2Fijerph8062020

Lievanos, R. S. (2018). Retooling CalEnviroScreen: Cumulative pollution burden and race-based environmental health vulnerabilities in California. *International Journal of Environmental Research and Public Health, 15*(4), 762. https://doi.org/http://dx.doi.org/10.3390/ijerph15040762

Min, E., Gruen, D., Banerjee, D., Echeverria, T., Freelander, L., Schmeltz, M., Saganić, E., Piazza, M., Galaviz, V. E., Yost, M., & Seto, E. Y. W. (2019). The Washington State Environmental Health Disparities Map: Development of a community-responsive cumulative impacts assessment tool. *International Journal of Environmental Research and Public Health, 16*(22). https://doi.org/http://dx.doi.org/10.3390/ijerph16224470

Moretto, A., Bachman, A., Boobis, A., Solomon, K. R., Pastoor, T. P., Wilks, M. F., & Embry, M. R. (2017). A framework for cumulative risk assessment in the 21st century. *Critical Reviews in Toxicology, 47*(2), 85-97. https://doi.org/10.1080/10408444.2016.1211618

Mullen, H. (2022). *Indigenous environmental justice and screening tools: Lessons learned from EJSCREEN and paths forward for the climate and economic justice screening tool*. University of Michigan. Retrieved June 27 2024 from https://deepblue.lib.umich.edu/bitstream/handle/2027.42/172180/Mullen_Haley_Thesis.pdf?sequence=1&isAllowed=y

Mullen, H., Whyte, K., & Holifield, R. (2023). Indigenous Peoples and the Justice40 Screening Tool: Lessons from EJSCREEN. *Environmental Justice*. https://doi.org/10.1089/env.2022.0045

National Academies of Sciences, Engineering & Medicine. (2022). New Approach Methods (NAMs) for Human Health Risk Assessment: Proceedings of a Workshop–in Brief. Retrieved June 27 2024 from https://nap.nationalacademies.org/read/26496/chapter/1

Parliament of Canada. (2023). *BILL C-226- An Act respecting the development of a national strategy to assess, prevent and address environmental racism and to advance environmental justice.* Retrieved September 9, 2024 from https://www.parl.ca/DocumentViewer/en/44-1/bill/C-226/third-reading

Paul, K. L., Carlson, H. A., Weatherwax, M. L. P., Caplins, L., Falcon, C., Carter, C. J., & Ruppel, K. T. (2023). The Piikani Well-being Project: Indigenous-led metrics and mapping to improve human and agricultural system health within the Amskapi Piikani Blackfeet Nation. *Environment and Planning F*, 26349825231154869. https://doi.org/10.1177/26349825231154869

Reid, M. G., Hamilton, C., Reid, S. K., Trousdale, W., Hill, C., Turner, N., Picard, C. R., Lamontagne, C., & Matthews, H. D. (2014). Indigenous Climate Change Adaptation

Planning Using a Values-Focused Approach: A Case Study with the Gitga'at Nation. *Journal of Ethnobiology, 34*(3), 401-424. https://doi.org/10.2993/0278-0771-34.3.401

Sanchez, Y. A., Deener, K., Hubal, E. C., Knowlton, C., Reif, D., & Segal, D. (2010). Research needs for community-based risk assessment: findings from a multi-disciplinary workshop. *Journal of Exposure Science & Environmental Epidemiology, 20*(2), 186-195. https://doi.org/10.1038/jes.2009.8

Satterfield, T., Gregory, R., Klain, S., Roberts, M., & Chan, K. M. (2013). Culture, intangibles and metrics in environmental management. *Journal of Environmental Management, 117*, 103-114. https://doi.org/10.1016/j.jenvman.2012.11.033

Schnarch, B. (2004). Ownership, control, access, and possession (OCAP) or self-determination applied to research: A critical analysis of contemporary First Nations research and some options for First Nations communities. *International Journal of Indigenous Health, 1*(1), 80-95. https://doi.org/10.18357/IJIH11200412290

Sexton, K. (2012). Cumulative risk assessment: an overview of methodological approaches for evaluating combined health effects from exposure to multiple environmental stressors. *International Journal of Environmental Research and Public Health, 9*(2), 370-390. https://doi.org/10.3390/ijerph9020370

Sexton, K. (2015). Cumulative health risk assessment: Finding new ideas and escaping from the old ones. *Human and Ecological Risk Assessment: An International Journal, 21*(4), 934-951. http://dx.doi.org/10.1080/10807039.2014.946346

Sexton, K., & Linder, S. H. (2011). Cumulative risk assessment for combined health effects from chemical and nonchemical stressors. *American Journal of Public Health, 101*(S1), S81-S88. https://doi.org/10.2105%2FAJPH.2011.300118

United Nations. (2018). *State of the World's Indigenous Peoples indigenous Peoples' Access to Health Services*. Economic and Social Affairs. Retrieved June 27 2024 from https://www.un.org/development/desa/indigenouspeoples/wp-content/uploads/sites/19/2018/03/The-State-of-The-Worlds-Indigenous-Peoples-WEB.pdf

Uppal, S (2023). Food insecurity among Canadian families. *Insights on Canadian Society.* Statistics Canada/Statistique Canada- November 2023. Retrieved June 27 2024 from https://www150.statcan.gc.ca/n1/en/pub/75-006-x/2023001/article/00013-eng.pdf?st=JTWoSHAw

US EPA (2024). *EJScreen: Environmental Justice Screening and Mapping Tool- Purposes and Uses of EJScreen*. Retrieved April 15 from https://www.epa.gov/ejscreen/purposes-and-uses-ejscreen

CONNECTING PARAGRAPHS

Chapter 6 provides an initial pilot-test of the use of existing IHI methods on a regional scale using data from the First Nations Food, Nutrition, and Environment Study (FNFNES). Novel to this case study was regional scaling of the IHI methodologies, the combination of methods to consider both quantitative and descriptive information, and the visual organization of survey data in relation to contaminant risk assessment information. Overall, Chapter 6 highlights inherent challenges with increasing the scale of application of an IHI approach, which is values based. The presented case study misses several important aspects of the originally developed method and contributes to a different overall goal and outcome. However, the case study also provides some insight into considerations for the development of new approaches to HHRA for Indigenous community contexts. The findings further highlight a gap in knowledge on the development of methods for assessing non-conventional aspects of human health of importance to Indigenous communities in risk assessments, including qualitative-descriptive and semi-quantitative information. These key findings were shared with collaborating community-based team members in Kanesatake.

Considering some of the key findings from chapters 3 through 6 contributes to the approach in chapter 7. This chapter outlines the initial stages of the design of an Indigenous Health Indicators tool of relevance to the Kanien'kehá:ka community of Kanesatake (including elements of the ‘empathize/define’, ‘ideate’, and ‘prototype’ phases of design thinking), and takes the form of a written progress report that was prepared for the Kanesatake Environment Department. It is the first of an intended series of iterative studies under the First Nations Baseline Assessment Program on Health and the Environment (BAPHE). Community leadership, communication, and meaningful collaboration have been important themes throughout this thesis and contribute to the approach in this chapter, which acknowledges that an important part of collaborative work with communities involves relationship building and reaching a mutual understanding of the goals, methods, and intended outcomes of the work. The Swinomish Tribal Community's Indigenous Health Indicators work, from which we draw our methodology, began with a similar approach to relationship building and community design, and has been in process for over a decade. We expect that the development of Indigenous Health Indicators relevant to Kanesatake will take several years and continue to evolve thereafter. Such a timeline does not fit into the academic requirements of this dissertation. Thus, this initial study focuses firstly on detailing the community-based and context specific approach for developing health indicators in Kanesatake, which was co-developed by the involved authors. Secondly, we provide an overview of our initial findings from qualitative, open-ended interviews with community members, from which we identify a few health indicator themes, and which drive the next stages of this work. In doing so, we provide a methodological resource and case example, which can be used to deepen the collaborative work based in Kanesatake that is planned for the next few years, and as a reference for those who may wish to conduct similar work.

This chapter is co-authored by myself, Valerie Gabriel, and Dr. Niladri Basu. I am the first author.

CHAPTER 7: Putting our minds together: Kanesatake Kanien'kehá:ka Perspectives on Developing a Health Indicators Tool- Progress Report

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7.2 Abstract

Decades of environmental justice concerns and polluting activities on the territory of the Kanehsatà:ke (Kanesatake) Kanien'kehá:ka (Mohawk) have resulted in concerns from community members about potential risks to their health. In response, in 2019 the Kanesatake Environment Department launched a project that documents contaminant concentrations in soil, food, and water, and conducted a human health risk assessment to characterize risks from exposure to local food sources. While an important start to understanding potential contaminant-related health risks, these conventional assessments use western-scientific definitions of physiological health, but do not include important aspects of health (ex: social, cultural) as defined by the community. 'Indigenous Health Indicators' are metrics that are specific to community knowledge, worldviews and priorities for health, and may be one tool that can complement ongoing environmental assessment work by helping to further understand and prioritize health risks related to contamination in and surrounding Kanesatake. This study is the first stage of a project that aims to develop a community-relevant Indigenous Health Indicators tool for assessing health and well-being as viewed from community perspectives. With this objective in mind, we acknowledge the historical and present failures of the academy in conducting research involving Indigenous communities that understands, respects and prioritizes cultural safety. We must begin by laying a groundwork for our project in the specific context of Kanesatake by nurturing a meaningful collaboration and clarifying the roles of community and academic researchers. Thus, the objective of this initial report is to first, detail our community-led approach to developing 'Kanesatake Environmental Health Indicators', including our guiding principles and methodological design; and second, to provide an overview of initially identified indicator themes that lay a foundation for the next stages of this process. Between May and

September of 2024, we developed key guiding principles of this work, which include creating a safe space for dialogue that follows cultural and community norms; safeguarding community knowledge; honoring living and iterative project execution; relationship building; and acknowledging limitations. Following these principles, from November to December 2024 we conducted semi-structured, open-ended interviews with five community members from multiple generations. These discussions identified that safety, community connectedness, and the land base are all important indicators of health that are impacted by environmental and resource changes in Kanesatake. Future work will continue to iteratively develop these themes, through ongoing consultation with community members and focus groups, prototyping, and testing in a variety of environmental assessment contexts.

