Digital Tools for Water Governance:
Repositioning Information Communication Technology in a Data-to-Wisdom Framework in the Great Lakes Basin

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November 2024

A thesis submitted to McGill University in partial fulfillment of the requirements of the degree of M.Sc. Bioresource Engineering – Integrated Water Resource Management Option

Abstract

Water governance in the Laurentian Great Lakes Basin (GLB) is a model for successful transboundary governance and public engagement with environmental issues. Recent technological advances have facilitated the collection, storage, and processing of data, including a shift towards the provision of open and accessible data for public use. Information Communication Technology (ICT) tools have emerged as a mechanism to communicate scientific data to a non-specialized audience, including dashboards, interactive web maps, virtual simulations, and data viewers. While many platforms exist, there is a lack of comprehensive reviews of these platforms, and limited emphasis on data outcomes and accessibility for non-scientists. The current focus on data provision risks these platforms becoming ends in themselves, instead of encouraging data-driven decision-making.

This thesis examines the ICT tools within the GLB. Specifically, this thesis seeks to assess (1) What delivery of freshwater data is provided through online ICT tools in the GLB?, and (2) How do practitioners perceive the role of ICT tools in driving platform user decision-making?

This research applies a knowledge sciences framework – the Data-Information-Knowledge-Wisdom (DIKW) Hierarchy – to explore the process of knowledge creation and mobilization through ICT. Chapter 1 introduces the methodologies used in this thesis, namely systematic scoping reviews and key informant interviews. Chapter 2 provides the historical and contemporary context of water governance in the GLB, the framing of ICT tools and their relevance to open data accessibility, and the conceptual framework that guides the thesis. Chapter 3 is a systematic scoping review of ICT platforms relevant to GLB water quality and quantity. Chapter 4 is a study of open data platform practitioners, utilizing semi-structured key informant interviews to explore outcomes and challenges of these tools in practice. The results of this thesis include an adapted DIKW framework to aid in understanding Data mobilization in this context, and indicate that ICT tools are in a state of transition. Recommendations argue for a repositioning of the value of these platforms as supplements – rather than substitutes – to in-person initiatives, and suggest specific measures for shifting the focus of ICT platform usage from data provision to informing platform user decision-making.

Résumé

La gouvernance de l'eau dans le bassin laurentien des Grands Lacs (BGL) est un modèle de réussite en matière de gouvernance transfrontalière et d'engagement public envers les enjeux environnementaux. Les récentes avancées technologiques ont facilité la collecte, le stockage et le traitement des données, comprenant un virage vers la mise à disposition de données ouvertes et accessibles pour un usage public. Les outils des technologies de l'information et de la communication (TIC) sont apparus comme une solution pour améliorer l'engagement public, incluant des tableaux de bord, des cartes web interactives, des simulations virtuelles et des visionneuses de données. Ces outils rendent la gouvernance participative de l'eau de plus en plus accessible en ligne. Bien qu'il existe de nombreuses plateformes, celles-ci ne font pas l'objet d'un examen approfondi et l'accent est peu mis sur les résultats et l'accessibilité des données pour les non-scientifiques. L'accent mis actuellement sur la fourniture de données risque de faire de ces plateformes des fins en soi, au lieu d'encourager la prise de décision sur les données.

Cette thèse examine les outils TIC au sein du BGL. Plus précisément, cette thèse cherche à évaluer (1) quelle fourniture de données sur l'eau douce est mise à disposition via des outils TIC en ligne dans le bassin des Grands Lacs, et (2) comment les praticiens perçoivent-ils le rôle des outils TIC dans la prise de décision des utilisateurs de la plateforme ?

Cette recherche applique un cadre des sciences de la connaissance - la hiérarchie Données-Information-Connaissance-Sagesse - pour explorer le processus de création et de mobilisation des connaissances par le biais des TIC. Le chapitre 1 introduit la méthodologie de l'étude systématique de la portée et des entretiens avec des informateurs-clés utilisés dans cette thèse. Le chapitre 2 présente le contexte historique et contemporain de la gouvernance de l'eau dans la BGL, la structure des outils TIC et leur pertinence pour l'accessibilité des données ouvertes, ainsi que le cadre conceptuel qui guide cette thèse. Le chapitre 3 est un examen systématique de la portée des plates-formes TIC pertinentes pour la qualité et la quantité de l'eau dans la BGL. Le chapitre 4 est une étude des praticiens des plateformes de données ouvertes, utilisant des entretiens semi-structurés avec des informateurs-clés pour explorer les résultats et les défis de ces outils dans la pratique. Les résultats de cette thèse comprennent un cadre adapté pour aider à comprendre la mobilisation des données dans ce contexte, et indiquent que les outils TIC sont dans une période de transition. Les recommandations plaident en faveur d'un repositionnement de la valeur de ces plateformes en tant que compléments plutôt que substituts, aux initiatives en personne, et suggèrent

des mesures spécifiques pour déplacer le centre d'intérêt de l'utilisation des plateformes TIC de la fourniture de données vers les résultats et impacts des plateformes.

Acknowledgements

I want to sincerely thank my supervisor, Jan Adamowski, for the opportunity to pursue this research and for his continued support. I'm also very grateful to my secondary supervisor, Gordon Hickey, whose helpful advice and ability to ask the hard questions consistently enriched this work. Thank you as well to my committee member, Murray Clamen, for his guidance and steady support throughout this process.

A big thank you to my collaborator, Bryant Serre, for all his help and the countless hours we spent working together and sketching out ideas on white boards. Your contributions were key to getting this done. At McGill, I'd like to acknowledge my lab mates in the Sustainable Futures Laboratory for making this experience both productive and enjoyable, and for providing peer-support and informal chats over coffee or on bus rides. I'd also like to thank Wietske Medema and Julien Malard-Adam for their continued mentorship and the opportunities they have provided to further my growth and experience in this field.

Finally, to my friends and family – thank you for your endless encouragement, love, and support. I could not have done this without you all.

This research was funded by the Social Sciences and Humanities Research Council (SSHRC) CGS M Grant, as well as the SSHRC Partnership Development Grant (PDG).

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Thesis Style and Contribution of Authors

This is a manuscript style thesis composed of six chapters. Chapter 1 presents an introduction, research objectives and questions, and general research methods. Chapter 2 contains a literature review on the context of water governance in the Great Lakes Basin (GLB), the role of digital tools as intermediaries of open data, and the conceptual framework applied in this thesis. Chapter 3 consists of a systematic scoping review to investigate the current state of digital platforms containing freshwater data water in the GLB. Chapter 4 builds on this work through semi-structured interviews with practitioners of these tools. Chapters 3 and 4 are prepared as journal articles and will be submitted for publication in an academic journal, likely to the Journal of Great Lakes Research. Chapters 5 and 6 summarize main findings to inform a broader discussion of the state of digital tools in the GLB, synthesize key contributions, and identify future work for both practitioners of digital tools and academics. Due to the manuscript-based format, there is some repetition across sections and references.

I am the lead author for all the thesis chapters. Bryant Serre, my collaborator, Jan Adamowski, my supervisor, and Gordon Hickey, my co-supervisor, are co-authors on Chapters 3 and 4. Bryant Serre contributed to the study design and methodology, data collection and analysis, and reviewing and editing these manuscripts. Jan Adamowski and Gordon Hickey assisted with conceptual framing, study design, and reviewing and editing on these chapters.

Chapter 1 – General Introduction and Methodology

1.1 Introduction

Open data is increasingly recognized as a prerequisite for successful participatory governance[1], offering transparency and empowering citizens to engage meaningfully in formal decision-making processes (Davies & Edwards, 2012; Kosack & Fung, 2014). Many solutions to public engagement often prioritize the provision of open data, yet face challenges in translating this data into actionable knowledge that drives decision-making (Attard et al., 2015). Within the context of this dissertation, public engagement is defined as the involvement of the public in decision-making contexts, with varying levels based on the direction of information flow between the public and decision-makers. Public engagement therefore encompasses public communication (information flows to the public), public consultation (information flows from the public), and public participation (a two-way exchange of information) (Rowe & Frewer, 2005). Among these solutions, online Information Communication Technology (ICT) tools, a term used interchangeably in this thesis with digital tools, are a relatively new approach to communicate scientific data to a broader public through formats including dashboards, interactive web maps, virtual simulations, and data viewers (Anderson et al., 2015; Nardi et al., 2022). Open data portals were among the first iterations of these technologies and emerged with the "open data movement" to provide increased access to data online (Attard et al., 2015).

The Laurentian Great Lakes basin (GLB) is one case where online platforms seek to engage members of the public in water issues. Despite these efforts, recent reports in the GLB highlight that there is still significant progress to be made towards data accessibility and use by individuals (Fusi et al., 2022). Additionally, foundational knowledge gaps persist (Learning for a Sustainable Future, 2022) and data accessibility efforts have been limited by fears of misinterpretation of data by the public (Goucher et al., 2021). The GLB serves as a compelling case study for examining these challenges due to its transboundary nature, complex governance needs, and rich history of successful environmental engagement (Millar et al., 2023; Watras et al., 2022).

[1] Participatory governance involves the active engagement of diverse stakeholders, such as citizens and community groups, in decision-making processes that affect them. This approach aims to enhance transparency, accountability, and trust, thereby improving the quality and equity of governance outcomes (Fung & Wright, 2001).

This thesis explores the potential of web-based open data tools to help bridge the gap between data availability and decision-making using Ackoff's (1989) Data-Information-Knowledge-Wisdom (DIKW) hierarchy.

1.2 Research Questions and Objectives

The central objective of this thesis is to critically assess the current availability and use of ICT tools for individual decision-making in the GLB. In order to address this broader objective, two research questions were developed:

1. What delivery of freshwater data is currently accomplished through online ICT tools in the GLB?
2. How do practitioners perceive the role of ICT tools in driving platform user decision-making?

To answer these research questions, Chapter 2 first reviews the context of water governance and ICT in the GLB, the role of ICT as intermediaries of open data, and the conceptual framework for Data transformation and mobilization. Chapter 3 addresses the first question through a systematic scoping review of ICT tools in the GLB. Chapter 4 builds on this work by investigating the outcomes of these platforms through key informant interviews with practitioners of relevant platforms. The DIKW hierarchy (Ackoff, 1989) is applied to better understand the process of inciting data-driven action, and is ultimately adapted to this context.

1.3 General Research Methods

1.3.1 Systematic Scoping Reviews

Chapter 3 aims to identify and assess the breadth of ICT tools in the GLB through a systematic scoping review (Peters et al., 2015). Given the evolving nature of ICT tools, scoping review methods were used to capture the range of platforms (Munn et al., 2018) through flexible search strategies (Campbell et al., 2023) across diverse forms of evidence (Peters et al., 2015). Systematic review methods were applied to ensure that the review is rigorous and replicable, drawing on PRISMA (2020) review standards (Page et al., 2021) and specific methodologies for searches in gray literature (Godin et al., 2015). Once platforms were identified they were assessed for key characteristics, as is consistent with evaluations in scoping reviews (Munn et al., 2015). Systematic reviews instead synthesize evidence to make recommendations (Grant & Booth, 2009), which is not a relevant approach given that final sources were ICT platforms and not academic articles. Systematic scoping reviews therefore allow for a more personalized review strategy that better aligns with the intentions of this work. Detailed information on methodology and study limitations can be found in Chapter 3.

1.3.2 Case Study Research

Chapter 4 employed a case study approach to explore how practitioners understand the outcomes and challenges of various ICT within the GLB. Case studies offer in-depth analysis of a specific phenomenon within its real-life context. This approach is particularly useful for addressing complex issues where the boundaries between the phenomenon and its context are not clearly defined (Yin, 2018). By focusing on a specific instance, case studies allow researchers to explore the "how" and "why" questions in greater detail (Yin, 2018). Applied to the GLB, case study methods allowed for detailed examination of how ICT tools function within the specific institutional and historical context of the basin. Following Thomas' (2011) typology of case study elements, this work examined a practical unit – ICT tools – through a theoretical framework – the DIKW hierarchy. Importantly, this work is exploratory and aimed to apply a new framework to a topic and context in which there is already a body of work to gain new insights (Murphy-Mills et al., 2019).

Semi-structured interviews with practitioners of open data platforms were used to collect data. Interviews are a key method in case study research (Baskarada, 2014), and semi-structured interviews were selected for the flexibility they offer (Fontana & Frey, 2005). This approach allowed for an open-ended and exploratory approach to data collection (Rubin & Rubin, 2012; Sayrs, 1998), enabling deeper exploration of topics while ensuring key topics are covered (Fontana & Frey, 2005). The decision to speak to practitioners aligns with key informant interview literature, emphasizing respondents' professional experience as criteria for suitability (Guest et al. 2006; Ahlin, 2019). This work is therefore an exploratory case study that posits practitioners as individuals in this system with unique insight and influence over ICT tools, and seeks to identify current pathways and barriers to action from open data provision using the DIKW framework.

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Connecting Text to Chapter 2

Chapter 1 briefly outlines the research need and resulting thesis research questions, including the general methodologies employed to answer these questions. Chapter 2 provides a more detailed literature review, providing the historical and contemporary context of water governance in the GLB, the framing of ICT tools and their relevance as intermediaries of open data, and the conceptual framework that guides the thesis.

Chapter 2 – Literature Review

2.1 Case Study Context: The Great Lakes Basin

2.1.1 The Great Lakes of Today

As the world's largest surface freshwater system (Talukder & Hipel, 2020), the Laurentian Great Lakes are a model for bi-national management between the United States (US) and Canada, supporting vast contingents of their populations and industry. However, these lakes have and continue to face substantial challenges to their sustainability under the legacy of colonial management.

Located in east-central North America at the border between the US and Canada, the Great Lakes basin (GLB) spans almost 250 000 square kilometers and comprises the five Great Lakes: Lakes Superior, Michigan, Huron, Erie, and Ontario (International Joint Commission [IJC], n.d.). This basin is a critical source of water for human consumption; it is estimated that about forty million people across the US and Canada are reliant on the Great Lakes for drinking water alone (Talukder & Hipel, 2020). Aside from drinking water, the Great Lakes supply various other critical, water-intensive industries such as farming and agriculture in surrounding lands, power generation and the cooling of power plants, and shipping both directly through the Great Lakes and by supplying human-made canals (Austin et al., 2007; Sproule-Jones, 1999).

Given the transboundary nature of water, the location and scope of the GLB, and the high reliance on this resource, there are many different rights-holders and stakeholders that have a vested interest in its governance. In government alone, organizations are involved at the international, federal, provincial, state, municipal, and Indigenous and tribal levels. This network of actors is further complicated by the large number of non-profits, community-based groups, and academic organizations working in the GLB. Consequently, the Great Lakes region is heavily researched and regulated; however, the resulting monitoring and governance systems are highly decentralized and fragmented (Cook, 2014). Such fragmentation can lead to an overload of information and a complicated open data ecosystem with varying levels of accessibility.

Present-day issues reflect a range of environmental challenges (McLaughlin & Krantzberg, 2011), many of which qualify as wicked problems – complex problems where data may exist, but solutions remain elusive or have yet to be implemented due to their interconnected nature (Rittel & Webber, 1973). Ongoing challenges are as follows:

Water Quantity and Extraction is a significant concern, particularly in areas like Aberfoyle, Ontario, where companies such as Nestlé have over-extracted water, threatening local supplies. This overuse raises questions about the sustainability and ethics of large-scale commercial water extraction (Petrash, 2007). Additionally, the potential redirection of Great Lakes water to the Midwest's agricultural areas, which have nearly exhausted the Ogallala aquifer, presents further risks to water availability (Mullen, 2021).

Water Quality in the GLB is compromised by numerous contaminants. Incidents like the Flint, Michigan lead crisis highlight critical failures in infrastructure and policy, exposing the vulnerability of water systems to political, economic, and social influences (Morckel & Terzano, 2019). Legacy contaminants such as polychlorinated biphenyls (PCBs) and mercury, alongside emerging contaminants like endocrine disruptors, continue to pollute the GLB (Baldwin et al., 2016; Barber et al., 2015; Blazer et al., 2018). Algal blooms in Lake Erie, driven by nutrient runoff from agriculture, result in hypoxia, fish kills, and contamination of drinking water (NOAA, 2023), illustrating the difficulty of managing diffuse pollution sources (Scavia et al., 2014).

Urbanization and Land Use Changes have changed the natural infiltration and percolation of water, reducing groundwater recharge, increasing stormwater runoff, and mobilizing contaminants into waterways (Barlage et al., 2002; Eimers et al., 2020). These changes exacerbate flood risks and strain existing water management systems, highlighting the need for integrated urban and water planning (Trudeau & Richardson, 2016). The destruction of wetlands, which are vital for biodiversity and water filtration, further complicates efforts to maintain water quality. Restoration initiatives are often hindered by competing land use interests and regulatory challenges (Wilcox, 2002).

Invasive Species, including Asian carp (Jerde et al., 2013) and lamprey eels (Hansen et al., 2016), pose an ongoing threat to the Great Lakes, with 190 species documented as of 2021 (Great Lakes Aquatic Nonindigenous Species Information System [GLANSIS], 2021). Their presence disrupts native ecosystems, creating additional challenges for conservation and management (Escobar et al., 2018).

These ongoing challenges demonstrate the web of factors affecting the Great Lakes and highlight the necessity for data-driven and collaborative management strategies. Informed and adaptive approaches are essential to address the evolving and interrelated threats to this freshwater resource.

2.1.2 History of Great Lakes Governance

Historic remediation of Great Lakes issues has been deeply rooted in public engagement, progressive policies, and collaboration between policymakers and the public. Understanding this history is crucial to evaluating the potential of digital tools in re-engaging a voting public that once played a vital role in environmental protection. The remainder of this section outlines over a century of relevant history in the basin, leading into the current governance context and the rise of digital tools.

Early 20th Century Initiatives (1900s-1950s)

Water governance in the GLB began taking shape in the early 20th century with the establishment of the International Joint Commission (IJC) in 1909, under the International Boundary Waters Treaty Act. This body was created to prevent and resolve disputes between the United States and Canada over the use of boundary waters, setting a precedent for binational cooperation. In 1946, the Conservation Authorities Act was passed in Ontario, aiming to address flooding and erosion control, while the Water Pollution Control Act of 1948 marked the first major effort in the US to address water pollution, preceding the formation of the US Environmental Protection Agency (EPA).