7.3 BACKGROUND

7.3.1 The Kanien'kehá:ka (People of the Flint) of Kanesatake

The Kanien'kehá:ka (Mohawk) community of Kanehsatà:ke (Kanesatake) is located at the meeting of the Ottawa and St-Lawrence rivers, northwest of the island of Tiohtià:ke (Montreal). Kanien'kehá:ka are one of five original members and the easternmost nation of the Haudenosaunee and are known as the keepers of the eastern door. For many decades, the community of Kanesatake has been facing environmental injustices that include polluting activities from government, industry, and the surrounding region (Bhat, 2022; Fayazi et al., 2020). Kanesatake Kanien'kehá:ka territory does not fall under reserve status as defined by *The Indian Act,* which creates a lack of legislative clarity over governmental fiduciary responsibilities to provide for local land management (Hurley, 2001; Fayazi at al., 2020). Unresolved historic and current injustices create complex legal and political relationships between Kanesatake and the federal (Canada), provincial (Quebec), and municipal (Oka) governments, which further complicates the management, assessment, and regulation of potential contamination in the community (Fayazi et al., 2020). One major concern is ‘G and R recyclage’, a large unregulated dumpsite with industrial waste of unknown content entering the community from the surrounding urban and peri-urban areas (Bergeron, 2023). Kanesatake elders have noticed an increase in cases of cancer in the community since the dumping activities began (Kanesatake Environmental Contaminants and Health Impact Project, 2020). There is also a potential threat to a variety of local traditional food sources of importance to Kanesatake (ex: cultivated fruits and vegetables, forest foods and medicines, locally caught fish), an agricultural community who consume fish from the St. Lawrence River and share a fishing and hunting ground (Tiowéro:ton) with their Kanien'kehá:ka sister community, Kahnawà:ke (Kahnawake). In response to concerns around these polluting activities, Ratishontsanonhstats Kanesatake Environment and their partners launched the Environmental Contaminants and Health Impact Project (ECHIP) in 2019 (FNECP, 2020). The ECHIP has worked on measuring heavy metal (ex: mercury, cadmium, arsenic, lead) and organic contaminant concentrations in soil, food, and water on the territory; testing human biomarkers (i.e.: hair and urine) for heavy metals; and conducting a human health risk assessment (HHRA), which seeks to understand potential health risks from exposure to contaminants in traditional foods and water (FNECP, 2020).

Measuring the presence and levels of heavy metals and organic contaminants and quantifying potential 'health risks' has been the subject of the ECHIP and numerous studies to date in the territory (Balkwill-Tweedie, 2020; Boudreau and Turcotte, 1982; Boulet et al., 1983; Fayazi et al., 2020; Bhat et al., 2022). However, this information addresses a narrow understanding of the potential health impacts of environmental contamination on Kanesatake community members. Conventional risk assessment approaches are rigid and narrowly focused on chemical exposure and toxicity, but do not broadly capture stressors and outcomes of community relevance, such as potential social, mental, spiritual, cultural, physical, economic, and environmental health impacts of contamination on community members (Assembly of First Nations, 2022; Eggers et al., 2018; Sexton and Linder, 2011). Throughout the ECHIP, community members have voiced their concerns about the availability and quality of traditional food systems, have expressed a lack of trust in local water sources, and have reported conflicts that have arisen from polluting events. Thus, as a next step to the ECHIP, there is a need to meaningfully include these losses and impacts in the environmental assessment methods currently employed. This knowledge is of the utmost importance in understanding how the community perceives their health and well-being, and ultimately for accurately understanding how contamination impacts the community. A meaningful environmental health assessment at Kanesatake may only be realized if approaches are used that views and defines health from the community perspective.

7.3.2 Indigenous Health Indicators

While many Indigenous communities, including Kanesatake, face disproportionate impacts from pollution, environmental health assessments by government agencies, industry, and non-community researchers most often fail to include Indigenous understandings of health and well-being (O'Rourke et al., 2024). Writing on community-based environmental assessment has identified that 'health indicators' are a potential way to better understand health risks related to environmental pollution for unique communities (Sanchez et al., 2010). Community-defined health indicators are metrics that are specific to community knowledge of health and well-being, which can be used in tandem with conventional environmental health assessments. Health Indicators may be descriptive (ex: access to traditional medicine, or community connection) or more quantitative (ex: socioeconomic status or disease rates) (Donatuto et al., 2016; Paul et al., 2023). There are a few available examples of community-based identification and measurement of health indicators. For example, the Swinomish Tribal Community (Puget Sound, Washington State) have published numerous papers since 2011 which outline methods for the identification and testing of 'Indigenous Health Indicators', that can holistically measure Indigenous health risks and impacts, including 'intangible' (ex: social, mental, cultural) information (Donatuto et al., 2011; Donatuto et al., 2016; Donatuto et al., 2020). Other communities (ex: the Squaxin Island Tribe and Tsleil-Waututh Nation) have participated in case studies using this method, and the results have been positive, demonstrating the potential for the approach to developing health indicators to be applicable in other settings (Donatuto et al., 2020).

In the context of Kanesatake, Indigenous Health Indicators may be one tool that can help to further understand and characterize health risks and impacts related to contamination in the community and surrounding area, and to document changes to community health overtime in relation to environmental conditions and as resource changes (ex: industrial development, access to clean water, remediation, etc.) are introduced. As such, the authors launched this study under the direction of the Kanesatake Environment Department through the First Nations Baseline Assessment Program for Health and the Environment (BAPHE). The overall objective of the project is to develop community-relevant Indigenous Health Indicators that can be used as a tool for understanding and assessing health and well-being, as viewed from community perspectives in Kanesatake. This study is the first of an intended series of steps towards this stated objective.

7.3.3 Approach to Developing Indicators

With this objective in mind, we must first acknowledge that to date, 'research' conducted in Indigenous communities globally and across disciplines has generally lacked the necessary components to maintain cultural safety and engage in meaningful collaboration between Indigenous and non-Indigenous researchers (Ball & Janyst, 2008; Castleden et al., 2012; Liboiron, 2021; Parsons et al., 2016). Ethical guidelines on research involving Indigenous Peoples emphasize relationship building and developing shared goals and expectations, though this stage is often compromised by time constraints fundamental to academic research projects (Castleden et al., 2012). Several ways forward and examples of improved collaborative relationships exist or have been proposed (Donatuto et al., 2011, 2016; Newing et al., 2024, Gellman, 2021), from which we learn that there is a need to lay a groundwork for our work in the specific context of Kanesatake.

Thus, the objectives of this initial study are two-fold: First, to detail our proposed community-led approach to developing Kanesatake Environmental Health Indicators, including our intentions, key guiding principles, and methodological design; Second, to provide an overview of our initial interviews with five key community members and the resultant themes identified, which lay a groundwork for the next stages of this iterative process. This report provides a methodological resource and case example, which can be used throughout this project's progression, and as a reference for those who may wish to conduct similar work.

7.4 METHODS

7.4.1 Basic Principles

This project's methodological approach draws upon the principles of community-based participatory research (CBPR). CBPR is an approach that is focused on equitable participation, local relevance, and the usefulness of the results to the community (Israel et al., 1998; Israel et al., 2001; Ochocka and Janzen, 2014). Rather than a research 'method', CBPR is a process by which decision-making power and ownership is shared between the researchers and community, with the goal of mutually respectful relationships between university researchers and Indigenous communities (Castleden et al., 2012; Israel et al., 2001). While there are guiding principles, CBPR does not have an overarching framework, and so the methods here are developed and driven by the community context. This work explores the key principles for developing a tool/method (Kanesatake Environmental Health Indicators) by community members themselves. In doing so, unlike conventional research in which the design, analysis, and control of the work takes place in the academy, this project brings forward the views and priorities of community members in shaping this methodological tool from the outset, which lays a foundation for this community-led project. We also draw inspiration from specific examples of the development of Indigenous Health Indicators, including publications from the Swinomish Tribal Community and Amskapi Piikani Blackfoot Nation, which emphasize the importance of acknowledging and fostering strong and communicative relationships, community leadership, and a clear understanding of the research intention (Donatuto et al., 2016, Paul et al., 2023). In line with this, the project team laid out several guiding principles prior to commencing the project, which are applicable to this and future stages of the work. These principles guide our methodological approach.

1. *Creating Space*

Central to this project is the need to build Kanesatake Environmental Health Indicators from the ground up. Institutionalized 'health indicators' that are commonly used by federal and provincial governments impose pre-existing and often colonial assumptions about what 'health' is (Donatuto et al., 2011), which is not suitable for use in Kanesatake. Historically, such measurements and frameworks have been imposed upon communities to measure and quantify health. Thus, to develop health indicators of relevance to the Kanien'kehá:ka of Kanesatake, it is necessary to start at the grassroots level, with local community members and their lived experiences and knowledge, as opposed to using a top-down approach. This project's initial exploration of potential health indicators was open-ended and came from the community members interviewed, without the bias of a pre-existing framework or internally identified indicators. The notion of creating space for dialogue without the imposition of colonial assumptions or norms is a key part of our approach to recruitment, interviewing, and follow-up. For example, under the direction of the community researcher (VG) we provide individuals with the complete study information, including the questions we will ask, as part of our informed consent process; to the best of our ability, we avoid imposing time limits to our recruitment and discussions, and maintain an open door for follow-up discussions and visits; we aim to facilitate the natural flow of dialogue between the community researcher and academic researcher and between the researchers and participants; we encourage participants to explore their thoughts and emotions connected to their experiences; we are mindful of the language used to describe the study and are transparent about our intentions and limitations; and we provide flexibility and adaptability to the needs of the community members in the interview format, team members present, and location.

2. *Safeguarding community knowledge and promoting cultural safety*

Aligned with the creation of a safe space, our team discussed at the outset the necessity of safeguarding community knowledge. Aligned with the founding principles of a health indicators project conducted by the Amskapi Piikani Blackfoot Nation (Paul et al., 2023), this project is intended to serve the community from which the knowledge originates. We maintain that the legitimacy and validity of this work is best judged by those for whom it is conducted (i.e.: Kanesatake Kanien'kehá:ka community members), and it is with this principle in mind that we shape our methodological design, reporting, and communications. We also acknowledge the traditionally extractive nature of non-Indigenous academic or governmental research, and the fact that there is not a specific or consistent mechanism in place to ensure that community knowledge is safeguarded, and cultural safety is upheld within these organizations. Our methods, detailed below, consider how knowledge and information is safeguarded throughout the process. Most importantly, the community lead (VG) is familiarized with community and cultural Kanien'kehá:ka traditional norms, is well integrated in the community, and can speak to the topic of cultural sensitivity and safety. Additionally, we work to safeguard knowledge by avoiding audio recording, and through mechanisms such as member checking (i.e.: verifying with participants that we have accurately captured their perspectives), ongoing consultation, and an informed consent process. This project follows the First Nations principles of data sovereignty, OCAP (Ownership, Control, Access, and Possession) (Neglia, 2022; Schnarch, 2004). Authors involved in this work have taken a course on how to enact the OCAP principles. This key principle will require ongoing consideration throughout the project's progression.

3. Living Culture- Living Project

Foundational to this project is an acknowledgement that Kanesatake has a living culture, and therefore the health indicators must be fluid and adaptable and the tool developed will be iterated to reflect this. In other words, this is not a 'one and done' project in which research will be conducted and then the tool left as-is; rather it is intended to continue to be adapted and changed based on the living definition of health in the community. Thus, we do not intend for there to be an 'ultimate' version of a Kanesatake Environmental Health Indicators tool, though we do intend to create a foundational set of indicators that we expect to evolve over time. We also intend for the resultant tool to be adaptable to the contexts in which it will be used (i.e.: 'fit for purpose').

4. Relationship Building

Aligned with the iterative and long-term nature of this work, we prioritize relationship building in both the design and implementation of this project. First, this means relationship building between Indigenous and non-Indigenous collaborators involved in the project, including through ongoing discussion, active communication, and having a shared vision, which are well known ethical principles foundational to CBPR (Castleden et al., 2012; Ochocka and Janzen, 2014). Second, and perhaps less-often enacted in conventional research, are relationships as part of the methodological design including in the involvement of community members in the entire process of designing Kanesatake Environmental Health Indicators. In contrast to conventional "key informant interviews", the involved community members have an opportunity for ongoing dialogue with the research team who will revisit the themes and engage in continuous discussions as new themes emerge. This design honors community and cultural norms around communications and relations. Third, we anticipate future interest from new community members who wish to share in the project. Though funding timelines for the current work are finite, we foresee the necessity of continuation of the Kanesatake Environmental Health Indicators work, which will require future navigating to ensure proper funding and planning alongside other environmental projects without delay. Although other environmental projects end, the nature of this work is a long-term intention and commitment from those involved to the community and to relationship building.