Post-War Environmental Awareness (1950s-1960s)

The 1950s saw further progress with the establishment of the Great Lakes Fisheries Commission (1955), which tackled invasive species control. The environmental movement then gained momentum in the 1960s, spurred by events like Rachel Carson's revelations in "Silent Spring" (1962) about the biomagnification of DDT and the burning of the Cuyahoga River in 1969 (Hardy, 2022), which brought national attention to the severe pollution issues plaguing the Great Lakes. These events sparked significant public awakening around environmental change and pollution risks and elicited wide ranging policy and governance responses including the Clean Air Act (US EPA, 1963) and the Water Quality Act (US EPA, 1965). The Experimental Lakes Area, prompted by the IJC, was established in 1966 and allowed for controlled studies on freshwater ecosystems, notably on acid rain.

The Environmental Revolution (1970s)

The 1970s built on the momentum of the previous decade and marked a pivotal era for environmental policy and public engagement. The US EPA was established in 1970, followed by the landmark Great Lakes Water Quality Agreement (GLWQA) in 1972 (US EPA, 1972), a binational policy to combat eutrophication and pollution (Muldoon & Botts, 2005), and the Safe Drinking Water Act of 1974 (US EPA, 1974), which underscored the public's right to clean water. In many cases, these responses were heavily supported by public outcry for environmental health, and contributions of observations by community scientists. Relatedly, in this period David Schindler's work at the Experimental Lakes Area provided critical insights into acid rain and its ecological impacts (Malley & Mills, 1992), results which were then echoed in observations by fishers and anglers in the basin, further galvanizing public and governmental action. Also beginning in this period was the focus on non-point source pollution and the engagement of agricultural communities, demonstrated by the Pollution from Land Use Activities Reference Group (PLUARG) study conducted from 1972 to 1979 (Land Use Activities Reference Group).

Sustained Efforts and Challenges (1980s-1990s)

In the 1980s, environmental awareness continued to grow, exemplified by a burst of activity at the policy level. This included the identification of Areas of Concern (AOCs) in 1987, which targeted regions within the Great Lakes suffering from severe environmental degradation (GLWQA, 1987). Importantly, the success of AOCs was correlated to the active involvement of stakeholders in this process (Sproule-Jones, 1999). Other programs included: the Surface Water Environmental Emergency Plan (SWEEP, 1985), the Great Lakes Water Level Control (GWLQ, 1988), the National Soil Conservation Program (NSCP, 1989), the Lakewide Management Plans (LMAP, 1987), the Environmental Stewardship Initiative (ESI, 1989), the Lake Simcoe Protection Plan (LS1 and LS2, 1986), the Green Plan (1990), the Aquatic Ecosystem Initiative (AEI, 1991), and the St. Lawrence River Environmental Quality Program (1991).

Recent Developments and Digital Engagement

The early 2000s saw significant events like the Walkerton, Ontario, groundwater contamination crisis in 2000, which led to the formation of Source Water Protection Plans under Ontario's Clean Water Act (Government of Ontario, 2006, s. 22). This period also witnessed further agricultural and non-point source pollution initiatives, such as the National Resources Inventory-Conservation Effects Assessment Project (NRI-CEAP) (United States Department of Agriculture [USDA], n.d.) and the Mississippi River Basin Healthy Watersheds Initiative (MRBI) (USDA, 2019).

Despite these successes, individuals today are arguably no more educated or interested in environmental issues than prior to the environmental revolution of the 1970s. Foundational knowledge gaps persist (Learning for a Sustainable Future, 2022), and previous environmental laws have been repealed in favor of economic interest in the absence of continued interest (e.g., Ontario Omnibus Bill 196, Government of Ontario, 2021). However, there is evidence of a recent trend towards increased awareness through the IJC's Great Lakes Regional Poll data, conducted in 2015, 2018, and 2021 (IJC, 2021). The poll indicates that concern about Great Lakes pollution is high, with a 6% decrease in "don't know" responses when participants were asked about the lakes' most pressing issues, suggesting that public understanding may be improving (slide 20). Respondents articulating concern for Great Lakes health (slide 17) and a need to protect this resource (slide 16) have also increased in this period. Findings on personal responsibility and participation are less clear: there is conflicting data on respondents' beliefs on the role and responsibility of the individual in Great Lakes environmental protection (slides 22-23), and participants were overall less willing to participate in formal decision-making processes than to take individual actions (slides 49-50).

Since the period of high engagement in the 1970s, digital tools have emerged as a means to share data and information with the public as part of a broader movement to share data openly and democratize science. Additionally, technological development has modernized community contributions to science, with platforms like eBird (Cornell Lab of Ornithology, 2002) and iNaturalist (2008), which enable community scientists to contribute observations on species presence and conditions more easily. However, despite efforts to build the capacity for better coordination of monitoring efforts, recent reports in the GLB highlight that there is still significant progress to be made towards data accessibility and use by individuals (Fusi et al. 2022), and that concerns over data misinterpretation by the public remain a barrier to broader data sharing (Goucher et al., 2021).

2.2 Open Data and Information Communication Technology

2.2.1 The Emergence of Open Data

Technological innovation in recent decades has driven significant changes in how research is conducted and disseminated, ushering in a new state of scientific inquiry and public access to information known as the Digital Age (Pedregal et al., 2015). Early on in this larger societal shift towards an embrace of technology was the big data movement, characterized by the large quantity of data newly available online and driven by advancements in data collection, storage, and sharing (Davies & Edwards, 2012). While originally this consisted of advancements like increased internet bandwidth and the merging of datasets, big data has since expanded to include user activity and interactions online and expanded data formats (Sagiroglu & Sinanc, 2013). Resulting from these newly available and scalable mechanisms is the big data that exists today: massive datasets with complex structures that require significant computer power to generate meaning (Sagiroglu & Sinanc, 2013; Vitolo et al., 2015). Importantly, the first iteration of the big data movement remained predominantly inaccessible to those outside of the institution owning these data. The initial value of big data therefore remained largely for large companies and for business (Davies & Edwards, 2012).

The subsequent movement to 'open' data resources aimed to shift the value of data to a broader public and arose from criticisms of government secrecy and neoliberal economic theory applications to intellectual property. Resulting from these criticisms were right-to-information campaigns and a move towards open data with the goal of transparency to disincentivize corruption (Attard et al., 2015; Krikorian & Kapczynski 2010). At the same time, a neoliberal perspective was applied to intellectual property, extending its coverage to include data. Institutions that held data were encouraged to treat data as commercial assets (Davies & Edwards, 2012). Following these original drivers of open data were applications to various sectors, including researchers and scientists stressing the benefits for scientific advancement and collaboration.

The benefits of open data follow these original incentives, and can be summarized as Transparency and Accountability, Releasing Social and Commercial Value, and Participatory Governance (Attard et al., 2015).

Transparency and Accountability

At its core, transparency refers to the openness and availability of information, allowing stakeholders to access and scrutinize data. Transparency for accountability is a variation of transparency relevant to governance contexts that specifies the use of transparency to hold decision-makers accountable (Kosack & Fung, 2014). The hypothesis underlying such interventions is that providing information will instigate a series of actions where beneficiaries, service providers, or policymakers enhance the quality of public services such as health, education, and infrastructure. This shift highlights transparency, specifically referring to open data, not as an end in itself, but as a means to foster accountability and improve governance outcomes (Noveck, 2009).

Releasing Social and Commercial Value

As neoliberal economic principles have been applied to intellectual property, there has been a recognition of the social and commercial value that can be derived from the release of data (Janssen et al., 2012). Governments, as major producers and collectors of data across various domains, possess data that can be repurposed for different uses than originally intended. By opening up access to data, governments and institutions provide a basis for the creation of new services and economic growth (Attard et al., 2015). The shift towards open data therefore fosters a culture of innovation. For scientists and researchers, this opening of the system of knowledge production means that organizations are not limited by geographical constraints, and reduces some resource constraints (Davies & Edwards, 2012).

Participatory Governance

Finally, at the nexus of a more open decision-making context and a new knowledge economy, there is Participatory Governance. Participatory governance refers to the active involvement of citizens and community members in the decision-making processes that affect their lives (Fung & Wright, 2001), and can be understood as an outcome of open data through the democratic engagement of non-experts. This engagement provides citizens with the opportunity to actively participate in governance processes, rather than merely voting in periodic elections (Attard et al., 2015).

Achieving these outcomes depends on the active use and engagement with the published data (Attard et al., 2015; Zuiderwijk & Janssen, 2014); The provision of open data can therefore be understood as a call to action.

2.2.2 Remaining Challenges and Intermediaries

Although open data initiatives aim to enhance citizen participation and collaboration, actual engagement is not guaranteed (Attard et al., 2015), and open data systems require more than just access to data (Janssen et al., 2012). Indeed, there is evidence that public use and outcomes of open data initiatives remain low (Attard et al., 2015; Janssen et al., 2012). Most work on barriers to open data focuses on technicalities and technological barriers (Janssen et al., 2012), identifying things like data ambiguity, poor metadata quality, inadequate search functionalities, and decentralized data sources (Attard et al. 2015). While technocratic solutions such as semantic links and standardized metadata have been identified as solutions to these issues (Attard et al., 2015; Vitolo et al., 2015), there is still a lack of attention to how open data is being interpreted by the end user (Janssen et al., 2012).

Scholars pointing out the lack of active use of open data platforms emphasize the disconnect between data providers and consumers (Attard et al., 2015). This disconnect, which manifests in inaccessible data formats and a lack of user-friendly interfaces, aligns with broader criticisms that platform use is predominantly passive. Merely creating open data portals is insufficient; there must be strategies to encourage active participation and ensure the data are meaningful and accessible to all stakeholders. This notion of increasing the accessibility of digital platforms has gained attention in recent years, and is reflected in data accessibility standards, as well as emerging bodies of work like evaluations of open data (Mukhtarov et al., 2018; Simonofski et al., 2022; Zhu & Freeman, 2019). Without accommodations for varying levels of existing knowledge, open data can have the inverse of its intended impact, thereby worsening digital divides, increasing confusion, and decreasing trust (Janssen et al., 2012). These findings highlight the need for further investigation of potential solutions to barriers to open data use.

Intermediaries are therefore necessary to bridge the gap between data providers and users (Attard et al., 2015; Mercado-Lara & Gil-Garcia, 2014; Mutuku & Colaco, 2012). Intermediaries can help interpret data and, through collaboration with software developers, create innovative applications or services. However, despite the potential for such collaboration through current technologies, Attard et al. (2015) maintain that this approach remains underutilized by public and governmental bodies.

2.2.3 The Role of Information Communication Technologies

Information Communication Technology (ICT) is a broad term that generally includes advances in the accessibility and availability of information facilitated through technology. Digital advances in ICT have extended beyond data collection and sharing, and now encompass modeling, data visualization, and communication and feedback mechanisms. Additionally, these platforms can serve as processing tools for Big Data (Vitolo et al., 2015). ICT platforms – including dashboards, interactive web maps, virtual simulations, and data viewers – are designed not only to inform users about local conditions but also to engage them in monitoring and stewardship efforts (Linders, 2012; Mukhtarov et al., 2018). By improving the accessibility and availability of data, ICT platforms are also thought to increase the value of open data, which is realized through its use (Attard et al., 2015). ICT tools are therefore understood as intermediaries of open data.

Existing reviews of ICT broadly focus on accessibility and equity considerations in open data portals (Fusi et al., 2022; Lourenço, 2015; McGrath et al., 2021; Simonofski et al., 2022); specific technologies, systems, and metadata (Attard et al., 2015; Janssen et al., 2012); and empirical descriptions of open data uses (Janssen et al., 2012). However, there is a relative lack of reviews that investigate the outcomes of ICT tools, and the influence that these platforms may have on decision-making by stakeholders. Importantly, Mukhtarov et al. (2018) investigated ICT and their influence on public participation in urban water governance, drawing on 32 case studies identified in academic and gray literature.

In the context of the GLB, the application of ICT for freshwater data has been explored in several studies. Goodspeed et al. (2016) conducted an evaluation of 37 web-based tools designed for the Great Lakes Aquatic Habitat framework, highlighting the diversity of ICT applications in environmental management. Sorensen (2014) provided an inventory of citizen-based ecological monitoring programs around Lake Superior, demonstrating the role of ICT in facilitating community engagement. Other studies focus on individual tools or initiatives in the GLB. For instance, Buckman et al. (2019) analyzed the use of visualization tools in public engagement efforts along the Lake Michigan shoreline, while Siebert et al. (2019) examined the impact of the CrowdHydrology project on citizen participation in water level monitoring.

Despite the rise of these platforms and continued investment in digital approaches to public involvement in Great Lakes issues, there is still significant progress to be made towards data accessibility and use by individuals (Fusi et al., 2022). Moreover, the literature lacks in-depth studies that assess the breadth of ICT tools and their broader impacts on decision-making in the GLB.

2.3 Conceptual Framework: The Data-Information-Knowledge-Wisdom Hierarchy

The Data-Information-Knowledge-Wisdom (DIKW) hierarchy (Ackoff, 1989) provides a valuable framework to explore the roles of ICT tools in supporting decision-making. The DIKW hierarchy distinguishes these concepts and describes how Data is transformed into Information, Information into Knowledge, and Knowledge into Wisdom:

Data refers to pure symbols and numbers that have no meaning beyond their existence (Ackoff, 1989; Bratianu, 2018). It is the lowest level of abstraction (Wessels et al., 2017), and requires processing to acquire significance.

Processing Data and adding context transforms it into Information. Davenport and Prusak (2000), identify five processes for this transition, namely: Contextualization, where Data is related to a specific context and purpose; Categorization, where data is prepared for different types of analysis; Computation, where data is processed using mathematical or logical methods; Correction, where errors in a dataset are found and eliminated; and Condensation, where Data is compressed to use less memory and computational effort. Information is therefore Data with the addition of context that answers the questions of "Who?", "What?", "Where?", and "When?" (Ackoff, 1989). Information therefore has meaning and relevance (Choo, 1996), and must have a sender and a receiver (Davenport & Prusak, 2000)

The transition from Information to Knowledge is not well understood (Bratianu, 2018), though at the simplest level, Knowledge is created through the incorporation of personal experience. The transition from Information to Knowledge is therefore the step of incorporating experience into scientific information to create an actionable, integrated understanding (Maruta, 2014). This description draws on the SECI (Socialization, Externalization, Combination, and Internalization) Cycle, a theory of Knowledge creation that describes Knowledge as a dialogue between Tacit Knowledge (from personal experience) and Explicit Knowledge (from Information). The resulting Knowledge is Information that has been transformed by an individual into a state of Knowledge by situating it relative to existing Knowledge. Knowledge is therefore subjective, as it relies on personal experience (Choo 2006) and exists relative to existing Knowledge in a knower (Davenport & Prusak, 2000). Importantly, Knowledge is able to answer the "How?" and is actionable (Ackoff, 1989; Bratianu, 2018).

Wisdom is the most elusive of these concepts, and has been excluded from iterations of the DIKW model for this reason. While there is no agreed upon definition of Wisdom (Bratianu,2018), Wisdom moves beyond Knowledge through the incorporation of morals and practical applications. Rowley (2007) describes this transition well, defining Wisdom as "The capacity to put into action the most appropriate behavior, taking into account what is known (Knowledge) and what does the most good (ethical and social considerations)" (p. 257). From this definition, it can be understood that if Knowledge is actionable, then Wisdom is the capacity to judge when to take action and what action to take. Data, Information, Knowledge, and Wisdom according to these definitions will be differentiated from more broad references to these ideas by capitalization of the first letter.

The origins of the DIKW hierarchy in academia are often credited to Russel Ackoff (1989) who proposed the hierarchical organization of these entities. Interpretations of this work led to the representation of the DIKW hierarchy as a pyramid, with Data at the base of Wisdom at the summit (Figure 1.1a). Through widespread adoption of the DIKW hierarchy various interpretations of the model have arisen, including the DIKW Continuum, which removes the hierarchical element and instead emphases DIKW as a process (Figure 1.1b).

Figure 1.1: Representations of the DIKW Framework

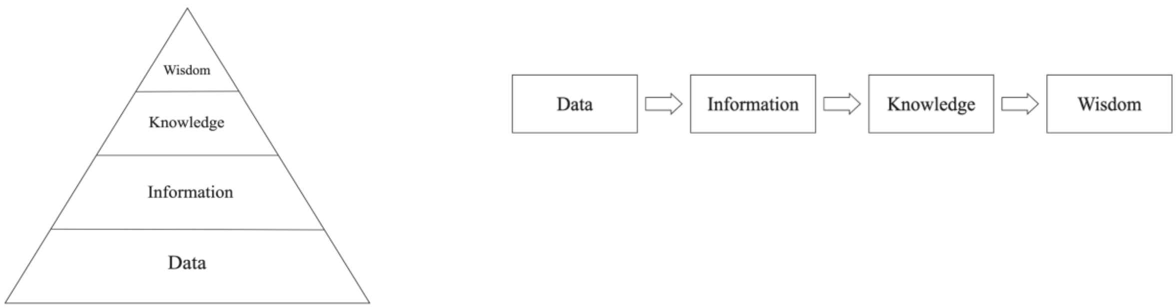

Figure 1.1a: The DIKW Hierarchy *Figure 1.1b: The DIKW Continuum*

Note: This figure displays representation of the DIKW framework as both a hierarchy (1.1a) and a continuum (1.1b).

Iterations of the DIKW hierarchy have been widely applied across contexts and disciplines to explore the ways in which data is given meaning. Artyukhov et al. (2021) conducted a bibliometric review to identify general uses of the DIKW framework and the fields with the highest demand for its application. In this review, they identified the following clusters of uses: knowledge management, data mining, and decision-making; and the most prominent fields as sociology, psychology, economics, business, and computer sciences. Applications of the DIKW hierarchy are therefore highly interdisciplinary due to the focus on learning (sociology) and technology (information studies). Applied to environmental sciences, the DIKW framework provides a unique lens to study data-driven decision-making

For this study, it will be used to help understand how open water data is being transformed into formats deemed suitable for non-scientists to support water management in the GLB. A practical example of the DIKW process applied to ICT for water governance is flooding: Presented as Data, flooding consists of raw data on water levels and rainfall amounts. Once this Data is processed to provide context and relevance it becomes Information, which in this case could be the probability of flooding events, such as 100-year floods. Information is then further analyzed into Knowledge by understanding the implications to the individual, such as patterns of flood events in their floodplain, and recognizing how local infrastructure and personal circumstances may influence this risk. Finally, the transition to Wisdom incorporates the ability to make informed decisions and actions based on this Knowledge. For example, an individual perceiving high vulnerability might decide to purchase flood insurance, invest in flood defenses, or engage in community planning to mitigate the potential impacts of floods.

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Connecting Text to Chapter 3

Chapter 2 provided the basis of the context, the theory of change described through open data, and the conceptual framework used to understand how this theory of change is operationalized through ICT. Chapter 3 builds on this work to address the first research question, investigating the current state of ICT in the GLB. To do so, this chapter employs systematic scoping review methods to identify and evaluate ICT platforms relevant to freshwater in the GLB.

Chapter 3 is a draft journal article that will be submitted for publication in an academic journal (likely the Journal of Great Lakes Research). I am the lead author on this chapter. Bryant Serre assisted with study design and methodology, data collection and analysis, and reviewing and editing the manuscript. Jan Adamowski and Gordon Hickey assisted with conceptual framing, study design, and reviewing and editing the manuscript.

Chapter 3 – Review of Information Communication Technology for Freshwater Data in the Great Lakes Basin

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Abstract

Online Information Communication Technology (ICT) platforms are increasingly used as tools to improve the accessibility and availability of open data. In the Laurentian Great Lakes basin (GLB), ICT tools help inform data-driven decision-making and facilitate public engagement in environmental issues. Despite the rise of, and continued investment in, these platforms, there are few systematic reviews of tools in the GLB. This study follows systematic review standards to assess the availability and attributes of ICT tools containing freshwater data in the GLB. A total of N = 145 platforms were identified and assessed. Key findings include potential saturation of ICT tools, high provision of platforms at large scales and by US government agencies, and the creation of a framework to differentiate tool types by attributes, with implications for data use by individuals. Greater discussion is needed on the utility of these platforms in informing decision-making among platform users.

Keywords: *Integrated Water Resource Management; Transboundary water governance; DIKW Hierarchy; Water Governance; Open Data Platforms; Systematic Scoping Review*

3.1 INTRODUCTION

Online Information Communication Technology (ICT) tools have emerged as intermediaries to make the volume of open data more digestible for non-specialized audiences. Although access to open data theoretically enhances public engagement in decision-making, non-experts require data in formats with additional context and interpretations to understand scientific information (Grainger et al., 2016). Specific to water, hydrological data is often not readily accessible in user-friendly formats (Addor et al., 2020), raising the issue of data remaining just that – data – rather than being transformed into formats that can be more easily understood and used (Jifa & Lingling, 2014; Sardar, 2020). By improving the accessibility and availability of data, ICT platforms are thought to increase the value of open data, which is realized through its use (Attard et al., 2015).

ICT tools come in various formats including dashboards, interactive web maps, virtual simulations, and data viewers, and serve diverse purposes – from informing individuals of local conditions and possible threats to fostering public participation in monitoring and stewardship efforts (Linders, 2012; Mukhtarov et al., 2018). Existing reviews of ICT broadly focus on accessibility and equity considerations in open data portals (Fusi et al., 2022; Lourenço, 2015; McGrath et al., 2021); specific technologies, systems, and metadata (Attard et al., 2015; Janssen et al., 2012); and empirical descriptions of open data uses (Janssen et al., 2012). However, there is a lack of reviews that investigate the outcomes of ICT tools, and the influence that these platforms may have on decision-making by platform users.

Specific to the Laurentian Great Lakes basin (GLB), data-driven decision-making and public engagement are essential to address ongoing environmental stressors, including: potentially toxic algal growth (NOAA, 2023), drinking water safety and aging civil infrastructure (Hughes, 2022), invasive species (GLANSIS, 2021), and flooding and property damage (Gallagher et al., 2020). Various ICT tools are used as mechanisms to communicate freshwater data to the public across the basin. The limited existing literature canvassing available platforms includes Goodspeed et al. 's (2016) evaluation of 37 web-based tools for the development of the Great Lakes Aquatic Habitat framework and Sorensen's (2014) inventory of citizen-based ecological monitoring programs around Lake Superior. In addition, despite the rise of these platforms and continued investment in digital approaches to public engagement in Great Lakes issues, there is still significant progress to be made towards data accessibility and use by individuals (Fusi et al., 2022).

Foundational knowledge gaps persist (Learning for a Sustainable Future, 2022), and ICT-driven efforts have been limited by fears of misinterpretation of data by the public (Goucher et al., 2021).

The 2021 Great Lakes Regional Poll conducted by the International Joint Commission (IJC) highlights an increasing awareness among the public regarding issues impacting the Great Lakes. According to the poll, 90% of respondents believe that it is important to protect Great Lakes health and quality (slide 15), and 65% expressed interest in Great Lakes news and information (slide 18). The survey also shows a decrease in "don't know" responses when participants were asked to identify the lakes' most significant problem (from 31% in 2015 to 17% in 2021, slide 20), suggesting that public understanding may be deepening.

Further work is therefore needed to (1) provide an updated review of ICT platforms for freshwater across the GLB, and (2) address the previously identified gap of linking these platforms to decision-making made by platform users.

Systematic scoping review methods are appropriate for this work as they guide a systematic and replicable identification of ICT platforms, but are more flexible than traditional systematic reviews through their ability to incorporate broader forms of evidence (Peters et al., 2015). Because final sources are ICT platforms and not academic articles, the emphasis of traditional systematic reviews on synthesizing evidence to provide recommendations is not applicable (Grant & Booth, 2009). Accordingly, systematic scoping reviews align better with assessing the identified gaps, as they seek to identify key characteristics, potential gaps, and provide an overview of the available literature (Munn et al., 2018).

This study explores the breadth of ICT tools available in the GLB. The aim is to inform a discussion on the ability of ICT platforms to transform data into more digestible formats for non-scientists and ultimately incite action among stakeholders. More specifically, this research seeks to answer the question: *What delivery of freshwater data is currently accomplished through online ICT tools in the Great Lakes basin?*

3.2 DEFINING ICT AND CONCEPTUAL FRAMEWORK

3.2.1 Approach to Defining ICT

Available ICT tools are diverse, and have grown significantly over the last decades. To date, several other studies have examined different categories of ICT tools (Linders, 2012; Mukhtarov et al., 2018). Various names for these tools exist – such as digital and virtual tools (Bull et al., 2022; Mackay et al., 2015) – as their categories can span data collection through educational purposes. Many data-driven platforms incorporate environmental data, and take form as open data portals, map-based portals (Langlois et al., n.d.), interactive web-maps (O'Brien & Cheshire, 2016), and digital citizen science platforms (Breuer et al., 2015; Duguay, 2021; Strobl et al., 2019). Other types of platforms that fall within one or across these four categories include Water Information Systems (Goodall et al., 2008), Earth Observation Systems (Lautenbacher, 2006; Nativi et al., 2020), Decision Support Systems (Goodspeed et al., 2016), Digital Catchment Observatories (Mackay et al., 2015), Environmental Virtual Observatories (Karpouzoglou et al., 2016), and Citizen Observatories (Wehn & Evers, 2015).

Non data-driven platforms are those that do not rely on environmental data, and instead seek to use ICT tools to facilitate dialogue and communication in participatory processes. These include approaches like participatory modeling (Henly-Shepard et al., 2015), shared vision planning (Palmer et al., 2013), decision support tools (Barnhart et al., 2018), and web-dialogue (Bevacqua et al., 2006). Even platforms like email and Zoom could be considered ICT when used in contexts for public participation in decision-making. Other examples include the gamification of decision-making (Gober et al., 2011), where participants can explore the outcomes of decision-making through the incorporation of game play elements, or the use of technologies to communicate traditional knowledge, such as the example of the Virtual Reality game of the creation story, created by First Nations in Canada (Hampton, 2017).

Importantly, there is significant overlap in categorizations of these tools. Many seek to fill this identified gap of providing open-access environmental data in accessible formats, though a unified understanding of these tools and what they offer does not exist.

In this work, ICT tools are understood as interactive, software-based, data-driven platforms openly available online. The interactive element helps to distinguish tools that incorporate accessibility measures for a broader audience than scientists, decision-makers, or specialists, including visualization mechanisms (Grainger et al., 2016). The specification of software-based tools distinguishes tools of interest from physical tools (such as individual phones, satellites) and includes tools or platforms like databases, websites, and phone applications. Finally, the emphasis on data-driven platforms focuses efforts on intermediaries of open data, rather than broader educational efforts.

3.2.2 Conceptual Framework

The Data-Information-Knowledge-Wisdom (DIKW) hierarchy serves as a valuable framework to understand how data is transformed and used to support decision-making (Ackoff, 1989). For this study, it will be used to help understand how open water data is being transformed into formats deemed suitable for non-scientists to support water management in the GLB. The DIKW distinguishes between Data, Information, Knowledge and Wisdom as follows:

Data, initially symbols and numbers, are transformed into Information through processing and contextualization (Bratianu, 2018; Davenport & Prusak, 2000). Information is therefore Data with the addition of context that answers questions of “Who?”, “What?”, “Where?”, and “When?”, and has a sender and a receiver. Knowledge is created by integrating personal experience with Information, resulting in Knowledge that is actionable by the individual (Ackoff, 1989; Bratianu, 2018; Maruta, 2014). Wisdom, the highest level, combines Knowledge with ethical considerations for sound, independent decision-making (Bratianu, 2018; Rowley, 2007).

For example, Data on water levels and rainfall becomes Information about flood probabilities (e.g., 100-year floods). Knowledge comes from understanding local flood patterns and assessing personal vulnerability, and becomes Wisdom when acted on in decisions like investing in flood defenses or community planning. Data, Information, Knowledge, and Wisdom according to these definitions will be differentiated from more general references to these ideas by capitalization of the first letter.

Adopting the DIKW hierarchy, ICT platforms are understood as intermediaries to transform Data along the DIKW hierarchy. Following this framework, existing reviews of ICT remain in Data and Information. This work seeks to build on these studies and, through the adoption of the DIKW hierarchy, explore how Knowledge and Wisdom may be reached through ICT platforms.

3.3 METHODS

This review followed the PRISMA (2020) systematic review standards (Page et al., 2021) to identify relevant tools across academic and gray literature. Upon the identification of relevant tools, data items were extracted on the organization providing the platform, the platform itself, and the data it displays.

3.3.1 Eligibility Criteria

Eligibility criteria for this review built on the literature of ICT for water governance and the subsequent definition of ICT tools as interactive, software-based, data-driven platforms openly available online (Section 3.2.1). Table 3.1 shows eligibility criteria and relevant definitions for tool inclusion, separated into two rounds of screening.

The criteria for the first round of screening included: discussion of an ICT tool; relevance to freshwater governance; availability for public use; and inclusion of data in North America (Table 3.1a). In the second round of screening, further exclusions were added to the criteria in order to limit the scope and allow for more rigorous screening. These included reductions in relevant data topics, such as biological indicators of water health and meteorological data (See Table 3.1b for a full list). Criteria from the first round was also re-applied according to refined definitions (Table 3.1b).

Moreover, there are other eligibility criteria unrelated to how ICT are defined. First, both French and English tools were included in this study, though searches were conducted in English. Secondly, platforms must be currently in use, and only academic articles published between January 2000 and May 2023 were screened. Finally, gray literature was included to accommodate ICT tools, as informed by existing work that reviewed gray literature on topics that were largely missing from academia (Piggot-McKellar et al., 2019; Ponce Romero et al., 2017). This work builds on Adams et al.'s (2017) framework of different formats of gray literature to create an operational definition of gray literature relevant to this work (Mahood et al., 2014). Diverse sources that could help to later identify relevant platforms were included. Relevant formats include: program evaluation reports, publications from governmental agencies, dissertations, policy documents, conference abstracts, book chapters, newsletters, publications from non-profits and consulting firms, blogs and social media, data sets, committee reports, working papers, and reports on websites, ICT platforms themselves, and web pages that consolidate ICT tools for a specific organization, geographic area, or purpose.

Table 3.1: ICT Tool Review Eligibility Criteria

Table 3.1a: Eligibility Criteria for the First Round of Screening

Inclusion Criteria	Exclusion Criteria	Relevant Definitions/Clarifications
First Round of Screening		
Discuss an ICT tool	No use of ICT, not data-driven Review or Summary of multiple tools[2]	ICT tools are understood as software-based, data-driven digital infrastructure. This includes tools or platforms like databases, websites, and phone applications. Physical tools such as individual phones or satellites are excluded. In this stage, if ICT use is uncertain, the source will be included. Sources must be individual platforms.
Relevant for freshwater governance.	Only for application outside of freshwater, such as ocean conservation.	Where water governance extends to include relevant social, political, economic, and administrative systems. Relevance to freshwater remains broad at this stage, and includes data on physical, chemical, biological, human, and policy aspects of freshwater. This includes flora and fauna mentioned relative to aquatic habitats, atmospheric conditions (temperature, wind) when linked to freshwater systems, and policy data related to conservation and protected areas. 'Only' specifies that these topics were not means for exclusion if among other relevant data topics, but if they were the only topic they did not justify inclusion of the platform.
Available for Public Use	Only for technical use Not hosted online	Platforms should be directed towards the public and available openly online. Platforms with limited access or that are explicitly developed for professionals or academics will be excluded.
Contains data in North America	Outside geographic scope of GLB	At this stage, tools will be included if they contain data in North America. Tools that explicitly only contain data outside of the GLB will be excluded.

[2] Reviews or summaries of multiple tools will be tagged "snowball" and used to identify additional relevant tools (See Section 3.3.2)

Table 3.1b: Eligibility Criteria for the Second Round of Screening

Inclusion Criteria	Exclusion Criteria	Relevant Definitions/Clarifications
Second Round of Screening		
Be a singular ICT tool	Does not meet definition of ICT Review or summary of multiple tools	At this stage all sources must be platforms, not academic papers or reviews of multiple platforms. The previous criteria is narrowed to exclude software itself, open source codes.
Data-Driven	Predominantly text-based platforms Platforms that do not incorporate real data	Where data includes numerical data, including GIS data, images, including, remote sensing data, documents, such as reports and evaluations of water resources, and survey data, such as community science observations. Platform that are predominantly text-based, such as articles or story maps without integrated platforms, and platforms that do not incorporate real data, such as those for educational purposes, are excluded.
Interactive platform	Static presentation of data	Platforms must have a visualization mechanism of some kind. This excludes many data portals and databases.
Relevant for freshwater governance	No direct link to freshwater	Freshwater governance relevance is narrowed at this stage to exclude biological indicators (fish, birds, amphibians, animals, insects, invasive species, biota, biodiversity) except algal blooms. Weather and climate platforms are excluded unless directly linked to freshwater (e.g., flood risk, buoy data). Soil, land, and geologic data are excluded unless directly linked to freshwater. Mapping data (e.g., watershed boundaries) is excluded. Glacial and ice data, groundwater, and stormwater are excluded. Lake guides and access materials are excluded. Included are projects, interventions, land policy, coastal data, and images of coastal conditions.
Available for public use	Only for technical use Download needed, not hosted online Membership, payment, or account needed	Data, platforms, or tools are freely accessible to all individuals without the need for login, membership, software download (except for mobile applications, which are included), or payment. These resources are designed to serve the general public or broader community without targeting specific researchers or specialists explicitly.
Contains data in the GLB	No data within the GLB	Tools must include data within the Laurentian Great Lakes basin
Currently in use	No longer active	Excluding platforms that are no longer active, have broken links, fail to load or have partial loading issues, are offline for maintenance during the research period, or do not yet include GLB data. Examples include broken map components or platforms explicitly undergoing replacement with a new version.

3.3.2 Information Sources and Searching Strategies

Consistent with Godin et al. 's (2015) joint source protocol for gray literature searches, this research pulled from a variety of sources to identify relevant platforms including (1) database searches, (2) targeted web searches, and (3) consultations with content experts.

Database Searches

Web of Science, Scopus, and Google Scholar were searched in May 2023 for literature using search terms to reflect (1) digital tools, (2) water and water issues, (3) application to participatory governance and community engagement, and (4) to emphasize a geographical constraint to the GLB. To source appropriate keywords, known sources of case studies and synthesis papers where digital tools are used in water-related issues within the Great Lakes were referenced (Goodspeed et al., 2016; Moody et al., 2017; Roth et al., 2017; Sorensen, 2014). Thus, within Web of Science and Scopus, all literature was sourced according to the search strategy outlined in Appendix I. Plurally, our search terms meant to accommodate the broad range of uses and terms for ICT (See Section 3.2.1). To refine by geography, we included search terms for studies specifically within the GLB, in addition to studies within the adjacent countries (United States and Canada). Because Google Scholar does not allow for Boolean Operators, 10 search phrases were developed using the previous search string (See Appendix I for search string and phrases) (Mahood et al., 2014). Exhaustion criteria for both traditional database searches and Google Scholar searches were defined as 20 consecutive irrelevant sources.

Targeted Web Searches

Google was used to identify specific examples of tools and case-studies, rather than academic articles. Following a methodology developed for Google (Godin et al., 2015), search phrases were developed based on the keywords used for database searches (See Appendix I). To reduce reproducibility errors (Mahood et al., 2014), we conducted all searches within a private web browser (to limit the influence of previous searches), from devices with registered IP addresses within the GLB. However, we acknowledge that this may still preferentially derive sources from websites and organizations closer to our Canadian-based research team. After every search, a new browser was opened to avoid browser memory preferentially filtering webpage results. In all searches, we included only up to the first five pages of resources, which is consistent with Google searches for gray literature by scholars such as Bowen et al. (2010).

Consultations with Content Experts

ICT tools were also provided by staff at the National Oceanic and Atmospheric Administration (NOAA) Great Lakes Observing System (GLOS) project team, selected for their ongoing work on consolidating data sources for their platform. 29 tools were identified through these consultations.

Snowball Sampling

Snowball sampling is a method of locating additional sources by tracing citations and resources from sources identified in database and web searches (Greenhalgh & Peacock, 2005). Two rounds of snowball sampling were conducted to maximize the number of relevant sources captured. These sources were subject to the same eligibility criteria used throughout the review.

3.3.3 Study Selection

The study selection process consisted of three phases: Initial identification by title, first round of screening by abstract or landing page, and second round of screening by full article or platform. The inclusion approach is illustrated in Appendix II, an adapted PRISMA (2020) flow diagram, which outlines the systematic scoping review process, including the steps of initial identification, screening, eligibility assessment, and final inclusion of sources.

Initial Identification

Initial sources were identified by article of website title for relevance (23382)[3]. This round was conducted by two reviewers. To ensure consistency, 5 pages of studies were screened together for each round before working individually. Sources were compiled in Zotero (2024). Duplicates were removed using both automated duplicate identification on Zotero, as well as manual identification by the reviewers (N = 45). The duplicate removal process was repeated in each stage of screening.