5. *Inherent limitations*

Finally, we work to develop the health indicators while acknowledging that they will never encompass all aspects of health important to the community, and this will always be a key limitation of the work. There is no written format or academic framework that can represent the complex nature of health and well-being of a community. Acknowledging this limitation, the researchers involved engage in reflexive practices (also a key tenet of CBPR) that ground the work in this understanding and strive to reach the limits of these inherent boundaries.

7.4.2 Interview Design

Prior to beginning this study, approval was obtained from the Mohawk Council of Kanesatake (MCK) through a Band Council Resolution (BCR), and from McGill University's Research Ethics board (REB) (file # 24-06-016). In line with the guiding principles described above, the methodology presented here was designed by the project's community lead (VG), whose lived experience as a community member and knowledge of cultural norms were essential to developing a method consistent with community needs. We also drew inspiration from the approach taken by the Swinomish Tribal Community to develop Indigenous Health Indicators, that is, beginning with conversations with local community members to better understand health from community perspectives (Donatuto et al., 2011). For this initial stage in which we begin to ideate health indicators, the project team planned open-ended qualitative interviews with community members. Community members invited for the interviews were able to speak about the concept of health and environment in Kanesatake. Our goal for this initial round was to speak with 6-8 Kanien'kehá:ka community members, with participation from multiple generations. Effort was made to recruit interviewees of diverse gender identities, ages, occupational backgrounds, and living and familial situations. The community members were provided with all information on the project, both written and verbally as needed, to decide whether they would like to participate. We returned to the community members two weeks after they received the study information, to ask if they were interested in participation. The recruitment occurred in October to November 2024, with the interviews occurring from November to December 2024.

The interviewing team included a Kanesatake-based community lead (VG), who has worked on numerous other environmental projects in the community, including an environmental indicators project using a similar interview style (Gabriel, 2018); and an academic lead (KC), who is a PhD candidate at McGill University and has been working on projects led by the Kanesatake Environment Department for over 3 years prior to the start of this project. Supervising the project were staff of the Kanesatake Environment Department, and an academic supervisor (NB) from McGill University, who has been collaborating with the Department for over 5 years.

General guidance on the approach for the interviews and a list of guiding questions were developed by the project team between May and September of 2024 (Supporting Information 1). The interviews take the form of "sitting down for tea"- they are informal, they are not audio recorded, and they have the option to be anonymous. The community members have the option to be interviewed by one or both members of the interview team, in the location of their choice. The interview team members take written notes during the interview, which are used to identify initial themes and then to return to the community member to clarify if it accurately represents what they meant (member checking) and to revise the themes as needed. The interviewees were also made aware that they could contact the team should additional information come to mind, and if so, the team would make another visit to them to hear their additional words.

Analysis of the interview information included in this report took place over several weeks beginning in November of 2024, as described above. After each interview, the researchers debriefed and reflected upon the information discussed for an additional 1-2 hours and then had several follow-up meetings to further develop a shared understanding of the information. The academic researcher (KC) used a qualitative, thematic analysis approach to analyzing the information (Braun and Clarke, 2019; Byrne, 2022), and the community researcher (VG) used a culturally and community-rooted approach, with ongoing discussions occurring throughout the analysis process between the involved researchers to come to a common and shared understanding of the information and the emergent themes. After the interview notes were transcribed, open coding was used to identify initial themes, using thematic analysis methods (Braun and Clarke, 2019; Byrne, 2022). Drawing from these methods, the analysis was an iterative process involving familiarization, generating initial codes, and generating themes (Byrne 2022).

7.5 RESULTS

This section provides a progress update on the interviews to date towards the development of community-based health indicators in Kanesatake. As mentioned above, the intention is to continue to develop and iterate the health indicators through further engagements and discussions. Thus, we present here a summary of our to-date findings, as well as proposed future directions and plans for ongoing indicator development. The results presented here are meant to be demonstrative of the process of indicator development, and to provide a sense of how the indicators are beginning to take shape. We present the themes identified here in general terms, and without direct quotations from interviewees, purposefully. This is because the themes will continue to evolve and require further consultation with involved community members. Our priority is to avoid misrepresentation of the interviewees, and to uphold the safeguarding of community knowledge as outlined in our guiding principles.

A total of 11 community members were contacted to participate in the study- five agreed (45%), one refused (9%), two did not respond (18%), and three agreed to be interviewed in the future, but were not available for this round of interviews (27%). The results presented here arise from the analysis of the five interviews to date. Discussions with the five community members who are included in this report took place in their home(s), or the community researcher's home, with both the community researcher (VG) and academic researcher (KC) present. The interviewees' ages ranged between 22 and 65 years old. The interviews lasted an average of 2-3 hours.

7.5.1 Overarching Themes

Throughout the interviews, two overarching themes emerged which may help to guide our conceptualization of health indicators specific to Kanesatake. First, when asked about health, 100% of the community members we spoke with conceptualized health as a more holistic state of wellbeing. Wellbeing, from the perspectives of the interviewees, exists in interconnected realms (mental, spiritual, physical, and emotional), which are maintained in balance. When one of these realms are affected, the others are thus also impacted. Second, central to all the interviews was the overarching theme of healing. The external pressures placed on the community, which have resulted from past and ongoing settler colonialism through genocide and assimilation, was voiced by community members as an important element that contributes to imbalance, and ultimately impacts community health and well-being. Pressures on all the realms, including through ongoing negative environmental changes (such as polluting events, dumping on the territory, and land base changes) and industrial developments (such as construction of commercial buildings on the territory), make it difficult for community members to achieve balance.

7.5.2 Health Indicator Themes

Understanding these overarching themes, three potential indicator themes emerged from the interviews, which were described as factors in health and wellbeing and contribute to achieving balance, and as having been impacted by changes to the environment over time. These themes comprise our initial set of indicator areas which will be explored in further depth, in addition to other themes that may arise, including through ongoing member checking, and additional interviews. Thus, we expect that these themes will develop, deepen and change over time. Safety, Community Connectedness, and The Land Base were the three initial indicator themes that emerged from the interviews, which are summarized in Table 7-1. Within each theme, we identify elements that make up the indicator, and their definitions.

Table 7-1- Identified indicator themes resulting from five initial interviews with Kanesatake Kanien'kehá:ka community members. The three indicator 'categories' identified encompass various elements that comprise health and well-being for community members. Each element was described by interviewees as having been impacted, in some way, by changes to the environment over time, including through local development and pollution.

Indicator category	**Indicator elements and definitions**
Safety	**Physical-** community members move around the community without fear of physical harm **Environmental-** community members can trust in the land for cultural practices and recreation **Relational-** community members can express themselves without fear of interpersonal conflict
Land Base	**Neutrality-** community members have access to community spaces free from pollution and/or conflict **Food sovereignty**- community members self-determine food systems, including access to agriculture and harvest **Land Stewardship-** community members have respectful relationships with the land
Community Connectedness	**Individual-** community members cooperate with one another **Familial-** the community engages in collective living and can rely on each other **Organizational-** community organizations work together towards a shared vision

7.6 DISCUSSION

The creation of safe space for community members to explore and share culturally relevant perspectives and lived experiences is important for the development of a culturally integrated understanding of community health, which will ultimately result in more meaningful and comprehensive environmental assessments. It is in this spirit that we title our project "Putting our minds together"- this signifies our intention and commitment to work with diverse community perspectives that may otherwise be ignored or mishandled within conventional and institutionalized environmental assessment studies. This title is also an important reminder of the respectful collaboration between the Indigenous and non-Indigenous researchers and Indigenous community members involved with this work. This report lays a groundwork for the current and future work of developing community and culturally relevant health indicators for use in parallel with scientific environmental assessments in Kanesatake.

Importantly, this first report outlines our methodological approach to co-designing community-based Indigenous Health Indicators in Kanesatake. Building upon the work of others (Donatuto et al., 2016; Paul et al., 2023), we also provide a case example of engaging in community co-creation of new tools for environmental health assessment. While the approach follows some key principles that have been described in writing on CBPR and Indigenous Health Indicator development, it has been specifically designed in the context of the cultural and community norms in Kanesatake. It is important to note that while approaches to engaging in community-based research may share commonalities, there is no 'one size fits all" method (Castleden et al., 2016; Israel et al., 2001; Ochocka and Janzen, 2014), and thus laying a groundwork of intentions, principles and methods prior to beginning a project is necessary for any team looking to conduct similar work. This requires a considerable amount of time, patience, and commitment from team members, which have been historically finite resources in academic settings and government-funded projects (Castleden et al., 2016). In the context of Kanesatake, the ECHIP has been ongoing since 2019, and over the past year we have begun to focus on the Kanesatake Environmental Health Indicators, which are intended to complement and advance the ECHIP. There is much more work to be done, and thus we emphasize and acknowledge here the time and resources required to sustain this collaborative work.

Aligned with the work by the Swinomish Tribal community, the indicators and themes that we plan to develop are intended to be used in parallel to other relevant environmental assessments (Donatuto et al., 2016), such as the human health and ecological risk assessments and environmental monitoring which are ongoing in Kanesatake. The community-identified indicators are not meant to be subsumed into these assessments or used 'piecemeal' towards predominantly western scientific endeavours, which has been an identified issue with past works which aim to understand non-chemical risks related to contamination and environmental change (Donatuto et al., 2016; O'Rourke et al., 2024). Furthermore, the themes and potential health indicators identified here are not new and have been known by community members in the form of oral tradition and discussed in response to environmental harms that span a timeframe of centuries. The writing and analysis of the themes presented here do not add to their validity, but rather they present an alternative way of documenting and communicating them, which is important for transmitting information across a variety of disciplines and sectors. The development of Kanesatake Environmental Health Indicators may support environmental health assessments that are consistent with a known, longstanding Kanien'kehá:ka statement that the health of the environment is the health of the people (Gabriel, 2018). The five initial interviews with Kanesatake community members spanned multiple generations and provided some initial perspectives on the development of Kanesatake Environmental Health Indicators. Specifically, we identified a few key themes which we will continue to co-develop and expand upon in ongoing interviews.

Some of the overarching themes, including balance and the four realms of wellbeing (mental, spiritual, physical, emotional), are aligned with previous writing from Kanien'kehá:ka communities, including Kanesatake's sister communities of Kahnawake and Akwesasne. For example, a study of perceived holistic health and physical activity in Kahnawake describes health as a balance, drawing upon the medicine wheel concept (Cargo et al., 2007). While we acknowledge that the balance conceptualization of health presented here has been visually depicted in other papers as a Medicine Wheel, we have chosen to refrain from using this visualization. This is firstly because interviewees did not explicitly mention the Medicine Wheel in our discussions, and second because of knowledge of the community researcher that the medicine wheel is relevant for some, but not all, Kanesatake community members. The findings so far provide some indication that community environmental initiatives may require a holistic and balanced approach, rather than a problem-based approach, to improving environmental health and wellbeing. These findings are aligned with studies based in Kahnawake that recommend a shift from problem-based to holistic approaches to improving community health and well-being (Cargo et al., 2007; Hovey et al., 2016).