First Round of Screening

Articles were then screened based on their abstract, table of contents, and headings according to initial inclusion criteria (N = 567) (Table 3.1a). The same inclusion criteria were applied to gray literature, on the content of the landing page for web-derived sources. Sources covering multiple ICT technologies were used as snowball samples (N = 129) to identify individual platforms. N = 1039 platforms were identified, N = 72 duplicates were removed, and N = 947 met inclusion

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[3] This number reflects initial search results in Scopus, Web of Science, and Google Scholar. The number of results in Google searches were not provided.

criteria for the first round of screening. This round was also done by two reviewers, and intercoder reliability was calculated for each stage of screening. At the end of the first round of screening, sources included from initial searches and snowball methods were combined, and an additional N = 161 duplicates were removed.

Secondary Screening

Subsequently, full text records and webpages were screened according to the inclusion criteria outlined above (see Table 3.1b) (N = 726). N = 76 duplicates were removed. A total of 145 platforms met final criteria. The full list of tools can be found in Appendix III.

3.3.4 Data Extraction

Upon identification of relevant platforms, data items were extracted according to the rubric in Appendix IV. Data items are categorized into three main areas: Organization (Type, Origin), Tool (Type, Intention), and Data (Topic(s), Spatial Coverage, Temporal Scale, Format). This rubric was developed by reviewers using both inductive (Thomas, 2006) and deductive (Mayring, 2000) methods. Data Topics were informed by Goodspeed et al.'s (2016) Great Lakes Aquatic Habitat Framework, while Organization and Tool categories were developed inductively after initial screening.

To ensure that data extraction is consistent across the broad range ICT tools included in this review, several assumptions were made. Firstly, some platforms contributed data to multiple other platforms, creating overlap; this was treated as a unique representation of data and therefore a distinct tool, rather than duplication. Additionally, some platforms allowed for the presentation of data across multiple scales. In cases where Great Lakes data were offered as a separate web page, the GLB was put as the geographic scope. Otherwise, the largest available scale was included. Because this work is only investigating the availability and representations of data within the GLB, this assumption does not change results within the study area. Lastly, data characteristics were not always consistent across the platform's scope. In such cases, the results aimed to capture the largest diversity or range of data provided. For example, the dates provided to complement the temporal scale of data are approximate and are based on the largest identified temporal range. For the implications of these assumptions, see Limitations (Section 3.5.4).

One reviewer collected data from all sources. In cases where uncertainty arose, the reviewer consulted with a collaborator to agree on the categorization of data. Automation tools were not employed in this process.

3.3.5 Synthesis Measures

The extracted data was synthesized and analyzed using descriptive statistics through Microsoft Excel (2023). Measures included frequency counts, proportions, and sub-group analysis in order to capture the distribution of key variables across platforms. Graphical representations were created to visually depict these distributions.

3.4 RESULTS

A total of N = 145 relevant platforms were included, and data was extracted on Organizations, Tool Types, and Data Topics.

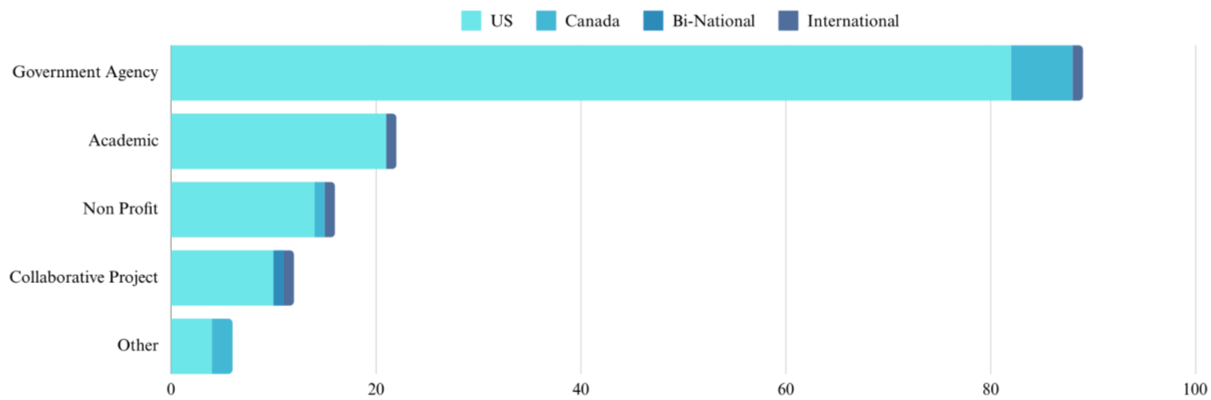
3.4.1 Organizations

Data items collected on the organizations themselves included Organization Name, Organization Type, and Organization Origin (at the country-level). A total of 68 organizations were identified as providers of digital platforms relevant for this review, or 83 unique providers of platforms when programs within a single organization were counted individually. Each organization provided one or more tools, with some organizations contributing multiple platforms, and some platforms being the product of collaborative efforts between multiple organizations.

Despite overlap in platform provision by the same organizations, numbers tabulated on organization characteristics were counted by individual platforms, rather than unique organizations. The resulting numbers (out of 145 platforms) better represent trends in platform provision across the basin.

Organization type categories were: government agencies (N = 88); academic institutions (N = 22); non-profit organizations (N = 17); collaborative projects (N = 12); other (N = 4), which included charities, research organizations and private companies; and watershed organizations (N = 2). These organizations were located primarily in the US (N = 131), with some in Canada (N = 9), (N = 4) from other countries or global efforts, and (N = 1) bi-national organizations between Canada and the U.S. Figure 3.1 shows the intersection of these organization characteristics, specifically organization type and origin. ICT platforms included in this review were primarily provided by US organizations, specifically US government agencies (N = 82).

Figure 3.1: Organization Type and Origin of Platform Providers



Note: Distribution of organizational geographic origins by category of organization type. Note that the x-axis represents the number of platforms (totaling 145), not the number of organizations.

3.4.2 Tool Type

Tool Type categories are provided below (Figure 3.2) with common characteristics, the amount of platforms that fit that description, and an example of a relevant tool from the review. Each platform was only included in one category despite some overlap in these distinctions. The only exception was Mobile Applications, which were often provided as alternate formats to web tools.

Figure 3.2: ICT Tool Types and Examples

Figure 3.2a: Data Portals with Visualizations

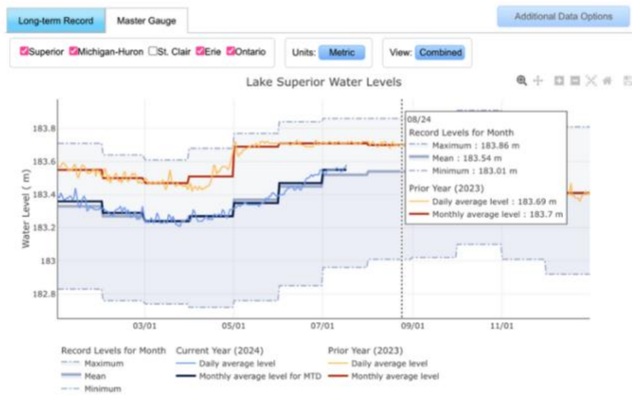
Figure 3.2b: Data Dashboards without Maps

Data Dashboards without Maps

Tools designed to display data through various visualization techniques, without using maps. Unlike data portals, they do not facilitate searching for data.

Their primary uses were to present trends and current conditions.

Total platforms identified: 3



Examples:
Water Level Dashboard (Left);
Lake Superior Buoys and Webcams (Right)

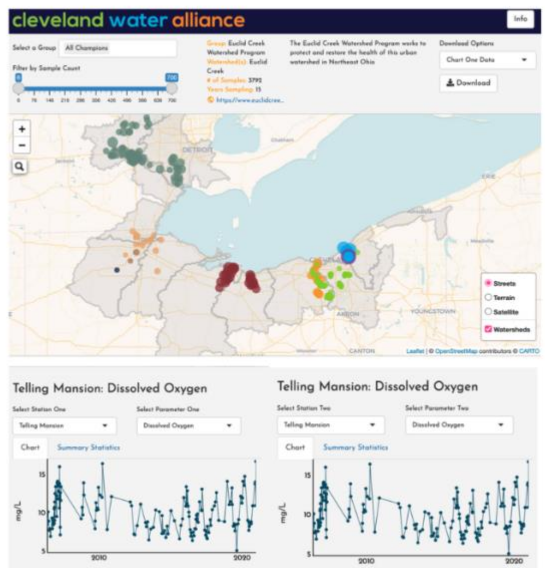
Figure 3.2c: Data Dashboards with Maps

Data Dashboards with Maps

Tools designed to display data through various visualization techniques, including maps. These platforms are distinguished from later formats by the equal, rather than primary, role that maps play in the tool design relative to other visualizations. Maps often defined the scope and content of data displayed elsewhere on the dashboard, though in rare cases was used as a visualization itself.

This format was predominantly used to provide data, including community-sourced data and current conditions, with some incorporating synergies between multiple variables.

Total platforms identified: 21

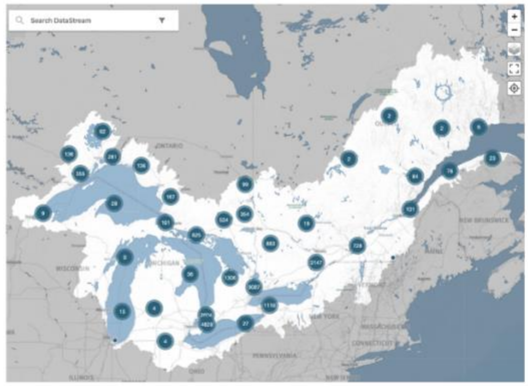


Example: Cleveland Water Alliance, Smart Citizen Science Widget

Figure 3.2d: Maps for Locating Data

Maps for Locating Data

Map-based platforms where the map component is primarily used to locate and show the scope of data provision. Data is represented by data points, some of which are colour-coded based on the type of data or information available. No data is directly accessible on the web page; users must click on links provided to access data. Some data on subsequent pages is provided through dashboard or other visualizations.



Example: Great Lakes DataStream

Their primary use was to consolidate data sources and provide data, including community-sources data, or to communicate current risks and conditions.

Total platforms identified: 14

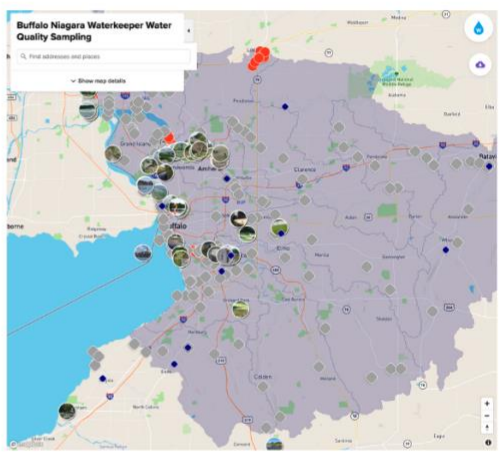
Figure 3.2e: Maps for Viewing Data

Maps for Viewing Data

Map-based platforms where maps display data points and provide data through pop-ups, all within the same web page. They often include colour-coded or otherwise symbolized data points. Users get all the data and information directly from the map, though primarily in numerical format. Supplementary materials can be linked.

Uses included showing current conditions, sharing community-sourced data, and investigating past events. In select cases, they were also used to assess current vulnerability, guide resource use, and overall provide data and management information.

Total platforms identified: 35



Example: Buffalo Niagara Waterkeeper Water Quality Sampling

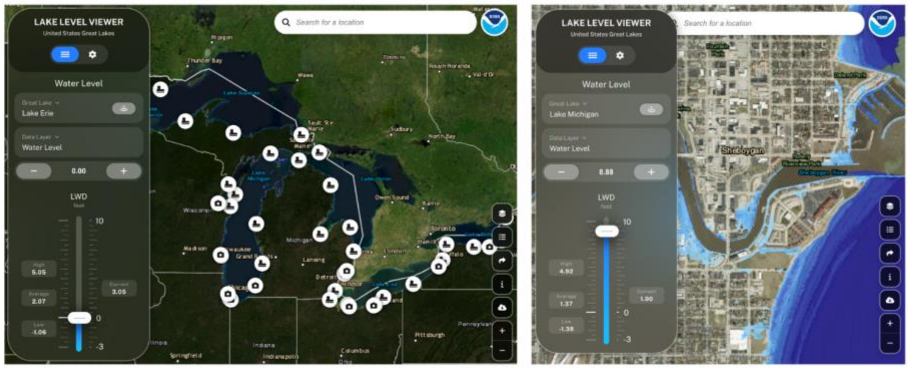
Figure 3.2f: Maps for Visualizing Data

Maps for Visualizing Data

Interactive map-based platforms where maps display primarily spatial data, rather than individual data points. Users can change data layers and input different parameters, such as water levels, temperature, or climate scenarios.

Uses were varied, though the primary use was to assess current vulnerability. Other uses included data provision, understanding synergies, consolidating data sources, and showing current conditions.

Total platforms identified: 37



Example: Lake Level Viewer

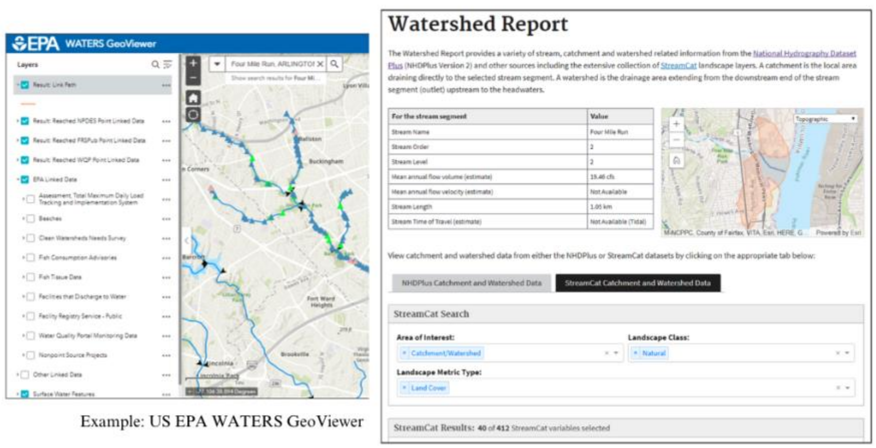
Figure 3.2 g: Maps for Analyzing Data

Maps for Analyzing Data

Interactive map-based platforms where data analysis is possible through the map interface. These tools enable users to conduct projections, delineate areas, upload data, and generate reports.

Uses were varied, and broadly included data analysis and simulation for past, current, and future events and impacts.

Total platforms identified: 11



Example: US EPA WATERS GeoViewer

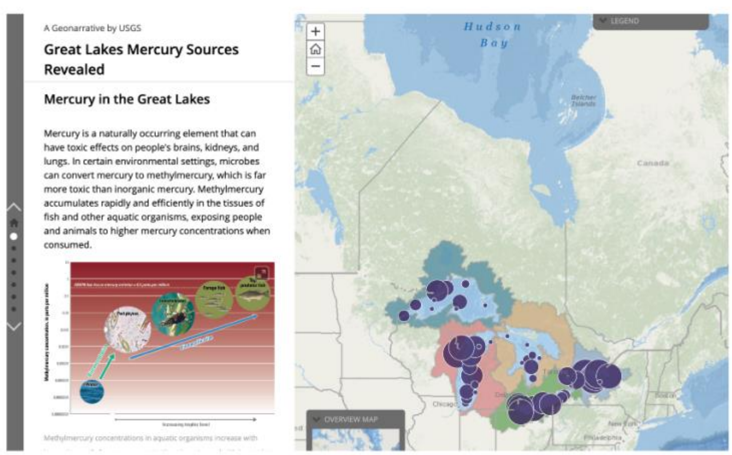
Figure 3.2h: Story Maps with Integrated Platforms

Story Maps with Integrated Platform(s)

Story Maps or Geonarratives that integrate data-driven platforms, which may exist independently or only within the platform. These situate data platforms within a text-based platform, providing significant context and explanations.

The primary use of this tool format was to share new technology or research. Other uses focused on showing historic, current, and future threats including climate change scenarios and past pollution events.

Total platforms identified: 8



Example: Great Lakes Mercury Sources Revealed, USGS

Figure 3.2i: Interactive Websites

Interactive Websites

Websites with numerous visualization components spread across multiple pages.

These platforms were predominantly used to show current conditions, with other uses ranging from showing historic and current threats, to understanding synergies, to tracking progress towards goals.

Total platforms identified: 14

Example: INFOS Milwaukee

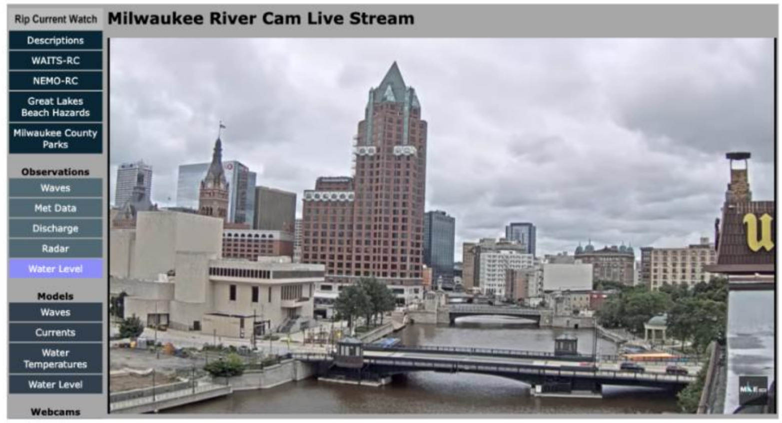


Figure 3.2j: Mobile Applications

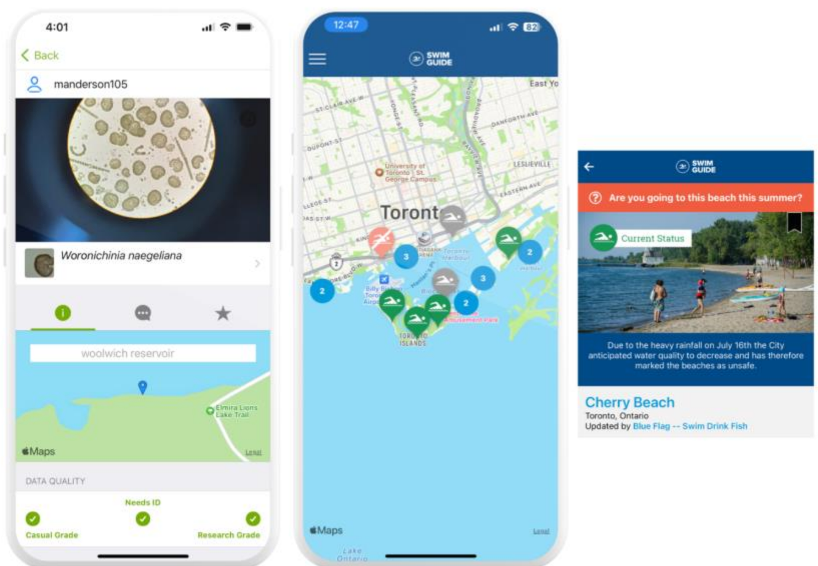
Mobile Applications

Software applications designed for use on mobile phones provided as supplementary ways to access platforms.

The primary use of mobile applications was to share and collect community-sourced data, with one application focused on showing current conditions

Total platforms identified: 5

Examples:
Cyanoscope, through iNaturalist App (Left),
Swim Guide, Swim Drink Fish (Right)



3.4.3 Data

Data Topics

Data topics were broadly categorized as: Water Quantity and Conditions (N = 133), Water Quality (N = 109), Human Activity Data (N = 27), Hydro-Geomorphology (N = 26), Applied Data (N = 26), and Extensive (N = 10). Figure 3.3 shows the distribution of data topics across platforms. Importantly, most platforms (N = 96) contained multiple data topics.

The category Water Quantity and Conditions consists of: data on water quantity (N = 64), including water levels and flood-related data; climatological data (N = 38), which was included when linked to water quantity; and lake conditions (N = 31), which refers to information that describes the physical and environmental characteristics of a lake at a given time. Lake conditions data often includes variables that directly impact the lake's ecosystem, water quality, and usage for activities like boating or research, such as real-time buoy data on wind speed and wave height.

Water Quality includes chemical (N = 36), biological (N = 21), and physical (N = 20) indicators of water quality. This category also included broad measures of water quality (N = 16), which often consisted of letter grades or overall ratings of a resource, as well as specific pollution sources, both actual and potential. Human Activity Data included socio-economic and development data when directly linked to freshwater. This included infrastructure (N = 14), socioeconomic (N = 6) data, land use (N = 3), vessel traffic (N = 2) and coastal economy (N = 2). Hydrogeomorphology data were often included as supplementary to water quantity and quality data, and were divided into coastal (N = 9) data, hydrologic features (N = 8), land cover (N = 6), and geomorphology (N = 2). Applied data includes data on impacts (N = 9), interventions (N = 6), advisories (N = 6) and projects (N = 2) related to water issues. Finally, the category Extensive denotes comprehensive data portals with visualization mechanisms where it was not judged feasible to go through all the data provided.

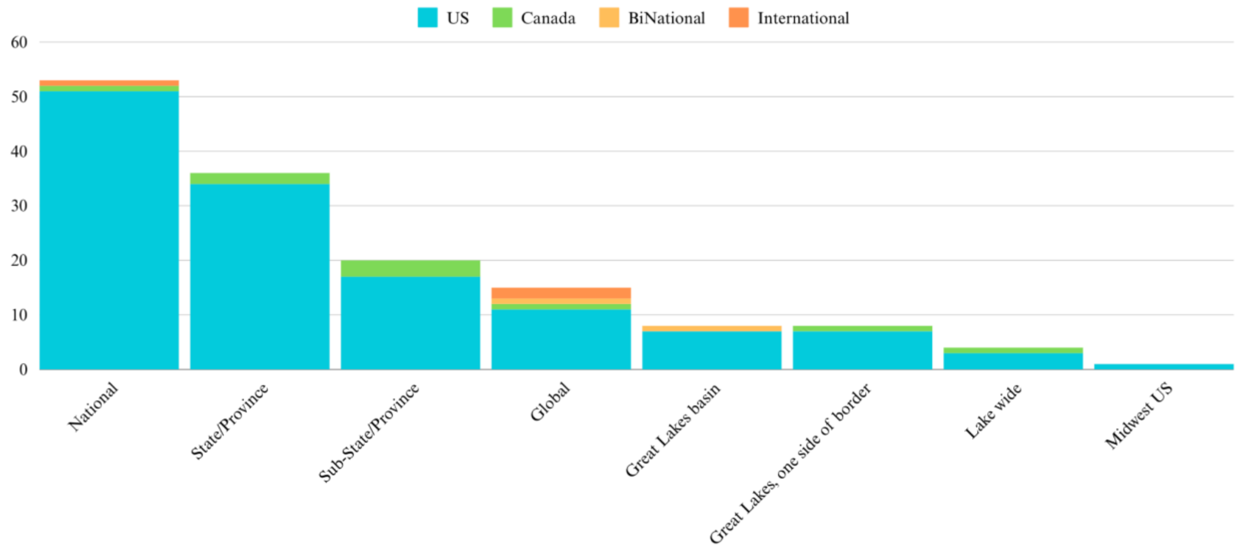
Figure 3.3: Occurrence of Data Topics Across Platforms

Note: Sunburst chart depicting data topics and their corresponding subtopics, highlighting their occurrence across various ICT platforms.

Geographic Scope

The geographic scope of platform data was categorized to assess the extent and scale of data provision. Categories included: National (N = 52); State or Province (N = 35); Sub-State or Sub-Province (N = 22); Global (N = 15); Great Lakes basin (N = 9); Great Lakes basin, on only one side of the border (N = 8); Lake-wide (N = 3); and Midwest US (N = 1). A full breakdown of geographic scope including distinctions by organization origin is provided in Figure 3.4.

Figure 3.4: Geographic Scope and Organization Origin



Note: Bar chart illustrating the geographic scope of data provided on platforms, with each bar subdivided according to the origin of the organization providing the platform. The y-axis shows the number of platforms.

Temporal Scales

The temporal scale of platform data was categorized to understand the timeliness and relevance of the information provided. The results indicate a diversity in data temporalities, with platforms offering: updated data (N = 91), which includes data that demonstrates regular updates and has been updated within the last 2 years, including ongoing projects and recent advisories; historical data (N = 80), defined as data not updated in over 2 years; real-time data (N = 40), defined here as data updated at least daily, meant to display current conditions, and often provided through an automated process; and projections (N = 23), which consists of data used to generate projections or simulations of events or conditions that have not yet occurred. Many platforms showed multiple temporal scales of data, particularly historic, as many kept records of past data provided.

Data Formats

The format of platform data was categorized to understand the types of data provided by the platforms. Results indicate a variety of data formats, including Numerical data (N = 128), Images (N = 20), Documents (N = 10), and Survey data (N = 9). Numerical data includes any data that are number based, including geographic coordinates and GIS data, though predominantly it is made up of measurement data. Images includes data formats like images from community science platforms, videos and live streams of current conditions, and remote sensing data when applied to freshwater, such as algal bloom monitoring. Documents and Survey data are both text-based data, where Documents includes reports and evaluations that are shared through a digital platform with visualization, such as located through an interactive map, and Survey data includes text-based community-sourced data such as tweets and written descriptions of conditions, impacts, or pollution sources. The understanding of data was intentionally kept broad in order to account for various forms of data provided online, often through community science platforms and live cameras.

3.5 DISCUSSION

3.5.1 Abundance and Overlap

The review identified an abundance of platforms and areas of overlap in platform provision and content. Results indicate disproportionate platform provision by US organizations (N = 131) as compared to Canadian organizations (N = 9) in the GLB (Section 3.4.1). The majority of U.S. platforms are provided by U.S. government agencies (N = 82), which contrasts efforts by Canadian government agencies (N = 6). The U.S. invests significant resources in water data infrastructure, which may be driven by higher-profile legacy water contaminants in the GLB, such as in the Cuyahoga River fires (Hardy, 2022) and the Flint, Michigan water crisis (Morckel & Terzano, 2019). Previous crises may generate mistrust of government agencies, leading to increased data transparency and accessibility efforts in the U.S. (Morckel & Terzano, 2019). While Canada received public scrutiny for the Walkerton crisis in Ontario (Driedger et al., 2013), the myth of water abundance in Canada has led to the under-investigation and underfunding of water data initiatives (Bakker, 2007). Additionally, while the US has well-established agencies like the US Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA) driving the development and provision of these platforms, Canada lacks equivalent national bodies that provide ICT tools. That said, the final list of platforms did not include certain Canadian platforms, including those by Conservation Authorities or the Ontario government. The reasons for these exclusions are investigated in the Limitations (Section 3.5.4)

Related to Data Topics (Section 3.4.3), results revealed high provision of platforms presenting Water Quality (N = 109) and Water Quantity and Conditions (N = 131) content. The emphasis on ICT on these topics is consistent with a broader emphasis on increasing accessibility of environmental data, as evidenced by work on open data accessibility by Fusi et al. (2022), Lourenço (2015), McGrath et al. (2021) and Simonofski et al. (2022). However, multiple platforms providing similar data can confuse users and a high number of tools makes it difficult for users to find tools relevant to their needs. For instance, during the Walkerton crisis in Ontario, Driedger et al. (2013) noted that some individuals expressed a desire for access to water data but were unaware of its availability. As a result, potential users and developers can be unaware of existing platforms, resulting in duplicated efforts and an overall lack of use. Saturation of digital platforms in the GLB highlights the need to streamline efforts and reduce redundancy.

3.5.2 Tool Types and DIKW Transitions

As discussed in Section 3.2.2, Data is transformed to Information through the addition of context. Davenport and Prusak (2000) identify five processes for this transformation: Contextualization, Categorization, Computation, Correction, and Condensation. The ICT reviewed in this study – those catered towards a non-specialized audience and involving visualization or interactive components – facilitate this transformation of Data into Information. Knowledge is then created through the integration of personal experience, or Tacit Knowledge, while Wisdom is generated through actions being taken and learning what decision to take when. Although digital tools alone cannot achieve Knowledge or Wisdom, certain tool characteristics can support this process. Differentiating between tool types (Section 3.4.2) provides a clearer picture of how Data is processed and utilized. Each previously identified tool type (Figure 3.2) is discussed below for its relevance to DIKW transformations.

Data Portals and Dashboards

Data Portals with Visualizations (Figure 3.2a) and Data Dashboards Without Maps (Figure 3.2b) use visualizations to make Data more accessible to non-experts and transition from Data to Information. Data Dashboards with Maps (Figure 3.2c) allow users to search for results based on the map and create links to users' specific locations or experiences. This makes it easier for users to find Data and Information relevant to them, thus beginning to bridge the gap towards Knowledge.

Map-Based Platforms

Map-based platforms provide advantages to achieving Knowledge, but there is considerable variance in how map-based platforms operate under DIKW. Maps for Locating Data (Figure 3.2d), provide a map as a searching mechanism but lack further Data interpretation elements such as visualizations. These platforms therefore require users to have more existing Knowledge to access and understand the Data and Information. Maps for Viewing Data (Figure 3.2e) merge visualization and location-based features to better facilitate the transitions from Data to Information to Knowledge. Maps for Visualizing Data (Figure 3.2f) then provide further opportunities for learning by incorporating interactive elements such as changes in layers and parameters. However, Maps for Analyzing Data (Figure 3.2g) are often designed for experts to perform analyses on Data and generate new Information. As a result, these tools are less usable and do not necessarily achieve Knowledge for casual users.

Text-Based Platforms

Story Maps (Figure 3.2h) stand out as particularly valuable among ICT platforms in the GLB. By integrating various Data sources and providing context, background, and guidance, Story Maps recognize the user's limited existing Knowledge and effectively start from the basics on the topic. By thoroughly contextualizing Data, this format of ICT facilitates the transformation of Data into Information and Knowledge.

3.5.3 Scale and Bounded Rationality

Geographic Scope

Results indicate a potential preference for large-scale data provision in the GLB ICT open data ecosystem. Of the 145 platforms included, 52 were provided at a national scale, and state/province level platforms (N = 35) outpaced sub-state and provincial coverage (N = 22) (See Figure 3.4 for complete distribution)

Given environmental and system complexities, there is often a need to expand the scope of analysis to larger jurisdictions (de Loe & Patterson, 2017; Neef, 2009). Government agencies, due to their organizational structure and broad mandates, may be inclined to provide Data and Information at larger scales, which is suited to their needs for national and regional planning and policy-making. However, for individuals and local entities, large-scale Data might not be sufficiently localized to inform and drive context-specific decision-making. If Data is processed into Information for a larger scale, it may miss local nuances. Users might then struggle to draw appropriate inferences at local scales, hindering the overall effectiveness of Data-driven decision-making processes. An interesting example of locally-provided platforms is the suite of tools provided by the Michigan Department of Environment, Great Lakes, and Energy (EGLE), which investigate local pollution events and related water quality testing and provide Data at sub-state levels.

When Data and Information are provided at a scale too broad for local application, the platform may not support the necessary relation to personal experience that facilitates the progression towards Knowledge and Wisdom. Bounded rationality theories suggest that individuals make decisions based on the limited information available to them and their ability to process this information (Bercht & Wijermans, 2019). The bias towards large-scale data can therefore limit users' ability to relate the data to their immediate environment and experiences.

The scale of Data and Information provision also raises questions about whether platform content allows individuals to gain the necessary Knowledge to engage in participatory water governance. It has been proposed that intermediaries facilitate engagement to transboundary environmental issues and engage individuals in democratic processes with larger institutions (Ostrom et al., 1961). While it cannot be presumed that ICT platforms are intended to fill the role of intermediary organizations as described by Ostrom et al. (1961), if ICT tools can be appropriately designed to address the issue of scale, they can be used to facilitate Knowledge and Wisdom generation needed to get involved in formal decision-making.

Despite the large scale of ICT tools identified in the GLB, some platforms manage to relate this broader content to individuals. For example, some platforms enable users to sort by location or enter their address to view impacts relevant to them (Section 3.4.2). Beyond the format of the platform, the type of Information presented can also facilitate the connection to personal impacts. Platforms that provide Information directly related to the use or impacts of a water resource – such as flood risk, water safety for recreational use, pollution sources and subsequent water quality monitoring results in drinking water – cater to individuals by offering Information that is contextualized to a user's daily life.

3.5.4 Limitations

This review has several limitations that should be acknowledged. First, certain assumptions were made in the data collection process pertaining to overlap between platforms, geographic distinctions, and inconsistencies in data provided through the platform (Section 3.5). Overlap resulting from the same data feeding into multiple platforms may inflate the perceived amount of duplicated efforts. Assumptions related to geographic distinctions included taking the largest scale available on the platform, unless there was one specific to the GLB, and a lack of distinction between National US and National conterminous US. Importantly, these assumptions do not impact the amount of tools and their coverage within the GLB, which is the region of interest. Additionally, inconsistent data within platforms may mean that the data items collected for each platform are not accurate for the entirety of the platform's geographic or temporal coverage. This could affect the reliability of results and the conclusions drawn from them. Nonetheless, this review aims to provide preliminary insights into the topic and offer a general overview of this space. By covering a broad scope, it may sacrifice some detail, but it is intended to guide future work towards more comprehensive reviews and assessments of direct overlap and gaps.

Furthermore, the platforms reviewed are not representative of the platforms available for all data types listed. The focus and the inclusion criteria for this review specified platforms concerning freshwater data, specifically water quality and quantity data. Other data topics, such as socioeconomic, geomorphology, land cover, and infrastructure, are therefore underrepresented. The actual quantity of available data in these categories is likely higher than reported in this review.

There are also potential limitations in the search mechanisms used to identify platforms, specifically those in gray literature. While a VPN and a private browser were used, Google searches still preferentially show results based on relevance, quality, user engagement, backlinks (links from other reputable sites), and overall search engine optimization (Google, n.d.). Higher web traffic from the U.S., due to its larger population, may have amplified the visibility of U.S.-based platforms over Canadian ones. Additionally, the process of snowball sampling involved, in some cases, identifying platforms through organization websites. As a result, platforms identified may disproportionately show those organizations' tools. While these search mechanisms influenced findings, they also reflect how an individual seeking one of these platforms may search for them, and therefore may indicate which platforms are more likely to be found online.

The choice of key informants, who were U.S.-based, may also have shaped the findings by highlighting U.S.-specific platforms. While this approach allowed for validation of selected platforms, identification of additional platforms, and the development of initial search terms, it may have inadvertently omitted key Canadian platforms, such as those managed by Conservation Authorities or the Ontario government. These limitations highlight the need for further research focused specifically on Canadian platforms, especially in light of emerging initiatives with the Canada Water Agency.

Lastly, potential biases in data collection were addressed by following PRISMA (2020) guidelines as closely as possible. Despite these efforts, some inherent biases may still exist due to the subjective nature of categorizing and interpreting the data, particularly due to the predominance of work done by a single researcher in this study. This limits the reproducibility of this study. To address these limitations, a clear and transparent methodology was employed, and efforts were made to cross-check and validate findings where possible. Future studies would benefit from involving multiple researchers for the entirety of the process.

3.6 CONCLUSION

This systematic scoping review of ICT tools in the GLB enhances existing literature by assessing the provision of open water data, revealing potential saturation of platforms, particularly those provided by U.S. government agencies and at larger scales. By integrating academic and gray literature and adapting the PRISMA (2020) review process, this work offers a methodological framework for identifying and assessing these platforms. Through application of the DIKW framework, the review highlights the role of digital tools in transforming Data into actionable Knowledge for stakeholders, emphasizing that while large-scale platforms are useful for formal decision-makers, they may lack relevance for local contexts.

The findings underscore the need to streamline ICT to reduce redundancy and improve their applicability for individual users by providing localized, interpretable Data and Information. Future investments should focus on integrating existing platforms and enhancing their unique features rather than creating new, overlapping tools. Collaboration between organizations, including between government agencies, can help consolidate efforts and provide more cohesive, user-friendly solutions. Future research should investigate user outcomes, and assess the relationship between platform and Data availability, aiming to better align digital tools with user needs and real-world impacts.

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Connecting Text to Chapter 4

Chapter 3 provides a systematic analysis of the ICT tools being used to make water data available in the GLB and offers insight into the resulting ecosystem of open data. Chapter 4 builds on this study by applying the DIKW framework to the outcomes and challenges of these platforms according to practitioners. This is accomplished through semi-structured interviews with practitioners of ICT in the GLB.