The three initial themes identified here are subject to change. However, findings from the five interviews thus far provide an indication that environmental changes on the territory, such as pollution and development, have a relationship to various elements of health and well-being for the interviewed members of Kanesatake, which are different from the health risks measured in conventional environmental assessment studies. Similarly, writings based in Akwesasne describe the impacts of industrial development on holistic well-being including mind, body, and spirit (Jacobs, 2018). We also note that the themes identified so far in Kanesatake are different from those identified in other Indigenous Health Indicators projects from other communities (Donatuto et al., 2011; Donatuto et al., 2016; Paul et al., 2023). Further, the social determinants of health recognized by the Assembly of First Nations (AFN) are similar to our findings in some instances (ex: historical factors and community connectedness), however there are some indicators (ex: safety) identified by Kanesatake community members that are not included in the AFN's framework (AFN, N.D.). These initial findings further support the need for this work in this specific and unique context.

7.6.1 Next steps

This progress report is the first iteration of the ongoing exploration of community-based health indicators for use alongside environmental assessments, and to better understand the impacts of environmental changes on community health. Our future stages of work will continue to develop and report on our learnings from the use of the methodological approach and foundational principles outlined here, and to adapt these overarching principles as needed. Guided by these evolving principles, our next step will be to continue to develop the initial themes identified here through ongoing discussion amongst the project team. Then, we plan to return to the original interviewees, as well as new interviewees, to further develop the themes in more depth, and to verify and add to the findings as we go. After another round of interviews at the individual level, we plan to include representatives from various organizations around the community. Once we have further developed our initial set of indicator themes, we will conduct another round of consultation with community members to understand community-relevant ways to measure the indicators, which may draw from a few pre-existing works which use descriptive scales (Donatuto et al., 2016) and could also include socio-demographic measures (Paul et al., 2023). We expect that this next phase will take a minimum of 12 months (from January to December 2025). We then plan to 'test' the prototype set of Kanesatake Environmental Health Indicators with collaborating community members to improve our understanding of community wellbeing in the context of the ongoing environmental assessment work in Kanesatake, including human health risk assessments through the ECHIP. Importantly, a necessity for continuing to build upon this work is to support the capacity of community members involved. With a desire to continue the work beyond the current project timeline, the next steps also involve planning for project sustainability including longer term funding. Finally, beyond the context of Kanesatake, an opportunity for future work exists for other communities who wish to develop community-relevant health indicators. Particularly, we provide one example here of a community-relevant approach, which adds to a relatively small number of case studies on the topic.

7.7 CONCLUSIONS

This report outlines our progress to-date on an intended ongoing, living documentation of the development of Kanesatake Environmental Health Indicators. The intention is to develop a community-relevant Indigenous Health Indicators tool for assessing health and well-being as viewed from community perspectives in Kanesatake, and for use by the community itself. The resultant tool may be used alongside environmental assessments to improve our understanding and documentation of the relationships between environmental changes and community health and well-being. The objective of this initial report was to highlight key founding principles of our methodological approach (creating safe space, safeguarding community knowledge; iterative work; relationship building; and acknowledging limitations), as well as to identify initial emergent themes. We conducted semi-structured, open-ended interviews with five community members, from which we have thus far identified three themes (Safety, Community Connectedness, and The Land Base) as potential indicators related to health and well-being in Kanesatake, and which may be impacted by local contamination and environmental changes. These themes require further exploration and development, including prototyping and testing in a variety of community-based contexts, which drives the future stages of this work.

7.7.1 Limitations

First, it is important to note that like the interview themes, the guiding principles of this work as stated are not developed to their ultimate stage. They are adaptable as the project changes, and as our understandings and collaborative relationships develop. Thus, as we engage in reflexive research practice and learn lessons, subsequent reports will revisit and adapt these principles.

Second, the five interviews conducted in this initial round of interviewing is not representative of the entire community. This work is a start to building upon our understanding of health and wellbeing in Kanesatake and gathering some initial perspectives. As previously mentioned, it is not possible to represent health and wellbeing in Kanesatake in the form of a written report, and thus this work presents a very narrow picture of the expressions of the interviewees. We note that the nature of thematic analysis involves several rounds of iteration to "solidify themes". Following our grounding principles, we do not aim for an ultimate version of a health indicators tool or to reach a consensus, but rather to continuously build upon the work, maintaining fluidity and adaptability as is aligned with health and wellbeing in Kanesatake.

7.8 References

Assembly of First Nations. (2022). *Submission to the Senate Standing Committee on Energy, the Environment and Natural Resources (ENEV) Study on An Act to amend the Canadian Environmental Protection Act, 1999, to make related amendments to the Food and Drugs Act and to repeal the Perfluorooctane Sulfonate Virtual Elimination Act (Bill S-5).* Retrieved June 27 2024 from https://sencanada.ca/Content/Sen/Committee/441/ENEV/briefs/Brief_AFN_VictorOdele_e.pdf

Assembly of First Nations (AFN). (N.D.). *Our Right to Health: First Nations' Perspectives Across the Generations.* Assembly of First Nations. Retrieved from: https://afn.ca/community-services/health-wellness/

Ball, J., & Janyst, P. (2008). Enacting research ethics in partnerships with Indigenous communities in Canada: "Do it in a good way". *Journal of Empirical Research on Human Research Ethics,* 3(2), 33-51. DOI: 10.1525/jer.2008.3.2.33

Balkwill Tweedie, H. (2020). *Effects of Weathering on Leaching Properties of Slag from a Niobium Mine, Oka, Quebec.*[Doctoral Dissertation]. Université d'Ottawa/University of Ottawa. Retrieved January 6 2024 from https://ruor.uottawa.ca/server/api/core/bitstreams/b8747a24-0ad1-4045-aa38-a3f35f71650f/content

Bergeron, U. (2023, April 3). *Un site de recyclage contaminé en héritage à Kanesatake.* Le Devoir. Accessed November 29 2024 from https://www.ledevoir.com/societe/787733/environnement-un-site-de-recyclage-contamine-en-heritage-a-kanesatake

Bhat, N. (2022). *Treading the Murky Depths of Environmental Racism- The Story of Environmental Contamination in Kanesatake*. Concordia University. Accessed December 20, 2024.

Boudreau, A. and Turcotte, J. (1982). Analysis of Gamma Radionuclides in Selected Farm Produce of Oka, Quebec-A Niobium Mining Community. *Journal of Food Protection* 45, no. 10. (1982): 905-908. https://doi.org/10.4315/0362-028X-45.10.905

Boulet, M., A. Boudreau, and J. C. Roy. (1983). Mesure de la radioactivité dans des tomates cultivées sur des résidus miniers d'Oka–Communauté minière de niobium. *Canadian Institute of Food Science and Technology Journal* 16, no. 4 (1983): 224-228. https://doi.org/10.1016/S0315-5463(83)72252-2

Cargo, M., Peterson, L., Levesque, L., & Macaulay, A. C. (2007). Perceived wholistic health and physical activity in Kanien'kehá: ka youth. *Pimatisiwin: A Journal of Aboriginal &*

Indigenous Community Health, 5(1). https://journalindigenouswellbeing.co.nz/media/2018/10/5_Cargo.pdf

Castleden, H., Morgan, V. S., & Lamb, C. (2012). "I spent the first year drinking tea": Exploring Canadian university researchers' perspectives on community-based participatory research involving Indigenous peoples. *The Canadian Geographer/Le Géographe canadien*, *56*(2), 160-179. https://doi.org/10.1111/j.1541-0064.2012.00432.x

Donatuto JL, Satterfield TA, Gregory R. (2011). Poisoning the body to nourish the soul: Prioritising health risks and impacts in a Native American community. *Health, Risk & Society*. 13(2):103-127. http://dx.doi.org/10.1080/13698575.2011.556186

Donatuto, J., Campbell, L., & Gregory, R. (2016). Developing responsive indicators of indigenous community health. *International Journal of Environmental Research and Public Health,* 13(9), 899. doi:10.3390/ijerph13090899

Donatuto J, Campbell L, Trousdale W. (2020). The "value" of values-driven data in identifying Indigenous health and climate change priorities. *Climatic Change.* 158(2):161-180. https://doi.org/10.1007/s10584-019-02596-2

Eggers, M. J., Doyle, J. T., Lefthand, M. J., Young, S. L., Moore-Nall, A. L., Kindness, L., Medicine, R. O., Ford, T. E., Dietrich, E., Parker, A. E., Hoover, J. H., & Camper, A. K. (2018). Community engaged cumulative risk assessment of exposure to inorganic well water contaminants, Crow Reservation, Montana. *International Journal of Environmental Research and Public Health,* 15(1), Article 76. https://doi.org/10.3390/ijerph15010076

Fayazi, M., Bisson, I. A., & Nicholas, E. (2020). Barriers to climate change adaptation in indigenous communities: A case study on the mohawk community of Kanesatake, Canada. *International Journal of Disaster Risk Reduction,* 49, 101750. https://doi.org/10.1016/j.ijdrr.2020.101750

FNECP (First Nations Environmental Contaminants Program) (2020). *Mohawk Council of Kanesatake Environment Contaminants Impact Health Study (Phase 1).* First Nations Portal on Environmental Contaminants and Health. Retrieved December 30, 2024 from https://fnecp-plcepn.ca/mohawk-council-of-kanesatake-environment-contaminants-impact-health-study-phase-1/

Gabriel, V. (2018). *Kanestake Environmental Indicators Report.* Ratishontsanonhstats Kanesatake Environment Department.

Hurley, M. C. (2001). *Bill S-24: The Kanesatake Interim Land Base Governance Act.* Parliamentary Research Branch. Accessed December 30, 2024.

Hovey, R., Delormier, T., & McComber, A. M. (2016). Social-relational understandings of health and well-being from an Indigenous perspective. *International Journal of Indigenous Health,* 10(1), 35-54. https://doi.org/10.18357/ijih.101201513195

Israel, B. A., Schulz, A. J., Parker, E. A., & Becker, A. B. (1998). Review of community-based research: assessing partnership approaches to improve public health. *Annual Review of Public Health,* 19, 173–202. https://doi.org/10.1146/annurev.publhealth.19.1.173

Israel, B. A., Schulz, A. J., Parker, E. A., Becker, A. B., & Community-Campus Partnerships for Health (2001). Community-based participatory research: policy recommendations for promoting a partnership approach in health research. *Education for Health*, 14(2), 182–197. https://doi.org/10.1080/13576280110051055

Jacobs, B.K. (2018). *Impacts of Industrial and Resource Development on the Wholistic Health of Akwesasronon: A Human Responsibility/Rights Solution.* [Doctoral Dissertation: University of Calgary]. https://prism.ucalgary.ca/server/api/core/bitstreams/99142791-5f14-4fea-800c-d411eceb1017/content

Kanesatake Environmental Contaminants and Health Impact Project (ECHIP) (2020). *Executive Summary for the Mohawk Council of Kanesatake.* Accessed December 16, 2024.

Liboiron, M. (2021). Pollution is colonialism. [Book]. Duke University Press.

Neglia, Kristine (2022, 23-24 Feb.). *2-Day Workshop – Deep Dive in The First Nations Principles of OCAP®.* FNIGC (First Nations Information Governance Center). [Workshop]. https://fnigc.ca/ocap-training/. OCAP® is a registered trademark of the First Nations Information Governance Centre (FNIGC).

Newing, H., Brittain, S., Buchadas, A., del Giorgio, O., Grasham, C. F., Ferritto, R., ... & Ghoddousi, A. (2024). 'Participatory' conservation research involving Indigenous peoples and local communities: Fourteen principles for good practice. *Biological Conservation,* 296, 110708. https://doi.org/10.1016/j.biocon.2024.110708

Ochocka, J., & Janzen, R. (2014). Breathing life into theory: Illustrations of community-based research: Hallmarks, functions and phases. *Gateways: International Journal of Community Research and Engagement*, *7*(1), 18-33. ISSN 1836-3393.

O'Rourke, R., Dunn, L., Taylor, D., O'Sullivan, A., & Donatuto, J. (2024). You say "natural resources," we say part of our community health: Using Indigenous Health Indicators to evaluate Coast Salish priorities when the environment is polluted. *Environmental Justice*. Ahead of print. https://doi.org/10.1089/env.2024.0035

Parsons, M., Fisher, K., & Nalau, J. (2016). Alternative approaches to co-design: insights from Indigenous/academic research collaborations. *Current Opinion in Environmental Sustainability,* 20, 99-105. https://doi.org/10.1016/j.cosust.2016.07.001

Paul, K. L., Carlson, H. A., Weatherwax, M. L. P., Caplins, L., Falcon, C., Carter, C. J., & Ruppel, K. T. (2023). The Piikani Well-being Project: Indigenous-led metrics and mapping to improve human and agricultural system health within the Amskapi Piikani Blackfeet Nation. *Environment and Planning F,* 2(1-2), 203-228. https://doi.org/10.1177/26349825231154869

Sanchez YA, Deener K, Hubal EC, Knowlton C, Reif D, Segal D. (2010). Research needs for community-based risk assessment: findings from a multi-disciplinary workshop. *Journal of Exposure Science & Environmental Epidemiology.* 20(2):186-195. https://doi.org/10.1038/jes.2009.8

Schnarch, B. (2004). Ownership, control, access, and possession (OCAP) or self-determination applied to research: A critical analysis of contemporary First Nations research and some options for First Nations communities. *International Journal of Indigenous Health*, *1*(1), 80-95. Retrieved October 29, 2024 from https://www.nswp.org/sites/nswp.org/files/SCHNARCH-OCAP.pdf

Sexton, K., & Linder, S. H. (2011). Cumulative risk assessment for combined health effects from chemical and nonchemical stressors. *American Journal of Public Health*, 101(S1), S81-S88. https://doi.org/10.2105%2FAJPH.2011.300118

CHAPTER 8: GENERAL DISCUSSION

8.1 Designing Human Health Risk Assessment Approaches for Indigenous Community Contexts

Environmental pollution disproportionately burdens Indigenous Peoples and communities, and this problem is pervasive and well-documented (Fernandez-Llamazares et al., 2020). The National Research Council's (NRC) *Science for Environmental Protection: The Road Ahead* defines environmental pollution problems of today as 'wicked problems'- that is, they exist on various spatial and temporal scales, across multiples systems and sectors, and extend beyond the understanding of a single discipline or organization (NRC et al., 2012). Pollution that impacts Indigenous communities, and the development of approaches that adequately and holistically assess the resultant health risks, is also a multifaceted challenge. Thus, there are many tools and approaches needed to develop and assess the complex dimensions of the problem (NRC et. al, 2012). This is consistent with the Assembly of First Nations' National Climate Strategy which describes the need to develop multidimensional and interconnected solutions to environmental challenges (Assembly of First Nations, 2023). The chapters of this thesis work with various tools and approaches, developing an understanding of the 'problem' at multiple levels- from regional, national, and international scales to a local and community-based focus. The chapters do not present a 'solution' to the wicked problem of HHRA approaches that are currently, and have historically been, employed in communities. However, the chapters present a range of sectoral, disciplinary, and methodological findings, contributing to a 'toolbox' that may be useful by and for Indigenous community-relevant human health risk assessment approaches.

Scoping and scaling

This thesis originally sought to design new approaches to HHRAs for contaminated sites in First Nations communities, which was motivated by the specific context of the Kanien'kehá:ka community of Kanesatake. The priorities stemmed from a collaborative Environmental Contaminants and Health Impact Project that was launched in response to concerns surrounding unregulated waste dumping, among other polluting events, in the community. At the outset, the importance of scope and scale became quickly apparent. The scope of this thesis broadened in many ways and narrowed in others. First, while contaminated sites are important in the context of First Nations communities, they are also of concern to Inuit and Metis communities in Canada and Tribal communities in the United States. While these groups are not homogenous, there are common environmental assessment challenges among them and thus the framing of the thesis was expanded to consider Indigenous communities in general. Second, while HHRA approaches serve an important purpose in assessing and managing formally classified federal contaminated sites, this is only one of many contexts in which they are used. Thus, the scope of the overall thesis expanded to HHRA approaches for contaminants in any application, and in fact, understanding that there is a wide diversity of risk assessment contexts was fundamental to the work. Outlined in Chapters 3-7 is the design thinking process through which we ideated and defined some of the key challenges with HHRAs, and then narrowed in on some existing key tools and approaches (namely RISK21 and Indigenous Health Indicators) to prototype and test for their relevance to a variety of unique risk assessment contexts.

Throughout the process, the scale of the chapters progressed from broad to specific. They involved first, gaining a broad understanding of the topic on an international scale; Second, addressing key knowledge gaps and gaining multi-sector perspectives on a national scale; Third, prototyping and testing an existing tool with two geographically and culturally diverse community case studies; and fourth, beginning to develop through existing methods a context-specific tool for use locally in Kanesatake. This multi-level approach that moves from broad understanding to testing specific solutions is consistent with the design thinking process, with the broader research focuses being important requisite knowledge for the subsequent narrower studies. Furthermore, though earlier chapters had a scope much broader than the specific context of Kanesatake, these steps provide a toolkit that can be further developed and utilized at this specific, local scale.

The chapters of this thesis highlight the importance of Indigenous leadership and involvement in the design of HHRAs for Indigenous community contexts and begin to consider how such approaches may be scaled for broader applications. While natural sciences researchers and federal and provincial governments have increasingly called for the inclusion of Indigenous science and Indigenous leadership in environmental assessment and management, these demands have not been matched with sufficient resources with which to do so (Eckert et al., 2020). Many communities' involvement in designing and implementing environmental assessments such as HHRAs may be hindered by significant capacity limitations that have resulted from systemic injustices, past and current exploitations, and severe underfunding. Chapters 3 and 4 highlight some of the capacity challenges experienced by communities in risk assessment work (ex: lack of adequate funding (amount and duration), lack of trained personnel), and these are aligned with a recent review examining barriers to Indigenous involvement in federal environmental assessment processes in Canada (Eckert et al., 2020). While scaling, adapting, and ultimately improving HHRA approaches for Indigenous community contexts requires the leadership and involvement of Indigenous peoples, it is essential to support the capacity of communities to do so. This may include increased federal and provincial support to communities to conduct environmental assessment work, longer-term capacity funding for communities, training opportunities, and equitable distribution of research funds to community partners.

Diversity and Interdisciplinarity

Another prominent theme that emerged throughout the chapters of this thesis was the importance of diversity and interdisciplinarity in the design of new risk assessment approaches. This theme highlights the importance of not only considering diverse perspectives, but engaging diverse disciplines, exploring diverse contexts, and using diverse methodologies towards a more comprehensive understanding of community-relevant HHRA approaches. For example, Chapter 4 highlights how perspectives on the challenges with risk assessment differ between sectors, especially those working at the community level compared to academics and federal and provincial government employees. Understanding these sectoral differences is important to developing new HHRA approaches that address diverse challenges at multiple levels. Chapter 5 explores the unique perspectives and contexts of three communities on the use of a RISK21 approach to HHRA, and chapters 6 and 7 highlight the need for new HHRA tools (i.e.: Indigenous Health Indicators approach) to be adaptable to unique and diverse contexts, and to include individual communities' input in their design. Furthermore, the importance of considering diverse information sources, including non-conventional sources such as descriptions, stories, and qualitative data, was highlighted in Chapters 5-7. Overall, the emergent themes of diversity and interdisciplinarity reinforced that the challenges with HHRA work for Indigenous community contexts are complex and multifaceted, and thereby must be addressed by complex and multifaceted solutions.

The importance of multi- and inter-disciplinarity has been included in writings on environmental management in general (Edwards, 2019; Hillman et al., 2005) and recognized by the Government of Canada in their recent funding calls for environmental impact assessment projects (Impact Assessment Agency of Canada, 2024). Furthermore, cumulative risk assessment (i.e.: the analysis, characterization, and possible quantification of combined risks to health or the environment from multiple agents or stressors (US EPA, 2024)) is intertwined with some of the approaches and tools described in this thesis (ex: RISK21's cumulative risk assessment framework and the inclusion of Indigenous Health Indicators information parallel to risk assessments). While writing on cumulative risk assessment methods have called for the inclusion of diverse information sources- not only quantitative, but also qualitative, socio-cultural information, there are no consistently agreed upon methods for doing so (Callahan and Sexton, 2007; Sexton 2012). We pilot-test one such tool here (i.e.: Indigenous Health Indicators) and future research may focus on building out tools to further support diverse information sources in HHRA work. This thesis supports that diverse information sources, when relevant to the community of focus, need be meaningfully included in risk assessments. Overall, the findings of this thesis, in combination with other works on cumulative risk assessment and holistic HHRA, point us towards an expanded risk assessment approach that engages multiple disciplines and considers diverse information of relevance to communities.

Design as adaptation and validation

Over the course of this thesis my understanding of 'design' has changed greatly. The initial proposal for this work included the design of a new risk assessment tool 'from scratch', through a series of methods including a Delphi survey which involves a multi-staged interview design process. However, the work revealed that the design process can look like multiple iterations and adaptations to existing tools and approaches, and testing and adapting them in new contexts (such as Indigenous community contexts) is a method of design. The external validity of existing tools and methods for risk assessment (RISK21, Indigenous Health Indicators) is explored through pilot tests in a diversity of contexts and scales.

Furthermore, my understanding of the diverse and complex nature of HHRA in Indigenous communities is that the development of any ‘one-size-fits-all tool’ is impossible. A single and streamlined framework, as is common in conventional and regulatory assessments for contaminants, is insufficient for addressing the complex situation of contamination in Indigenous communities in general, as well as the specific needs of individual communities. Rather, several tools and techniques may need to be adopted and used to adequately capture the human health ‘risks’ of contaminants in a variety of contexts. Akwesasronon scholar Abraham Francis writes on the concept of context specificity, which involves the recognition of the social, cultural, political, and environmental histories that have implications for natural resource management (Francis, 2019). Context specificity brings us towards the uniqueness of community contexts and away from the concept of ‘one-size-fits-all’ in environmental management (Francis, 2019), which is important to consider in the design of risk assessment approaches that meet community-level priorities and is consistent with the findings of this thesis. The design of HHRA approaches is a context-specific process, which is thereby iterative and continuous as opposed to finite.