Chapter 4 is a draft journal article that will be submitted for publication in an academic journal (likely the Journal of Great Lakes Research). I am the lead author on this chapter. Bryant Serre assisted with study design and methodology, data collection and analysis, and reviewing and editing the manuscript. Jan Adamowski and Gordon Hickey assisted with conceptual framing, study design, and reviewing and editing the manuscript.

Chapter 4 – Inciting Action through Information Communication Technology: Insights from Practitioners in the Great Lakes Basin

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Abstract

The principle that open data needs to be used to be valuable has led to the emergence of intermediaries that seek to make complex data easier for non-experts to understand. Among these intermediaries are Information Communication Technology (ICT) tools – digital platforms that aim to increase the accessibility and useability of data online. In the Great Lakes basin (GLB), a region with a rich history of public engagement and a model for transboundary governance, there is evidence that digital alternatives to engagement are not reaching their full potential. This study explores the ability of ICT tools drive platform user decision-making in the GLB. To investigate this issue, semi-structured interviews with practitioners of ICT tools are conducted. The Data-Information-Knowledge-Wisdom hierarchy is applied as a conceptual framework to understand how data leads to action by individual stakeholders. Findings suggest that while these platforms increase data accessibility, the outcomes of these platforms are largely unknown. This paper proposes an adapted DIKW process based on interview findings, emphasizing the importance of in-person engagement and group accountability for sustained engagement and to incite action, as well as attention to on outcomes and measures of success. Overall, this work argues for a repositioning of the value of these platforms as complementary, rather than substitutionary, to other approaches to engagement.

Keywords: *Integrated Water Resource Management; Transboundary water governance; DIKW Hierarchy; Water Governance; Open Data Platforms; Semi-Structured Interviews; Digital Tools*

4.1 INTRODUCTION

Open data can lead to more successful participatory governance through an ongoing process of informing the public and providing opportunities for action (Attard et al. 2015). Driven by the logic that open data exists to be used in order to attain its value (Janssen et al., 2012), intermediaries have emerged to facilitate the transformation of data into more digestible formats for non-scientists (Davies & Edwards, 2012). Among these intermediaries are digital platforms, broadly characterized as Information Communication Technology (ICT) tools, which include data-driven, web-based platforms like data dashboards, interactive web maps, virtual simulations, and data viewers. These intermediaries serve to increase the accessibility of data, enhance knowledge creation, and support stakeholders in interpreting and using data effectively (Attard et al., 2015; Davies & Edwards, 2012; Janssen et al., 2012).

Despite efforts to increase the accessibility and utility of data provided online, there is evidence that open data is not reaching the full potential of its use (Attard et al., 2015). Criticisms suggest that open data may reinforce existing power dynamics and worsen the digital divide, and that its use does not extend past specialists (Janssen et al., 2012).

Water governance in the Great Lakes basin (GLB) is one such case where digital tools for communicating freshwater data have been implemented. Despite the basin's rich history of public engagement and environmental remediation (Millar et al., 2023; Watras et al., 2022; See Thesis Section 2.1 for a comprehensive review), contemporary policy efforts face challenges in data accessibility and public use (Fusi et al., 2022), hindered by foundational knowledge gaps (Learning for a Sustainable Future, 2022) and fears of data misinterpretation (Goucher et al., 2021). Existing studies on digital platforms for environmental data in the GLB have focused on the accessibility of platforms (Mukhtarov et al., 2018; Simonofski et al., 2022; Zhu & Freeman, 2019) or on community-based monitoring efforts (Murphy-Mills et al., 2019). However, work on the outcomes of these platforms is largely absent from existing literature.

The purpose of this study is to build on previous research that has identified and assessed the diversity of digital tools available to support decision-making in the GLB to investigate their various roles in participatory water governance. This research aims to answer the following question: *How do practitioners perceive the role of ICT tools in driving platform user decision-making in the GLB?* To answer this question, semi-structured interviews were conducted with practitioners of ICT tools across the GLB to understand the processes of data transformation and mobilization that are being used to inform water-related decision-making, and subsequently assess their limitations and measures of success.

4.2 CONCEPTUAL FRAMEWORK

The Data-Information-Knowledge-Wisdom (DIKW) hierarchy provides a valuable framework to understand the roles of data in supporting decision-making (Ackoff, 1989; Bratianu, 2018). For this study, it will be used to help understand how open water data is being transformed into formats deemed suitable for non-scientists to support water management in the GLB. The DIKW framework distinguishes between Data, Information, Knowledge and Wisdom as follows:

Data – defined as pure symbols and numbers – require processing to gain significance (Bratianu, 2018; Wessels et al., 2017). Data are transformed into Information by acquiring meaning through processing and adding context, answering questions of “Who?”, “What?”, “Where?”, and “When?” (Ackoff, 1989; Choo, 1996). There is a persistent lack of understanding of specific mechanisms for the transition from Information to Knowledge (Bratianu, 2018). Generally, Knowledge is created by an individual by situating Information relative to existing Knowledge, specifically Tacit Knowledge (personal experience), to create something that can be acted upon (Ackoff, 1989; Bratianu, 2018). The transformation into Wisdom is more elusive, and involves acting on Knowledge and incorporating morals in this decision-making (Bratianu, 2018); Wisdom is therefore the ability to judge what action to take and when (Rowley, 2007).

A practical example of this process is flooding. As Data, it consists of raw measurements like water levels and rainfall amounts. When processed and contextualized, this Data becomes Information, such as the probability of 100-year floods. Information is then further analyzed into Knowledge by understanding individual implications, such as patterns of flood events in their floodplain, and recognizing the influence of local infrastructure and personal circumstances on risk. Finally, Wisdom involves making informed decisions based on this Knowledge, such as purchasing flood insurance, investing in flood defenses, or engaging in community planning to mitigate flood impacts. Data, Information, Knowledge, and Wisdom according to these definitions are capitalized to distinguish them from broader references in this text.

The DIKW hierarchy is applied in this work to investigate the transformation and mobilization of open data through digital platforms. Building on the understanding of open data as valuable through its use (Janssen et al., 2012), the value of open data is created through its transformation along the DIKW Hierarchy. The identified gap of literature on the outcomes of open data platforms is therefore explored using this conceptual framework, where outcomes, such as decision-making by platforms users, are understood as indicators of Knowledge and Wisdom being attained.

4.3 METHODS

This work utilizes qualitative case study methodology (Baskarada, 2014). Semi-structured interviews were conducted with practitioners of ICT tools for participatory water governance in the GLB, positioning them as key informants with unique insight and influence over ICT tools (Guest et al., 2006; Ahlin, 2019). Content analysis of interview data was guided by the conceptual framework (Hseieh & Shannon, 2005). This work is therefore exploratory (Murphy-Mills et al., 2019), and seeks to identify current pathways and barriers to action from open data provision using the DIKW framework.

Semi-structured interviews were selected for their flexibility, allowing both open-ended and focused exploration of key topics (Fontana & Frey, 2005; Rubin & Rubin, 2012; Sayrs, 1998). This method enabled clarification of terms, rephrasing of questions, and follow-up as needed, making it well-suited for discussing complex topics such as ICT tools for open data provision. By speaking with practitioners, who are positioned as key informants, this approach aligns with best practices in key informant literature (Guest et al. 2006; Ahlin, 2019). The selection of 12 key informants prioritized relevance and expertise over breadth, focusing on platforms engaged in participatory governance. While a survey might have reached more respondents, it would have lacked the depth needed to explore the complexities of ICT tool governance. In-depth case studies were not pursued to maintain focus on broader trends across platforms, making semi-structured interviews the most appropriate method for capturing both diversity and detail.

4.3.1 Participant Recruitment

Participants were selected based on the following inclusion criteria: Participants must (1) work on a platform that is operational in the GLB, (2) be a Program Coordinator or equivalent for a relevant digital tool, (3) be able to speak to both the implementation and monitoring of ICT tool(s) at their organization, and (4) be proficient enough to converse about their work in English.

Participants were recruited through public websites of the tools they were associated with. If the appropriate contact was unclear, a general contact at the organization was asked to identify a suitable respondent. Upon correspondence an Information Sheet (Appendix V) was included disclosing the purpose of the project, expectations of participants, details of confidentiality, and any anticipated risks and benefits. Prior to interviews a Consent Form (Appendix VI) was sent to and returned by participants. A simplified interview guide was also shared with participants, which included broad themes and sub-topics. All documents and methods received ethics approval from the Research Ethics Board at McGill University (REB# 23-08-012).

12 key informants from different ICT tools were recruited. The participant breakdown by organization type was as follows: Government agency: 5; Non-profit: 4; Academic: 1; Collaborative Project: 1; Other: 1. Eight participants were based in the US, and four were based in Canada.

4.3.2 Data Collection

The interview guide was developed following Kallio et al.'s methodology (2016), where pre-testing with professionals in this sector helped guide content selection and question development (See Appendix VII) (Baskarada, 2014). The final interview guide can be found in Appendix VIII. Key informants were interviewed virtually over Microsoft Teams, where the number of interviewees was determined by saturation (Guest et al., 2006). Audio recordings were transcribed and verified by the second researcher.

4.3.3 Data Analysis

Content analysis of interview data consisted of multiple cycles of qualitative coding, following a methodology informed by Saldaña (2013). An initial 'lumper' coding helped establish broad categories, followed by inductive 'eclectic' coding as a first pass of the data, and deductive sub-coding to apply the DIKW conceptual framework described in Section 4.2.

Inductive codes were drawn from a subset of two interviews to identify preliminary themes and codes. A preliminary codebook consisting of broad topics and preliminary sub-topics was developed. This preliminary codebook was used to inform the first round of coding, which used a descriptive coding approach to categorize interview data by topic. This round, which can be described as 'lumper coding', focused on assigning these broad topics to data rather than investigating the content (See Table 4.1 for lumper codes). Intercoder reliability was checked at this stage and disputes were resolved through agreement of both coders (Barbour, 2001; O'Connor & Joffe, 2020).

Table 4.1: Lumper Codes and Definitions

Lumper Code	Definition
Context	Details about the platform or organization, including its name, type (of organization), the interviewee's role, geographic scope, data of interest, and reasons for tool development.
Tool Use	Describes the intended and actual uses of the tool, including the target audience, engagement goals, links to decision-making, and platform outcomes.
Success	Assesses the tool's success through interviewee's perceptions and measure, highlighting what works and what may be lacking.
Tool Characteristics	Identifies factors affecting the platform's success, such as tool design, incorporation of feedback, capacity and funding, and outreach.
Changes	Covers modifications interviewee's want to make, have made, or plan to make to the platform, such as data expansion, increased outreach, and improved data visualization.

Subsequently, inductive eclectic coding was used to investigate the contents of the data. Eclectic coding describes using a combination of coding approaches together as applicable (Saldaña, 2013). The codebook was then iteratively developed through code mapping to reorganize the codes and reduce duplicates in MaxQDA (2024). All codes were subject to inter-coder reliability, requiring members of the research team to reach consensus on assigned codes (Barbour, 2001; O'Connor & Joffe, 2020).

At this stage, the DIKW framework was applied to the codebook to delimit codes according to framework categories, as presented in Appendix VIII. Codes pertaining to Tool Use and Tool Characteristics were categorized along the DIKW framework, split between concepts and transitions between concepts. Each category's application builds on the definitions provided in the Conceptual Framework (See Table 4.2).

Table 4.2: Application of DIKW to Codes

DIKW Component	Application to Interview Codes
Data	Tool Use codes relating to aggregating, storing, compiling, collecting, and managing raw data; increasing the findability, visibility, and transparency of raw data; emphasis on data provision; collaboration in the form of data sharing.
Data to Information	Tool Characteristics codes relating to these five methods of transforming data, as well as efforts to make these processes of Data transformation more accessible to the average user, such as those related to simplicity, interactivity, and visual representations of Data.
Information	Tool Use codes that rely on this incorporation of context but do not move further towards action.
Information to Knowledge	Tool Use and Tool Characteristics that serve as mechanisms for connecting the public and personal experience to the Data and Information presented on platforms, including in-person engagement and outreach efforts.
Knowledge	Tool Use codes that describe the attainment of Knowledge that is context-specific and actionable, but does not include the action itself being taken.
Knowledge to Wisdom	Tool Use codes that combine the public engagement that define Knowledge with steps towards taking independent action and critical thinking, including a deliberation process that infers incorporation of morals.
Wisdom	Tool Use codes that explicitly describe an action being taken by users of the platform.

The final cycle of coding was deductive, applying the finalized codebook with DIKW distinctions, and followed the same methods as the first round. Intercoder reliability was checked using a subset of the interview data. A second coder independently coded 10% of the transcripts (2 transcripts) for all codes, and 10% of codes were then randomly selected and checked for consistent application (O'Connor & Joffe, 2020). The second coder assigned all codes to account for nuanced distinctions between codes. All instances and uses of these 16 codes were then checked for agreement based on pre-agreed upon definitions. The resulting numbers for agreement and disagreement therefore pertain to code occurrence. In the two interviews assessed, there was a 95.45% agreement rate. Cases of disagreement were resolved through discussion until consensus was reached (Barbour, 2001; O'Connor & Joffe, 2020).

4.4 RESULTS

Content analysis yielded code occurrences according to the DIKW framework, identification of other influences on the transformations of Data, and measures of platform success. The final codebook – including definitions, examples of relevant text, and code occurrences – can be found in Appendix IX.

4.4.1 Code Occurrences According to the DIKW Framework

Application of the DIKW framework to interview data revealed that practitioners mentioned tool uses consistently across Data (two uses identified), Information (four identified), Knowledge (five identified), and Wisdom (four identified). Codes pertaining to the transitions between these entities were less consistent: Data to Information consisted of 18 relevant codes; Information to Knowledge had 11 codes; and Knowledge to Wisdom had one relevant code. Distribution and occurrence of codes according to the DIKW framework can be found in Table 4.3.

Table 4.3: Interview Codes and Occurrence According to the Conceptual Framework

Data	
Collecting Data	4
Data Availability	9

Data to Information	
Internal Analysis	3
External Analysis	5
Utilize New Technology	3
Scientific Language	6
Information Balance	7
Simplicity	10
Data Trends and Summaries	6
Interactive Data	7
Images	3
Visual Elements	6
Linked Information	8
Instructions on Tool Navigation	3
Additional Information	9
Interoperable and Reusable Data	8
Quality Assurance	7
Search Capacities	10
Customize Interface	1
Accessibility Features for Disabilities	5

Information	
Communication Tool	9
Data Accessibility	8
Contextualize Conditions	1
Identification of Threats	4

Information to Knowledge	
Joint Problem Solving	8
Group Management	3
Generating and Maintaining Interest	6
Increasing Accessibility of the Environment	2
Public Engagement	4
Gap Analysis	4
Program Partnerships	3
In-Person Engagement	9
Citizens Upload Data	2
User Feedback, Positive	9
Messaging	4

Knowledge	
Inform Local Populations	9
Education	5
Program Design	6
Broader Understanding	5
Data as Evidence	5

Knowledge to Wisdom	
Create Shared Identity/Vision	2

Wisdom	
Decision Making	8
Legal Uses	5
Incite Action	6
Enhance Equity and Resilience	2

4.4.2 Other Influences on the Transformation of Data

Other influences on the transformation of Data through ICT tools were also identified in the interview data. These factors are categorized into three sections: general Mechanisms and Prerequisites that enable DIKW transformations, Barriers that impede or delay this process, and Drivers of Change that influence platform modifications and advancements.

Mechanisms and Prerequisites

Beyond the Tool Characteristics identified as mechanisms specific to a step in this process (see Table 1), respondents identified a number of other contributing factors that can help the process of Data transformation across DIKW. Italics identify codes, and parentheses reflect how many interviews the code appeared in.

Resources: *Human* (4) identified cases where there were in-house specialists able to support platform development and operations; *Financial* (3) described how the online format and collaborative nature of the field reduced financial barriers.

Technology: *Technology Needed for Use* (7) revealed low technological barriers to entry; Participants described reduced costs to use platforms due to openness and minimal requirements (*Cost of Use*, 4); In some cases, technology was described as supporting platform use and accessibility (*Technology as Facilitator*, 4).

Simplicity: *Knowledge Needed for Use, Positive* (7) identified low levels of required knowledge for utilizing their product or service effectively.

Interactions with Users: While *User Feedback* (9) and *In-Person Engagement* (9) were included above as mechanisms of Knowledge production, these two codes were described by respondents as key to the success of the platforms.

Barriers

Respondents also highlighted various barriers that impede or slow the process of Knowledge creation and mobilization. These issues can be divided into Barriers for Data Providers, Barriers for Data Users, and Broader Challenges that impact both groups.

Barriers for Providers: Participants expressed a lack of adequate human capacity, such as the absence of on-staff developers, being small organizations or teams, constraints related to contract length, limited human capacity, and lack of time (*Human Capacity, Negative*, 10). Challenges related to financial support were also mentioned, including costs of data management, budget constraints, and concerns about financial sustainability of the platform (*Financial resources, Negative*, 8). A lack of resources as a limitation to progress was also identified more broadly (*Overall Lack of Resources*, 4). Within this discussion certain barriers for providers were explicitly linked to organization type. Interviewees representing government agencies described institutional barriers stemming from needing to be risk-averse and prioritize neutral messaging. Respondents from non-profits described passive outreach resulting from a lack of resources, and a respondent from academia articulated that this type of work is not valued in academia and therefore not afforded any resources.

Barriers for Users: When asked about user requirements, respondents primarily noted the existing knowledge of users as a barrier. Some (10) described a level of required expertise or prior understanding that may hinder effective use of the platform, including the need for a certain level of education or specialized knowledge to utilize the platform's full potential and, in some cases, extract meaning (*Knowledge Needed for Use, Negative*). Technological barriers were noted, both in terms of Knowledge, such as basic technological literacy missing particularly among older participants, and technological access, such as limited internet access and the need for specific devices like laptops (*Technology as Barrier*, 5). Finally, language barriers posed significant challenges due to linguistic differences, as most platforms were only available in English. This issue was further complicated by the difficulty of translating scientific content (*Language Barrier*, 3).

Broader Challenges: Participants also described certain barriers that do not fit neatly into these categories and, rather, impact both groups and characterize the nature of these tools were also included. Respondents described overlap in the space and an abundance of tools, highlighting a need to carve out a distinct niche to ensure relevance and utility of their platform (*Finding a Niche*, 7). Various challenges related to data quality and management (*Issues with Data*, 6).