8.2 Local, Scientific and Societal Significance

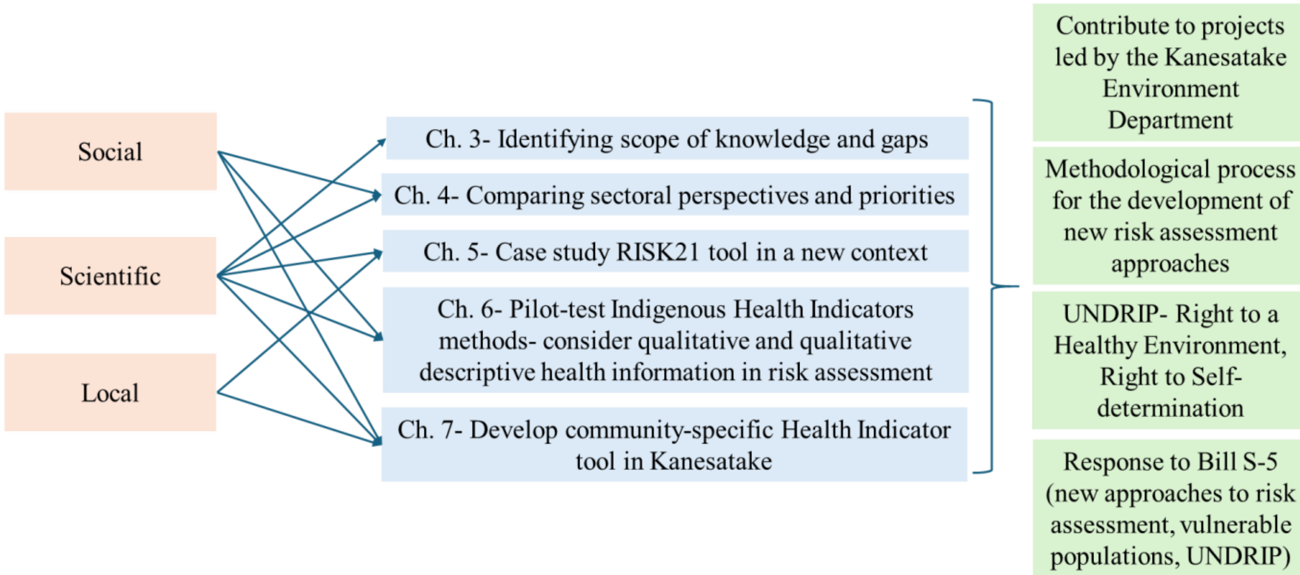

Figure 8-1: Summary of the social, scientific, and local significance (orange boxes) of each chapter (blue boxes). The green boxes represent the overarching significance of the thesis.

A summary of the potential local, scientific, and societal significance of this thesis is shown in Figure 8-1. First, an important contribution of this thesis is the exploration, prototyping, and testing of HHRA methods that may be used locally to better understand and assess community health risks related to contamination. Specifically, this work was embedded in a larger community-based project led by the environment department of Kanesatake (the Environmental Contaminants and Health Impact Project (ECHIP) and the ALLIANCE Project), which aims to understand how local contamination impacts the health of the community, including through monitoring and the development of new assessment tools. The chapters of this thesis refine the tools which the Kanesatake Environment team may use in their ongoing assessment and monitoring work. The initial prototype of the Indigenous Health Indicators tool in Kanesatake may be useful for the communication of community environmental health information at a variety of levels- including from community members to the environment department, and to external collaborators and governments. To my knowledge, there are very few case studies which explore the design of new risk assessment approaches for Indigenous community contexts. Thus, the presented work is potentially useful locally for Kanesatake, but the approach to testing and developing risk assessment tools may also serve as an example for other communities who wish to conduct similar work.

Second, the chapters of this thesis contribute to scientific advancement in the field of risk assessment, with a specific focus on Indigenous communities. Chapters 3 and 4 identify knowledge gaps, challenges, and priorities in this area, which are necessary first steps in the advancement of knowledge on the topic. Then, in Chapters 5-7 we ideate, test and develop existing risk assessment tools (RISK21 and Indigenous Health Indicators) over three studies, in various contexts and scales. This addresses a paucity of existing information on the testing of these tools in the scientific literature and identifies areas which may be considered for their adaptation and development. Together, the approach outlined in these chapters contributes to a methodological and multidisciplinary 'roadmap' for continuing to develop and design new risk assessment approaches that are both locally relevant and operational in diverse contexts. This thesis intentionally collaborates with Indigenous communities to co-develop risk assessment tools and approaches, which begins to address a lack of information in the scientific literature on community-based design of HHRA methods to date. Chapter 7 specifically examines not only the design of new methods, but places emphasis on methodological approaches to design work that are community-relevant and culturally safe, lessons from which may help to inform a variety of collaborative scientific contexts.

Third, the chapters of this thesis respond to a societal and regulatory shift towards new risk assessment approaches and the recent proposed amendments to the *Canadian Environmental Protection Act (CEPA)* through *Bill S-5* (Government of Canada, 2017; 2023; Moretto et al., 2017; NRC, 2012), which presents an opportunity to develop HHRA methods to be more suitable for Indigenous community contexts than conventional methods. *Bill S-5* mentions the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP), which includes the right to self-determination and to a healthy environment. These rights may be supported by the findings of this thesis through the development of methods to be usable, accessible and relevant to communities. Furthermore, *Bill S-5* promotes the development of cumulative risk assessment methods and the consideration of vulnerable populations (Government of Canada, 2017, 2023). Testing the operationalization of new risk assessment approaches using specific case studies contributes to a better understanding of their use and transferability to multiple settings, towards their development across a variety of contexts, uses, and populations. Furthermore, the recent passing of *Bill C-226* on June 20, 2024, holds the Canadian government accountable for developing a national strategy on environmental racism within the next two years (House of Commons of Canada, 2024). As outlined in Bill C-226, the forthcoming national strategy will include a commitment to the meaningful involvement and participation of environmental justice communities (including Indigenous, racialized, and marginalized communities) in assessing and addressing environmental justice issues (House of Commons Canada, 2024). The work presented in this thesis contributes to the advancement of methods that aim to meaningfully engage communities that have historically been subject to environmental injustices, particularly through disproportionate exposure and vulnerability to contaminants, and thus supports key goals outlined in Bill C-226.

Designing a consistent approach to HHRA that can address both community-level and regional or federal needs is a challenge, and this is reiterated in work by the US EPA comparing community, state, and federal cumulative risk assessment approaches and frameworks (Barzyk et al., 2015). Many communities (both Indigenous and non-Indigenous) want assessments to reflect their exposure realities and consider unique costs to their health, while federal approaches must be unbiased and transferable across contexts (Barzyk et al., 2015). While community and federal approaches to human health and cumulative risk assessments generally have common goals (i.e.: to protect human health), their approaches differ greatly. Further development of a harmonized and consistent risk assessment has been advocated for, to ensure better communication between sectors and long-term applicability (Barzyk et al., 2015). However, the importance of avoiding a 'cookie cutter' approach is also paramount. This thesis work focuses on the priorities and experiences of HHRA work at the level of Indigenous communities, however, these findings may be used in future works at other levels (for example, regional or federal) towards the development of a flexible yet consistent risk assessment approach.

8.3 Strengths and Limitations

8.3.1 Limitations

First, it is not feasible to develop a single approach or tool that will be appropriate for HHRA in all Indigenous communities- while a few case studies are presented here, they are not necessarily broadly applicable. The external validity of the work is a limitation. However, as described, the uniqueness of communities means that there is no 'one-size-fits-all' approach to HHRAs, and these case studies add to a relatively small pool of examples. These examples contribute to a ‘toolbox’ from which communities and other researchers may draw inspiration from, as is relevant to their specific contexts.

Second, the timeline of a PhD program places limitations on the work. In the example of the Swinomish Indigenous Health Indicators, it has taken over a decade to develop and test the community-relevant set of indicators, and this work continues to be ongoing. For an academic such as myself who isn’t from the community, the nature of relationship building in Kanesatake, and indeed in many Indigenous communities, requires a long timeline that includes the establishment of trust and continual work to understand and engage with the unique context. A relationship between my supervisor at McGill and the community has developed since 2019, with my involvement in the project since 2021. Although my thesis work is finite, the research presented is situated within the larger context of a co-led project between Kanesatake Environment and McGill University. As an example, the Kanesatake Health Indicators project presented in Chapter 7 requires, at a minimum, several more years of work and is planned to continue well beyond a thesis timeline. Thus, while a short timeline is a limitation, the shared nature of the work with the project team ensures its continuity beyond the chapters presented here.

Third, and similarly, my positionality is a limitation of the work. As a non-Indigenous academic, my worldviews and personal context places limitations on my interpretation and representation of the data, and thus the results of this thesis. While I am the primary author of this thesis, I acknowledge that the best people to research and speak about HHRAs in Indigenous community contexts are those from communities themselves. The focus of this thesis is on highlighting these voices and perspectives, and actively reflecting on how the results can accurately represent them. This includes listening closely to those I collaborate with to determine research priorities, practicing humility, and continuing to check my personal and positional biases.

Fourth, this thesis focused on *Human health* risk assessment, while it generally does not address ecological risk assessment (ERA), except in chapter 4. HHRA and ERA are methodologically distinct in many ways, though they generally follow the same framework (i.e.: hazard assessment, dose-response assessment, exposure assessment, risk characterization). Writing from Indigenous environmental leaders suggests that these two assessments should not be considered as separate entities, as the interconnection of human and ecological health is central to many Indigenous communities globally (Redvers et al., 2022). Indigenous environmental leaders have advocated for risk analysis models that include a holistic view of interconnected human, ecological, and socio-cultural risks (Harris, 2000). Thus, a limitation to this thesis is that it generally isolates HHRA as a method separate from ERA, despite the worldview of many Indigenous communities that the two do not exist siloed. However, the expansion of HHRA approaches to consider health more holistically has the potential to include ecological health risks, and further, many of the findings of this thesis may be generally applicable to ERA processes- for example, the need for improved communication and the consideration of multiple and interacting stressors. Further research is needed to understand these challenges and bridge the gap between these two related but different assessment types.

8.3.2 Strengths

One of the main strengths of this thesis is its engagement of multiple disciplines and fields. The chapters used an interdisciplinary approach and engaged a diversity of those involved in the work of risk assessment, whose experiences come from a wide variety of unique community contexts. While this thesis is housed in the Faculty of Agricultural and Environmental Science at McGill, its methods draw from the social sciences, health sciences, and humanities. Beyond the methodology, this thesis research involved collaborations with Indigenous community researchers, community environment departments, research consultants, and other academics. Doing so has developed the work's understanding of the diversity of needs and perspectives that need be considered in the design of new risk assessment approaches.

Another strength of this thesis is its relevance to the current regulatory climate, given recent governmental commitments to environmental justice through Bill C-226, and as well as to upholding the UN Declaration on the Right of Indigenous Peoples and on advancing contaminant risk assessment through Bill S-5. The opportune timing of these Bills moving through the house of commons supports and reinforces the importance of engaging with communities in the design of new risk assessment tools and approaches.

Finally, and importantly, a strength of this thesis is its situation within a larger, community-led project in Kanesatake. This research was conducted under the guidance of the Kanesatake Environment Department, who drove the research questions, provided feedback on new research ideas, and were engaged in fruitful discussions at all stages of the work. Simultaneously, the team was developing and carrying out a local environmental monitoring program (Environmental Contaminants and Health Impact Project/ECHIP), which provided important insight into the realities of environmental and human health risk assessment in a community context and set the priorities for this thesis work. The research questions, while spanning multiple levels and sectors, were driven by ideas that arose through meetings with the environment department, conversations with community members, and observations in day-today community work. This continued engagement inspired and guided each chapter and was an integral part of this thesis.

8.4 Future Directions

Overall, the chapters of this thesis demonstrate that the design of new HHRA approaches of relevance to communities may involve multiple tools and approaches that can be utilized based on the specific context. Thus, the co-development and use of a 'toolbox' by risk assessors, communities, and regulators may be an appropriate step towards achieving more relevant assessments. This 'toolbox' may encompass multidisciplinary strategies, including the two explored here (RISK21 and IHI approaches), which can be leveraged by communities as they see fit to develop a greater understanding and measurement of health risks related to contaminants. Similar 'toolboxes' have been developed that provide tools to fit specific risk assessment contexts, including for example Canada's Chemicals Management Plan Risk Assessment toolbox (Government of Canada, 2016) and the US EPA's Expobox (US EPA, 2023). Future directions may involve further case studies and other testing methods towards the adaptation and improvement of the approaches described here, and to build out a toolbox that provides user-friendly and community-engaged tools for Indigenous communities to conduct context-specific risk assessments.

Communication of risk assessment results is another centrally important theme that emerged in all the chapters of this thesis. While considerations for adequate communication of HHRA process and results are discussed (particularly in Chapters 4 and 5), further research led by communities may continue to refine and adapt new risk assessment tools that can be easily and transparently communicated in a community-relevant manner. This thesis used components of User Experience methodologies, which explore the "perceptions and responses that result from the use and/or anticipated use of a product, system or service" (Vermeeren et al., 2010) which is common in design research. For example, Chapter 5 explores and discusses community perceptions of the use of the RISK21 approach. User experience methods may be leveraged in future research to understand and improve the accessibility of HHRA tools and outputs to diverse communities.

Overall, this thesis work contributes to an ongoing, iterative process that is fundamental to design thinking. The developments to existing risk assessment tools and approaches made here need to continue to cycle through iterations, prototyping and testing for new contexts and scales. Doing so will help to ensure that new HHRA approaches meet the dynamic and complex priorities and needs of diverse Indigenous communities.

CHAPTER 9: GENERAL CONCLUSION

Following a design thinking process, this thesis developed and adapted new approaches to HHRAs to increase their relevance to Indigenous community-level contexts, in collaboration with communities themselves. The work encompassed multidisciplinary, multimethodological, and multisector approaches. First, a scoping review comparing grey literature, scholarly literature, and federal contaminated site data was conducted to identify priority research areas and the state of knowledge; second, a survey was conducted comparing the challenges and perspectives on risk assessment work across sectors; third, RISK21 (a relatively new HHRA approach) was pilot tested in collaboration with three communities in two case studies; fourth, a regional scale pilot-test of the operationalization of an Indigenous Health Indicators Tool was conducted; and fifth, the early development of an Indigenous Health Indicators tool in the local context of Kanesatake was carried out. Together these studies contribute to the development of tools that may improve the relevance of HHRAs for communities compared to conventional methods, including through enhanced communication outputs, considering multiple information sources (including qualitative), and expanding the conceptualization of health risks related to contaminants towards a more holistic understanding. This thesis also serves as an example of the process for adapting and developing risk assessment tools which may be used by communities and their collaborators who wish to conduct similar work.

MASTER REFERENCE LIST

This section lists references from the front-matter, general introduction, connecting paragraphs, general discussion, and general conclusions.

Abookire, S., Plover, C., Frasso, R., & Ku, B. (2020). Health design thinking: an innovative approach in public health to defining problems and finding solutions. *Frontiers in Public Health,* 8, 459. https://doi.org/10.3389/fpubh.2020.00459

Assembly of First Nations. (2022). *SUBMISSION TO THE HOUSE OF COMMONS COMMITTEE ON ENVIRONMENT AND SUSTAINABLE DEVELOPMENT. Study on Bill S-5 An Act to amend the Canadian Environmental Protection Act, 1999, to make related amendments to the Food and Drugs Act and to repeal the Perfluorooctane Sulfonate Virtual Elimination Act*. Retrieved June 20 2024 from https://www.ourcommons.ca/Content/Committee/441/ENVI/Brief/BR12143095/br-external/AssemblyOfFirstNations-e.pdf

Assembly of First Nations. (2023). National Climate Strategy. Retrieved July 4 2024 from https://afn.bynder.com/m/77556e1d9da51db7/original/2023-Climate-Strategy-Report.pdf

Barzyk, T. M., Wilson, S., & Wilson, A. (2015). Community, state, and federal approaches to cumulative risk assessment: Challenges and opportunities for integration. *International Journal of Environmental Research and Public Health, 12*(5), 4546-4571. https://doi.org/10.3390/ijerph120504546

Callahan, M. A., & Sexton, K. (2007). If cumulative risk assessment is the answer, what is the question? *Environmental Health Perspectives,* 115(5), 799-806. https://doi.org/10.1289/ehp.9330

Chan, H. M., Fediuk, K., Batal, M., Sadik, T., Tikhonov, C., Ing, A., & Barwin, L. (2021). The First Nations Food, Nutrition and Environment Study (2008–2018)—rationale, design, methods and lessons learned. *Canadian Journal of Public Health, 112*(Suppl 1), 8-19. https://doi.org/10.17269/s41997-021-00480-0

Choi, B. C., & Pak, A. W. (2006). Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 1. Definitions, objectives, and evidence of effectiveness. *Clinical and Investigative Medicine,* 29(6), 351‑364. PMID: 17330451

Chong, K., & Basu, N. (2023). Contaminated sites and Indigenous peoples in Canada and the United States: A scoping review. *Integrated Environmental Assessment and Management*, 20, 5, 1306–1329, https://doi.org/10.1002/ieam.4869

Chong, K., Hickey, G. M., Chan, H. M., & Basu, N. (2024a). Exploring practices, challenges, and priorities for human health and ecological risk assessments in Indigenous communities in Canada. *Integrated Environmental Assessment and Management,* 20, 5, 1677–1692, https://doi.org/10.1002/ieam.4927

Chong K., Chavez M, Dersch A, Doyle J, Eggers M, LaFrance J, Lefthand M, MacDermid F, McAuley C, Simonds V, Young S, and Basu, N. (2024b). Exploring the use of the

RISK21 approach for Indigenous community-based human health risk assessments: Two case studies. *Facets.* 10: 1-16. DOI: 10.1139/facets-2024-0085

Dorst, K. (2011). The core of 'design thinking' and its application. *Design Studies,* 32(6), 521-532. https://doi.org/10.1016/j.destud.2011.07.006

Eckert, L. E., Claxton, N. X., Owens, C., Johnston, A., Ban, N. C., Moola, F., & Darimont, C. T. (2020). Indigenous knowledge and federal environmental assessments in Canada: applying past lessons to the 2019 impact assessment act. *Facets,* 5(1), 67-90. https://doi.org/10.1139/facets-2019-0039

Edwards, G. I. (2019). Multidisciplinary approach to environmental problems and sustainability. *Encyclopedia of Sustainability in Higher Education,* 1184-1189. https://doi.org/10.1007/978-3-319-63951-2_179-1

Embry, M. R., Bachman, A. N., Bell, D. R., Boobis, A. R., Cohen, S. M., Dellarco, M., ... & Doe, J. E. (2014). Risk assessment in the 21st century: roadmap and matrix. *Critical Reviews in Toxicology,* 44(sup3), 6-16. https://doi.org/10.3109/10408444.2014.931924

Fernández-Llamazares, Á., Garteizgogeascoa, M., Basu, N., Brondizio, E. S., Cabeza, M., Martínez-Alier, J., McElwee, P., & Reyes-García, V. (2020). A state-of-the-Art review of Indigenous Peoples and environmental pollution. *Integrated Environmental Assessment and Management, 16*(3), 324-341. https://doi.org/https://doi.org/10.1002/ieam.4239

Francis, A. T. (2019). Haudenosaunee Forest Stewardship. Cornell University. Retrieved July 4 2024 from https://ecommons.cornell.edu/bitstream/handle/1813/67512/Francis_cornell_0058O_10712.pdf?sequence=1

Government of Canada (2016). Chemicals management plan risk assessment toolbox. Fact sheet series: Topics in risk assessment of substances under the Canadian Environmental Protection Act, 1999 (CEPA 1999). Retrieved July 26 2024 from https://www.canada.ca/en/health-canada/services/chemical-substances/fact-sheets/chemicals-management-plan-risk-assessment-toolbox.html

Government of Canada (2017). Committee report- November 16-17, 2016. Chemicals Management Plan Science Committee. Accessed May 28 2024 from https://www.canada.ca/en/health-canada/services/chemical-substances/chemicals-management-plan/science-committee/meeting-records-reports/committee-report-november-16-17-2016.html

Government of Canada (2022). *Bill S-5, Strengthening environmental protection for a healthier Canada act- Summary of Amendments.* Ottawa, Ontario 2022. Retrieved May 28, 2024 from https://www.canada.ca/en/services/environment/pollution-waste-management/strengthening-canadian-environmental-protection-act-1999/bill-c-28-strengthening-environmental-protection-healthier-canada-act-summary-amendments.html

Harris, S. G. (2000). Risk analysis: Changes needed from a Native American perspective. *Human and Ecological Risk Assessment, 6*(4), 529-535. DOI: 10.1080/10807030008951325

Harris, S. G., & Harper, B. L. (2000). Using eco-cultural dependency webs in risk assessment and characterization of risks to tribal health and cultures. *Environmental Science and Pollution Research, 2*(2), 91-100. Retrieved June 20 2024 from https://superfund.oregonstate.edu/sites/superfund.oregonstate.edu/files/harris_harper_2000_eco-cultural_dependency_webs_espr.pdf

Health Canada (2019). *Guidance for Evaluating Human Health Impacts in Environmental Assessment: Human Health Risk Assessment*. Ottawa, Ontario: Health Canada; 2019. p. 28. Retrieved June 20 2024 from https://publications.gc.ca/collections/collection_2019/sc-hc/H129-54-6-2019-eng.pdf

Hillman, T., Crase, L., Furze, B., Ananda, J., & Maybery, D. (2005). Multidisciplinary approaches to natural resource management. *Hydrobiologia,* 552, 99-108. https://doi.org/10.1007/s10750-005-1508-3

House of Commons Canada (2024). BILL C-226- An Act respecting the development of a national strategy to assess, prevent and address environmental racism and to advance environmental justice. Retrieved September 10 2024 from https://www.parl.ca/legisinfo/en/bill/44-1/c-226

Impact Assessment Agency of Canada. (2024). Impact Assessment Agency of Canada Research Program. Retrieved July 3 2024 from https://www.canada.ca/en/impact-assessment-agency/corporate/research-program.html

Interaction Design Foundation (2021). *Design Thinking.* Accessed May 28 2024 from https://www.interaction-design.org/literature/topics/design-thinking.

Klein, J. (1990). Interdisciplinarity: History, theory, and practice. Wayne State University Press. Accessed July 22, 2024.