4.4.3 Measures of Platform Success

Perceived Success

Interviewees were asked directly about the perceived success of their platforms in meeting the intended goals. Of the 12 participants, most (7) said 'Yes', four said 'Somewhat', and one said 'No'. Responses of 'Yes' and 'Somewhat' were contextualized by respondents. Elaborations included stating that while the platform is effective in meeting its intended goals, those goals have since shifted, and the platform is not meeting those new goals. Other respondents articulated a similar experience of differing goals of the organization and of the community, with the platform only meeting organizational goals, and a need to reconcile these two.

Specific Measures of Success

Interviewees were asked to elaborate on how they measured success, revealing provider-centric and user-centric measures. The following list outlines these measures, with the number of interviews in which each measure was mentioned indicated in parentheses.

Provider-centric measures, defined by data providers, include quantitative metrics such as Traffic Analytics (11), User Analytics (7), Data Analytics (4), and Tracking Downloads (2), all of which were often attributed to Google Analytics. Tracking External Use (6), Known Users (4), and Tracking Outcomes (1) were used to assess platform use in more depth. Internal Feedback (2), Sustainability of Project (1), and Cost of maintenance (1) were also considered. User-centric measures, categorized as Direct Contact (10), include reliance on user feedback, user-driven expansion, and troubleshooting. Many of these measures depended on users reaching out, often for troubleshooting. Additionally, some measures like Service provided (4), Breadth of Use (2), Usability (1), and Good Relationships (1) did not fit neatly into the provider-user distinction.

Despite the measures identified, interviewees expressed doubts about the accuracy of their tracking mechanisms and noted a lack of guidance on setting goals:

> “Because [it’s] an open access platform, we don't have any specific requirements around use of the data. So we're not always sure how the data is being used and who's accessing it, unless we have some kind of some kind of a dialogue with them.” (Non-Profit respondent, Canada)

Furthermore, some respondents admitted that tracked data were not reviewed or integrated into future planning.

Missing from Measures of Success

Respondents were then asked to identify what may be missing from the measures of success they previously mentioned. Respondents highlighted a gap in tracking platform usage outcomes, with one interviewee stating:

> “The harder piece is where do we then see movement out in the real world, right? Because this is really intended to call people to action within this very small universe, we're trying to reach and drive change [...]. And so that will be a real effort in and of itself, to be able to see [that outcome]. I can't tell you that it's actually happened yet.” (Collaborative Project respondent, U.S.)

Interviews also identified a need to better understand user demographics and expectations, and uncertainty about whether the platform has met users' goals. Included in this was mention of overlooked communities who may face additional barriers to platform use.

4.5 DISCUSSION

4.5.1 Gaps in the DIKW Process

The application of the DIKW framework to open data platforms in the GLB revealed that while practitioners articulate a desire to incite actions through these platforms, their mechanisms to transition between entities become more limited as they approach Knowledge and Wisdom (Table 4.3). Previous work on the DIKW hierarchy confirms the lack of concrete mechanisms for attaining Knowledge and Wisdom (Bratianu, 2018). Our interview participants reiterated the existence of this gap in ICT:

> "To be able to perform the search, it's not very high at all right? Like if they know the name of their lake or stream they can see the data, they can access the data. So that's pretty basic, a few clicks and you're there. Where the challenge comes in is understanding" (Other respondent, U.S.)

Additionally, although Tool Uses are distributed evenly across the DIKW continuum (Table 4.3), inconsistent tracking and evaluation of platform success (Section 4.4.3) may not accurately reflect the outcomes of ICT tools. Accordingly, it is unclear if the tools reached Knowledge and Wisdom along the DIKW framework.

Concern over the ability of these tools to reach Knowledge and Wisdom aligns with broader criticisms of open data and ICT, namely that the innate value of open data is overvalued (Janssen et al., 2012) and that Data only gains value when it is comprehensible, which typically requires existing background knowledge (Attard et al., 2015). Additionally, existing literature highlights that ICT platforms fall short in sufficiently facilitating participation in decision-making processes (Mukhtarov et al., 2018).

4.5.2 Adapting the DIKW hierarchy to the GLB

In order to explore the identified gap in attaining Knowledge and Wisdom, successful cases as identified by interviewees were used as a basis to modify the DIKW process, which is traditionally visualized as a pyramid (Figure 4.1a) or along a continuum (Figure 4.1b).

Figure 4.1: Representations of the DIKW Framework

Figure 4.1a: The DIKW Hierarchy

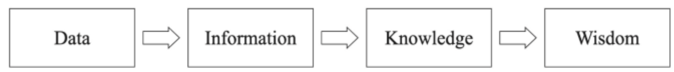
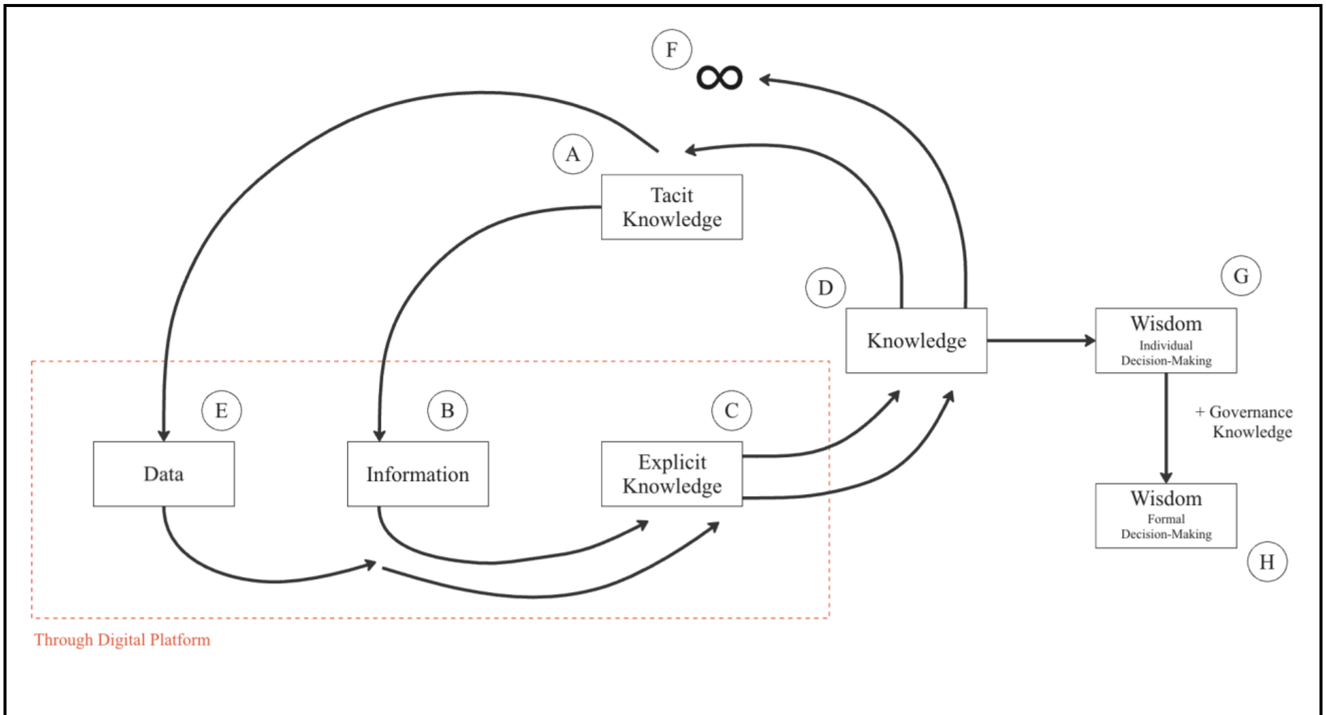


Figure 4.1b: The DIKW Continuum

In adapting the framework, Knowledge is split between Tacit Knowledge – which is derived from personal experience – and Explicit Knowledge – which is the continuation of Information and is based on empirical data (Bratianu, 2018). Other scholars reinforce that Knowledge is created through the incorporation of personal experience (Choo, 1996), and that the process of Knowledge creation is “achieved by relating the input to existing knowledge” (Maruta, 2014, p. 28).

The adapted DIKW framework is presented below (Figure 4.2), and depicts how the transformation and mobilization of open water data functions in the GLB based on our analysis. According to the proposed framework, Knowledge creation and mobilization can be divided into eight sequenced phases.

Figure 4.2: Adapted DIKW Framework for the GLB



A. Beginning with Tacit Knowledge, individuals engage with platforms based on personal experience.
B. Initial interest drives individuals to access Information provided through the platforms, such as landing pages, dashboards, and summary reports.
C. Explicit Knowledge is reached through further investigation of the platform (i.e. science explainers, interactive data) and engagement facilitated by the organization (i.e. educational efforts).
D. Knowledge is reached by combining Tacit Knowledge and Explicit Knowledge. This step involves platform-specific mechanisms linking displayed information to specific contexts and in-person efforts.
E. Users are then able to relate newly acquired Knowledge back to Tacit Knowledge, and seek out more Data or Information to further their understanding. The link to Data includes community science groups, where individuals will then be involved not just in accessing Data, but generating it as well.
F. Linking Knowledge from digital platforms to personal experience begins this iterative, ongoing process of Knowledge creation. Users are motivated to learn more as it fulfills their initial interest and relates to their lived experience. Digital tools facilitate this, but links to personal experience drive engagement.
G. Wisdom is attained when an action has been taken, such as changing consumption patterns or sustained engagement in citizen science efforts. While Wisdom is therefore a product of this process, it is not an end; the process of Knowledge creation continues and can generate further actions come from this
H. The addition of Governance Knowledge – Knowledge on governance and formal decision-making processes – can transform individual actions into changes in decision-making contexts, such as policy changes.

4.5.3 Implications of the Adapted Framework

The proposed framework addresses gaps in the transition from Information to Knowledge and from Knowledge to Wisdom by expanding and exploring implicit steps in the DIKW framework. Key findings to emerge from the adapted framework include: The iterative nature of Knowledge creation; the need for sustained engagement; clear goals to mobilize Knowledge; and the limited reach of ICT tools.

Iterative Nature Knowledge Creation

According to the adapted framework, Knowledge creation is not a linear process of linking different types of Knowledge. Instead, it is an iterative cycle where one gains Explicit Knowledge, relates it to pre-existing Tacit Knowledge, and allows this new understanding to inform future interpretation of Information and Data. Respondents highlighted the benefits of users connecting Explicit Knowledge to personal experiences, fostering deeper understanding and increased interest:

> "I think that our volunteers are more likely to stick with our program and stay involved when they see the value and they feel like wow, I really understand my stream or lake better because of my participation in this program." (Other respondent, U.S.)

In-person engagement is valuable in its ability to facilitate this link between personal experience and Explicit Knowledge, thereby creating Knowledge (Pope & Gilbert, 1983). ICT tools that were successful without in-person engagement employed alternative measures to connect Tacit Knowledge and Explicit Knowledge, such as interactive simulations and geo-location of local data.

Need for Sustained Engagement

Given the iterative nature of Knowledge creation, sustained engagement of users is necessary. However, some interviewees mentioned the challenge of retaining users, with one respondent revealing that most participants only submitted data once. In such cases, participation is unlikely to be an engaged process of Knowledge creation, and rather a once-off deposition of Data.

Research indicates that direct interactions help individuals better connect personal experiences to Explicit Knowledge, thereby enhancing comprehension and retention (Pope & Gilbert, 1983). Respondents reiterated the importance of in-person engagement for maintaining platform users:

> "And I think that when you get people who don't usually have to go to the water and test it to go and do those things, what we found is that they suddenly take the time to notice what's happening to the water. And that often leads to them taking actions other than just water testing. They want to get more involved and do more to help the water to help the environment." (Non-Profit respondent, Canada)

Many of the successful cases also targeted groups of users rather than individuals. While this was partly due to resource constraints and logistical considerations, it was also articulated that groups add a layer of mutual accountability and more formal engagement in a process that otherwise heavily relies on individual motivation. The ability of in-person mechanisms and groups to encourage sustained engagement aligns with work by Pradhananga and Davenport (2017), who found that strong environmental and social ties predicted higher civic engagement in water issues in the Minneapolis-St-Paul metropolitan area.

Clear Goals to Mobilize Knowledge

The subsequent step of mobilizing Knowledge and achieving action is split into two parts in the adapted framework: Individual Decision-Making and Formal Decision-Making. Individual Decision-Making is the initial outcome of this cycle of Knowledge creation, and includes independent, sustained behavior such as consistent water sampling or reductions in household water consumption. Formal Decision-Making is understood as changes at the level of policy or governance decisions.

Interviews revealed the importance of Governance Knowledge in reaching Formal Decision-Making: The link to outcomes in policy and regulations was easier to establish when tools were managed by governing authorities, used by government agents, or when there was a clear goal of enacting specific changes, such as collecting evidence to oppose local development. Explicit intention to motivate change at the level of Formal Decision-Making should therefore be established early on, either at the organization or project level. The evolution of platforms from open data platforms to more complex ICT may explain why many platforms struggle to transition from Data provision to inciting action. Governments may therefore be best suited for providing open data platforms due to their ability to connect with Formal Decision-Making processes, but they are limited in terms of what they can provide through a platform alone.

Limited Reach of ICT tools

Finally, as identified in the adapted framework, digital tools are not initiators of the DIKW process. Involvement begins with Tacit Knowledge and is therefore reliant on users seeking out engagement opportunities or on outreach efforts that relate the platform to users' lived experiences. Passive outreach described by some respondents emphasizes the dependence on existing user motivation:

> "We don't go out and recruit people to use our platform that much. We wait more for people to reach out and say they have a need to use our tools because we found that when we push, then people can maybe start using a platform but then it falls through. There needs to be that initial interest for them to use it and then once they reach that, we just support them as much as we can." (Non-Profit respondent, Canada)

The reliance on users to initiate this process indicates a more limited reach of ICT tools than described in interviews. Nine respondents included the 'general public' in the audience of their respective ICT tools, in some cases alongside more specific users. While well-intentioned, the inclusion of a broad, undefined public as an audience may overstate who is actually using these ICT platforms. When outreach is passive, ICT platforms therefore risk only engaging a subset of the population that is already interested in environmental issues. Interviews revealed further evidence of catering to an existing database rather than doing more broad engagement, including outreach through existing users and networks, and tailoring tools based on user feedback. Without effective outreach and equity considerations, these platforms may ultimately further a digital divide (Janssen et al., 2012). A repositioning of these platforms as complementary to other forms of education and engagement is therefore needed.

4.5.4 Assumptions and Limitations

This study has several limitations. First, the sample of interviewees was limited to practitioners who develop and manage ICT for open data, excluding other stakeholders like end-users and policymakers. Consequently, the findings only reflect the perspectives of those directly involved in the technical and administrative aspects of these platforms. Additionally, the emphasis on ICT tools aimed at a broader public rather than technical platforms for more specialized audiences limits the generalizability of findings to ICT more broadly. Finally, with only 12 interviews, the small sample size limits the generalizability of the findings and may not capture the diversity of experiences in the field.

Regarding the coding methodology, the coding process for qualitative data inherently involves a degree of subjectivity. Despite efforts to ensure consistency and reliability, different researchers might interpret and categorize data in varying ways, which could influence the themes and patterns identified in the study. Moreover, the coding framework used may have limitations in capturing the full breadth of insights provided by the interviewees. As a result, this study should be viewed as exploratory rather than explanatory or conclusive.

Finally, a significant limitation identified in the study is the lack of systematic tracking of outcomes related to the use of open data platforms. While platform use and engagement metrics are relatively well-documented, the actual impacts and outcomes – such as the creation of new knowledge, informed decision-making, and societal benefits – are not consistently tracked. This gap makes it challenging to assess the outcomes of open data initiatives comprehensively. The reliance on anecdotal success stories shared by users further underscores the need for more rigorous outcome measurement to understand the broader implications of open data use.

4.6 CONCLUSION

This exploratory case study sought to investigate the outcomes of ICT tools for freshwater data in the GLB, specifically the process of Data transformation and mobilization facilitated by these platforms and perceptions of platform success. Main findings from this research include the identification of a gap in Knowledge and Wisdom transformations among ICT tools in the GLB, the development of an adapted DIKW process in this context, and insight into successful Knowledge creation and mobilization.

This work has several specific implications for practitioners of ICT for freshwater data in the GLB and beyond. First, measures that facilitate the linking of Explicit Knowledge and Tacit Knowledge should be incorporated into digital tools. Understanding the audience of each tool can help guide this process; digital mechanisms may suit audiences that are not close to the water resources, while in-person engagement may benefit those nearby, and broader educational efforts can be used as a starting point to engage new users. Tracking outcomes should also be a priority, with parent organizations and funding bodies providing incentives and resources to support this.

Future work should prioritize developing improved metrics for evaluating the success of digital platforms containing environmental data in informing decision-making and encouraging data use. Establishing standardized guidelines or incorporating outcome tracking into funding requirements could serve as a starting point for these improvements. Additionally, exploring the motivations behind platform use, how users discover these platforms, and their environmental education levels and perspectives before and after platform use could provide critical insights for refining tool design and implementation. Such research could enhance the effectiveness of digital platforms by aligning them more closely with user needs and expectations.

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Connecting Text to Chapter 5

Chapter 4 contributes the perspective of practitioners on the role of ICT tools in the GLB, providing insight into how these platforms and the related process of Knowledge creation and mobilization operate in practice. Chapter 5 summarizes the main findings from the previous two chapters, synthesizes these findings to discuss the current ability of ICT tools to support action in the GLB, and expands on applications of the adapted DIKW framework proposed in Chapter 4.

Chapter 5 – Summary and General Discussion

5.1 Summary

This thesis critically assesses the current state of ICT tools for freshwater data and their role in driving decision-making in the GLB. Chapter 3 did this by applying systematic scoping review methods to ICT in the GLB to provide an overview of what platforms are currently available. Key findings include potential platform saturation, high provision at large scales and by US government organizations, and creation of a framework to distinguish tool types. The DIKW framework was applied to interpret results, and findings suggest the need to mitigate redundancy and prioritize investments in integrating and enhancing existing platforms, as well as improve the relevance of digital tools for individual decision-making by offering localized, easily interpretable data is crucial. Additionally, the review emphasizes that digital platforms could better connect data outcomes with real-world impacts, such as improved water quality and increased public engagement.

Chapter 4 built on the scoping review by investigating the outcomes of ICT for water governance in the GLB, focusing on data transformation and practitioner perceptions of ICT platform success. This was done through semi-structured key informant interviews and by applying the DIKW hierarchy to the resulting data. The main findings include a gap in Knowledge mobilization, resulting in an adapted DIKW framework for the GLB. Results emphasize the role of in-person engagement and group accountability for transforming Knowledge to Wisdom, and the limited reach of tools through current outreach mechanisms. ICT practitioners in the GLB could further focus on linking Explicit and Tacit Knowledge, understanding their audience, and tracking outcomes to maximize the value of Data provided through ICT platforms.