Maher, R., Maher, M., Mann, S., & McAlpine, C. A. (2018). Integrating design thinking with sustainability science: a Research through Design approach. *Sustainability Science,* 13, 1565-1587. https://doi.org/10.1007/s11625-018-0618-6

Mondou, M., Hickey, G. M., Rahman, H. T., Maguire, S., Pain, G., Crump, D., Hecker, M., & Basu, N. (2020). Factors Affecting the Perception of New Approach Methodologies (NAMs) in the Ecotoxicology Community. *Integrated Environmental Assessment and Management*, 16(2), 269–281. https://doi.org/10.1002/ieam.4244

Moretto, A., Bachman, A., Boobis, A., Solomon, K. R., Pastoor, T. P., Wilks, M. F., & Embry, M. R. (2017). A framework for cumulative risk assessment in the 21st century. *Critical Reviews in Toxicology,* 47(2), 85-97. https://doi.org/10.3109/10408444.2014.931924

National Research Council (NRC), Division on Earth, Life Studies, Board on Environmental Studies, & Committee on Science for EPA's Future. (2012). Science for environmental protection: the road ahead. National Academies Press. Retrieved July 31 2024 from https://nap.nationalacademies.org/catalog/13510/science-for-environmental-protection-the-road-ahead

National Research Council (NRC) (2012). Exposure science in the 21st century: a vision and a strategy. National Academies Press. Retrieved July 5 2024 from https://www.nature.com/articles/jes2012109

O'Neill, C. A. (2000). Variable justice: Environmental standards, contaminated fish, and acceptable risk to Native peoples. *Stanford Environmental Law Journal, 19*, 3. Retrieved June 20 2024 from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2263492#

Peters, M. D., Godfrey, C. M., Khalil, H., McInerney, P., Parker, D., & Soares, C. B. (2015). Guidance for conducting systematic scoping reviews. *JBI Evidence Implementation,* 13(3), 141-146.

Redvers, N., Celidwen, Y., Schultz, C., Horn, O., Githaiga, C., Vera, M., Perdrisat, M., Plume, L. M., Kobei, D., & Kain, M. C. (2022). The determinants of planetary health: an Indigenous consensus perspective. *The Lancet Planetary Health*, 6(2), e156-e163. https://doi.org/10.1016/S2542-5196(21)00354-5

Sandlos J, Keeling A. (2016). Aboriginal communities, traditional knowledge, and the environmental legacies of extractive development in Canada. *Extractive Industries and Society-An International Journal.* 2016;3(2):278-87. https://doi.org/10.1016/j.exis.2015.06.005

Sexton, K., & Linder, S. H. (2011). Cumulative risk assessment for combined health effects from chemical and nonchemical stressors. *American Journal of Public Health*, 101(S1), S81-S88.https://doi.org/10.3390/ijerph9020370

Tschimmel, K. (2012). *Design Thinking as an effective Toolkit for Innovation.* Proceedings of the XXIII ISPIM Conference: Action for Innovation: Innovating from Experience. Barcelona. ISBN 978-952-265-243-0.

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., ... & Straus, S. E. (2018). PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Annals of Internal Medicine,* 169(7), 467-473. DOI: 10.7326/M18-0850

United Nations. (2007). *United Nations Declaration on the Rights of Indigenous Peoples*. Retrieved June 20 2024 from https://www.un.org/development/desa/indigenouspeoples/wp-content/uploads/sites/19/2018/11/UNDRIP_E_web.pdf

US EPA. (2023). Basic Information About EPA Expobox. United States Environmental Protection Agency. Retrieved January 2 2024 from https://www.epa.gov/expobox/basic-information-about-epa-expobox

US EPA. (2024). Framework for Cumulative Risk Assessment. Retrieved July 4 2024 from https://www.epa.gov/risk/framework-cumulative-risk-assessment#:~:text=Cumulative%20risk%20assessment%20is%20an,activities%20related%20to%20cumulative%20risk.

Vachon, J., Campagna, C., Rodriguez, M. J., Sirard, M. A., & Levallois, P. (2017). Barriers to the use of toxicogenomics data in human health risk assessment: A survey of Canadian risk assessors. *Regulatory Toxicology and Pharmacology,* 85, 119-123. https://doi.org/10.1016/j.yrtph.2017.01.008

Witjes, S., & Vermeulen, W. J. (2020). Transdisciplinary research: Approaches and methodological principles. *Transdisciplinarity for Sustainability* (pp. 27-52). Routledge. Accessed May 28 2024 from https://repository.ubn.ru.nl/bitstream/handle/2066/233321/233321.pdf?sequence=1

Supporting Information for Chapter 3

A word document with supplemental materials (Tables S1-S17, Figures S1-S2) and an Excel spreadsheet with supplementary tables and data (Excel Table S1-S7) can be found in the 'Supporting Information' section of the published manuscript at: https://setac.onlinelibrary.wiley.com/doi/10.1002/ieam.4869

Supporting Information for Chapter 4

Supporting information for this chapter can be found in the 'Supporting Information' section of the published manuscript, and includes:

- The survey instrument (Supporting information A)
- Various tables and figures that provide deeper information about the study (Supporting information B)
- An excel spreadsheet of raw survey results data (Supporting information C)

The information can be found here:
https://setac.onlinelibrary.wiley.com/doi/10.1002/ieam.4927?af=R

Supporting information for Chapter 5

Supporting information can be found in the 'Supplementary Material' section of the published manuscript, which includes a word document containing supplementary materials S1-S7: https://www.facetsjournal.com/doi/10.1139/facets-2024-0085

Supporting information for Chapter 6

Supporting Information 1: Grouping of identified FNFNES data into indicator categories (PWI and Swinomish IHI)

Health Indicator Categories	**Relevant FNFNES Data**
IHI Indicators	
Community connection- Work, sharing, relations	
Natural Resources Security- quality, access	• "% wanting more traditional foods in their household" (access) • "food security scale" (quality and access)
Cultural Use- respect and stewardship, sense of place	• "Traditional Food Harvesting and Production Practices Reported Per Household" (Sense of place) • "Mean Traditional food intake days per year"
Education- the teachings, elders, youth	
Self-Determination- healing and restoration, development, trust, restoration	
Resilience- self-esteem, identity, sustainability	• "Self-reported health status" (self-esteem) • "Self-reported activity level" (self-esteem, sustainability)
PWI Indicators	
Our Health	• "% absence of diabetes" • "% absence of obesity"
Our Lands and Stewardship	
Our Food Sovereignty	• "Traditional Food Harvesting and Production Practices Reported Per Household" • "Mean Traditional food intake days per year" • "Food security scale"
Institutional Capacity and Traditional Governance	
Our Culture	
Social and Educational, Lifeway	• "Highschool education or greater"
Our Business, Affairs, and Economics	• "% Main source of income is wages"
Out Land Tenure	

Supporting Information 2: FNFNES HHRA Data tables, using 95th percentile exposure estimates

		Hazard Quotients (95th percentile)						
Contaminant		**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**AT**
METALS								
Arsenic	Mean	4.58	0.02	0.05	0.05	0.1	0.17	1.8
	Maximum	6.57	0.02	0.06	0.07	0.11	0.17	3.09
Cadmium	Mean	1.17	0.22	0.14	0.17	0.17	0.69	0.1
	Maximum	2.23	0.26	0.16	0.17	0.17	0.69	0.22
Lead	Mean	0.23	0.25	0.05	0.17	0.41	0.39	0.05
	Maximum	0.46	0.43	0.12	0.17	0.48	0.4	0.36
Mercury	Mean	0.29	0.12	0.32	1.5	0.45	0.27	0.08
	Maximum	2.19	0.14	0.35	1.64	0.49	0.75	0.21
ORGANIC CONTAMINANTS								
HCBs	Mean	0.0073	0.00014	0.001	0.00038	0.00235	0.002	0.001
DDE	Mean	0.0003	0	0	0.00004	0.00019	0.0001	0.00004
PCB	Mean	0.0011	0.00006	0.002	0.00055	0.01273	0.01	0.001
Chlordane	Mean	0.0113	0.00023	0.002	0.00007	0.01338	0.005	0.003
Toxaphene	Mean	0.0075	0.00005	0.0002	0.00002	0.009	0.001	0.001
PAH	Mean	0.00004	0.00003	0.0002	0.00003	0.00128	0.00001	0
PFCs	Mean	0.0238	0.00333	0.07	0.02554	0.14652	0.05	0.05
PBDE	Mean	0.0251	0.00087	0.01	0.03644	0.03289	0.12	0.002
Dioxan and Furan	Mean	0.0001	0	0.01	0.00002	0.00054	0.05	0.00001

References:

Chan, L., Batal, M., Sadik, T., Tikhonov, C., Schwartz, H., Fediuk, K., Ing, A., Marushka, L., Lindhorst, K., Barwin, L., Berti, P., Singh, K., & Receveur, O. (2019). *FNFNES Final Report for Eight Assembly of First Nations Regions: Draft Comprehensive Technical Report.* Retrieved June 27 2024 from https://www.fnfnes.ca/docs/FNFNES_draft_technical_report_Nov_2__2019.pdf

Donatuto, J., Campbell, L., & Gregory, R. (2016). Developing responsive indicators of Indigenous community health. *International Journal of Environmental Research and Public Health, 13*(9), Article 899. https://doi.org/10.3390/ijerph13090899

Paul, K. L., Carlson, H. A., Weatherwax, M. L. P., Caplins, L., Falcon, C., Carter, C. J., & Ruppel, K. T. (2023). The Piikani Well-being Project: Indigenous-led metrics and mapping to improve human and agricultural system health within the Amskapi Piikani Blackfeet Nation. *Environment and Planning F*, 26349825231154869. https://doi.org/10.1177/26349825231154869

Supporting Information for Chapter 7

Supporting Information 1: Interview Guide

Title of Project: Putting Our Minds Together: Kanesatake Kanien'kehá:ka Perspectives on Developing a Health Indicators Tool

While the following questions serve as prompts for the interview, we will follow the interviewee's lead. The questions represent general themes that we hope to address. However, after explaining the project's purpose, we will allow the interviewee to express themselves freely outside of these questions. Prior to beginning the interview, and periodically throughout the interview, the interviewer will remind participants that they can choose not to respond to any questions, or stop the interview, at any time. To protect the privacy of others, the interviewer will invite the interviewee to use pseudo-names as needed and when possible.

1. **Understanding 'Health'**
   Question: What does being healthy mean to you?
   - ***Possible prompts:***
   - *Individually (What are some personal experiences (past, present or future) that you and your family members went through which have impacted your health? There is no time limit, so feel free to share anything.)*
   - *As a community (Looking to other families, and community organizations, what do you think is normalized as healthy? What is normalized as being unhealthy?)*

   Question: How has health of the community changed over time?
   - ***Possible prompts:***
   - *Where have the biggest differences taken place (physical, mental, social, spiritual) and why?*

2. **Connection of the environment to community health**
   Question: What do you think is the importance of the environment (natural world/nature) to the health of the community?
   - ***Possible prompts:***
   - *Has your relationship with the environment changed over time? Why or why not? (examples: contamination, access, availability, cultural connection, etc.)*

3. **Connection of contamination to health**
   Question: There are a number of pollution sources around and on Kanesatake lands (examples: G and R, pesticide use, niobium mine). Do you think that contamination affects the health of the community? If so, how?

   Questions adapted from: Donatuto J (2008). When seafood feeds the spirit yet poisons the body: Developing Health Indicators for Risk Assessment in a Native American Fishing Community. University of British Colombia, Vancouver. Retrieved June 18 2024 from: https://open.library.ubc.ca/media/stream/pdf/24/1.0066720/1