5.2 General Discussion on the Current State of ICT

ICT tools are the latest iteration of technological advances that seek to make scientific Data more accessible and usable for non-specialized audiences. Application of the DIKW framework shows how different iterations of open data provision have progressed from Data to Information and towards Knowledge and Wisdom. Open data provision began purely as Data as an initial step towards transparency (Attard et al., 2015). More recent work has investigated the accessibility of open data provision (Mukhtarov et al., 2018; Simonofski et al., 2022; Zhu & Freeman, 2019), reflecting a transition to providing Information. Further technological development has created mechanisms that are better able to engage audiences, including interactive platforms, visualizations, increased overall access to technology, and intersections with in-person engagement (Buckman et al., 2019). These advancements facilitate the creation of Knowledge and ultimately Wisdom among platform users, thereby reaching open data's initial aims of being acted upon (Janssen et al., 2012).

The findings from Chapters 3 and 4 provide insight into the current state of ICT platforms in the GLB according to the DIKW framework. Ultimately, it is argued that ICT tools in this basin are in a transitional phase, where they are moving towards fostering Knowledge and Wisdom, but are limited by a lack of clear mechanisms and measures of success.

Findings from Chapter 4 reveal that intended uses of platforms in the GLB are consistent across the DIKW framework. Many of the ICT tools included in this study can therefore be included in this final iteration of open data platforms that seek to not only provide Data and Information to broad audiences, but also reach Knowledge and Wisdom to incite action among users. The emphasis on platform user actions aligns with larger shifts towards participatory governance, where individuals are encouraged to actively engage in decision-making processes. Despite this shift, there is a relative lack of mechanisms for generating Wisdom (Section 4.4.1) and of measures for tracking resulting outcomes (Section 4.4.3). For example, although platforms aimed to ultimately incite action among users, their success metrics remained concentrated on Data and Information rather than Knowledge and Wisdom.

These disconnects between the intentions of tools and specific mechanisms for the process suggests that current ICT tools in the GLB are in a transitional phase. Simply put, mechanisms and measures have not caught up with evolving intentions of these platforms. Existing literature emphasizes that ICT platforms do not go far enough to facilitate participation in decision-making processes (Mukhtarov et al., 2018). Chapter 3 provides further evidence of this transitional period. The abundance of ICT tools geared towards non-experts demonstrates how open data provision has evolved along the DIKW hierarchy. However, without appropriate mechanisms to link platforms to individual stakeholders, the abundance of tools may overwhelm users without providing Information easily relatable to their personal experiences (Section 3.5.3). This is evidenced by a lack of localized tools (Section 3.4.3). Additionally, multiple entities collecting and drawing on similar data for platforms can result in duplicated efforts and modified data, leading to inefficiencies and confusion (Attard et al. 2015).

A persistent focus on providing Data and Information rather than evaluating the outcomes and impacts of these platforms risks these tools becoming ends in themselves, similar to open data portals (Lourenço, 2015; Janssen et al., 2012). Respondents emphasized the need for platforms to find a niche to stay relevant, which relates to the broader issue of Big Data and potential reductions in the utility of Data and platforms due to overlapping scopes. To avoid further saturation and duplicated efforts among ICT tools that are currently available, there is a need to diversity platforms and strengthen their relevance to individual decision-making. The adapted DIKW framework provides a tool to identify how existing tools are successful to guide the necessary adaptations of other platforms so that they can move beyond this transitional phase and achieve Knowledge and Wisdom.

5.3 Expanded Discussion on the Adapted Framework

The adapted DIKW framework illustrates successful cases of digital tools mobilizing individuals in the GLB. Platform characteristics identified as facilitating successful engagement according to practitioners include the following: the necessary role of personal experience in both initiating and continuing the process of Knowledge creation and mobilization (Pope & Gilbert, 1983), the utility of in-person mechanisms and group accountability (Pradhananga & Davenport, 2017), and specific digital features to facilitate the linking of Tacit Knowledge and Explicit Knowledge in water management.

As a result of personal experience being the starting point of the adapted DIKW process, the audience of many water-related ICT tools is likely more limited than presumed by some practitioners. Many respondents in Chapter 4 articulated their audience as ‘the general public’. However, outreach strategies reveal that these platforms likely operate through networks of users who already have awareness of and empathy for environmental issues, are already engaged in decision-making, and are relatively well-educated on related topics. This aligns with citizen science literature of disparate participation (Pandya, 2012). The resulting echo chamber – where digital tools primarily only reach people who have an existing interest in and care for the environment – highlights a need to reposition these platforms as supplementary tools to more involved efforts such as community science and educational programs.

This is not to say that there is no place for digital tools, but that they may overpromise in terms of the democratization of information and widespread engagement that many propose. The utility of digital tools may not be for outright education but for use by those already engaged based on their personal experiences. This aligns with the findings of Mukhtarov et al. (2018), who discuss the importance of prioritizing a select group of active stakeholders in digital participation. Similarly, Fung et al. (2013) and Wesselink et al. (2015) argue that Information Communication Technologies (ICT) alone are not enough to drive a shift towards participatory governance. It can be argued that these platforms do not bring new people to the lakes, but instead complement existing education and care for the environment, enhancing the Tacit Knowledge that drives people to these platforms. This may be more appropriate in environments better able to foster education, such as the use of platforms in schools. Lejano et al. (2013) and Feldman et al. (2006) similarly argue that participatory processes play a necessary complementary role to digital engagement, particularly within policy contexts. Nevertheless, the success of these tools when relying on users with Tacit Knowledge is still not well understood; as interviews identified, continued engagement is subject to motivation among users.

Limited Applications of the Adapted Framework

The context to which this framework was adapted and its potential applicability to broader contexts also merits further discussion. Importantly, this work focused only on ICT with open freshwater data, specifically water quality and quantity. This topic provided an interesting case study because water is easily related to personal experience through direct links to health and property in cases of pollution or flooding. The emphasis of links to personal experience are therefore anthropocentric, based on the assumption that people have experiences with water quality and quantity impacts. If applied to other natural resource sciences, the framing may need to be revised to incorporate the eco-centric impacts of environmental changes, such as habitat changes for local species. The DIKW process in such contexts likely requires increased Tacit Knowledge and empathy for nature, which opens up a larger conversation of societal values related to the environment.

The adapted framework is also limited in its ability to include other forms of Knowledge, specifically Indigenous Knowledge. Indigenous groups across what is now Canada and the United States have long been water stewards, pre-dating colonization and the formal decision-making contexts that exist today. Increasingly, western institutions are recognizing the value of Indigenous

Knowledge to inform environmental stewardship (Sillitoe & Marzano, 2009). The rise of open data and digital tools has numerous conflicting implications for ongoing reconciliation processes towards the co-creation of Knowledge (Walter et al., 2021). On one hand, a move towards digital platforms may further exclude Indigenous voices by prioritizing scientific knowledge. Additionally, the underlying logic of open data motivating policy responses and influencing decision-making may discredit other forms of Knowledge and their credibility in decision-making contexts, and does not leave space for issues of data sovereignty and cases where groups that have been historically exploited for the sake of research or data collection and do not wish to share data openly (Ruckstuhl, 2022). These potential impacts align with research where open data is found to reinforce existing power dynamics (Walter et al., 2021; Janssen et. al., 2012). The lack of Indigenous participants and platforms in this work – while not intentional – may therefore be a result of the framing of this work and the language used. That said, more dynamic ICT may offer potential to share alternative formats of Data, Information, and Knowledge. These include a Virtual Reality (VR) game of the creation story (Hampton, 2017), or the recent platform 'Biinaagami'[4] launched by Swim Drink Fish in collaboration with First Nations that seeks to merge TEK and western science through a digital platform. Additionally, displaying Data and Information openly through ICT can alert local populations of threats in cases where Data exists, and be used to identify gaps in cases where Data is not available and not owned by the community.

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Connecting Text to Chapter 6

Chapter 5 provides a summary of key findings and an overall discussion on the implications of this work for the future of ICT. Chapter 6 builds on this to provide an overview of key contributions, as well as a path forwards for practitioners of ICT and academics seeking to further this work.

Chapter 6 – Contributions and Recommendations

6.1 Contributions to Literature

Chapter 3 provides a methodological contribution of utilizing PRISMA (2020) review methods to identify digital tools for freshwater data communication, thus using systematic review methods to identify data products that are themselves gray literature. The adapted PRISMA flow chart (Appendix II) offers a clear and replicable process for this merging of academic and gray literature, which can be applied to other fields beyond water governance. This approach enabled the inclusion of a wide range of sources that are often overlooked in traditional academic reviews, thereby providing the empirical contribution of a more complete understanding of the landscape of ICT tools In the Great Lakes basin (GLB). Finally, an inductively generated framework for collecting data items provides a tentative framework for categorizing tool types.

Chapter 4 introduces an adapted DIKW framework, expanding the basic DIKW framework to better capture the process of Data transformation and Knowledge creation in the context of ICT for freshwater data in the GLB. By incorporating perspectives from practitioners, this chapter also offers an empirical contribution, providing insights into how these platforms are perceived and utilized by the organizations that develop them.

Overall, this thesis advances both conceptual and practical understandings of ICT in the GLB by integrating conceptual models with empirical data. It provides an overview of the role of digital tools, and proposes a repositioning of their value and intentions based on these findings.

6.2 Moving Forwards

6.2.1 Recommendations for Future Research

Exploring Emerging Technologies

One promising area for further investigation is the integration of emerging technologies in order to facilitate the process of Knowledge creation and mobilization through platforms themselves. These advancements offer new ways to engage users without compromising the physical accessibility that digital tools offer. One possible approach is gamification, which involves the incorporation of gaming elements. Existing work on gamification shows that this approach supports enhanced learning through active participation, collaboration, and real-world applications

(Deterding et al. 2011; Lin 2021). However, gamification using real data remains relatively unexplored, and gamification elements were not identified in platforms in this review. Exploring how gamification can be effectively integrated into ICT could provide new insights to enhance user participation and data utilization. Virtual Reality (VR) presents another example of a strategy for digital engagement that has been implemented and linked to behavioral change in users, specifically in environmental spaces (Hsu et al. 2018). The flexible nature of these technologies may allow for inclusions of diverse forms of Knowledge, as seen in the VR game of the creation story by First Nations in Canada (Hampton, 2017).

Additionally, emerging technologies such as Artificial Intelligence (AI) and Big Data analytics hold significant potential for enhancing the success of open data platforms. These technologies can provide meaningful visualizations and insights without dramatically increasing resource use at the organization level. For example, the use of AI to create visual simulations of environmental impacts on local shorelines and cities could make data more accessible and engaging for users, and more easily relatable to their experiences in that region (Government respondent, U.S.). Future work should explore how these technologies can be leveraged to improve the functionality and outcomes of ICT.

Measures of Success and User Perspectives

A key finding of this work was the overall lack of measures for assessing platform outcomes. Future research should focus on developing robust measures of success for ICT platforms relevant for participatory water governance. As one interviewee stated, "There's probably a lot of stuff missing that we haven't thought of. I just don't know what that is." This work should be guided by an investigation of current outcomes and perspectives of platform users to supplement platform provider-driven markers of success and ensure that there are shared goals between platform providers and users. Specific research topics focusing on platforms could include user motivations for platform use, mechanisms for platform discovery by users, and environmental education levels and perspectives before and after engagement.

Further Reviews

Finally, further reviews can help to synthesize ICT, so that both non-experts and experts are aware of existing digital tools. This can help to reduce duplicated efforts, identify points for collaboration, and increase the visibility of these platforms for potential users.

Specific areas for further review identified through this work include: (1) Investigation of the intersections between platforms in order to identify direct overlap and duplicated efforts, as well as get a better picture of where there may be gaps in data availability and accessibility, therefore differentiating between gaps from a lack of data or from the absence of suitable tools; (2) Comparison of ICT and data products between states and provinces, as Chapter 3 revealed that particularly state-level agencies were spearheading this work; and (3) Expansion of this review to include biological indicators of watershed health and overall biodiversity, which would help to inform a broader discussion on eco-centric and anthropocentric platforms.

6.2.2 Recommendations in Practice

Practitioners of digital platforms could better implement mechanisms for tracking the outcomes of their platforms. This could include collecting feedback from participants to understand the effectiveness of the programs and identifying areas for improvement. Establishing guidelines or incorporating outcome tracking into funding requirements may be a starting point to incentivize such changes.

Additionally, this work offers a list of existing platforms, as well as of platform characteristics and mechanisms for Knowledge creation. This includes searching by geographic location, integrating platforms into story maps to provide further context, providing content at more localized scales, and using these platforms in tandem with in-person engagement, either through community science initiatives or in schools. Practitioners should incorporate more features that do this work of transforming Data. Additionally, practitioners should draw on existing work before developing new platforms. By integrating existing platforms and enhancing their unique features rather than creating new, overlapping tools, further duplication of efforts and saturation could be avoided.

Finally, while digital tools offer an important mechanism for furthering interest and education in environmental governance spaces, this work reveals a critical need to reemphasize in-person mechanisms that foster deeper connections and understanding of environmental issues. Chapter 3 emphasizes that ICT tools are in a transitional state, and that there is a need to reposition the utility of these platforms. Where ICT tools are limited is in their ability to engage new users and initiate the process of Knowledge creation and mobilization. This process is instead motivated by the individual. The utility of digital tools may not be for widespread education and democratization of information, but rather as tools to further existing education and care for the environment. Their application may therefore be more appropriate when balanced with strategies that incorporate direct, hands-on experiences and education. This can be done through further collaboration with educational groups and community science organizations to complement environmental education and community outreach efforts to foster that care for the GLB.

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Appendix I

Search Strategies

Search String for Database Searches

Web of Science and Scopus, all literature was sourced according to the following search string :

> TITLE-ABSTR-KEY ("stakeholder*" OR "citizen*" OR "participat*" OR "communit*") AND TITLE-ABSTR-KEY ("water") AND TITLE-ABSTR-KEY ("virtual*" OR "digital*" OR "environmental virtual observator*" OR "information communication technolog*" OR "open data") AND TITLE-ABSTR-KEY ("canad*" OR "great lakes" OR "united states" OR "north america*" OR "USA" OR "laurentian great lakes")

Search terms were searched within Article, Abstract, and Key Words. Date restrictions were applied from 2000 to June 2023.

Search Phrases for Google Scholar Searches

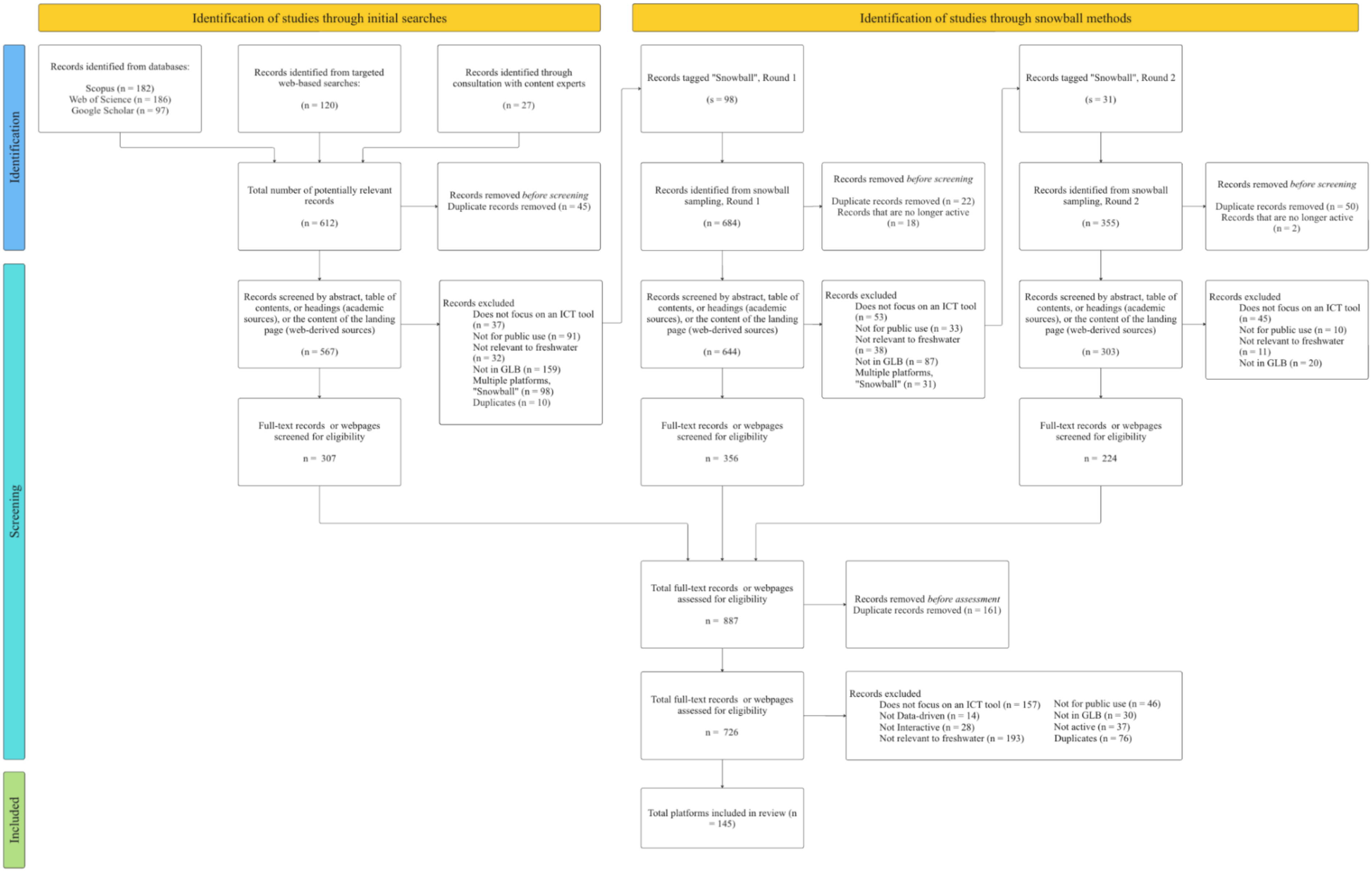
1. "User-friendly open water data platforms for addressing algal blooms in the Laurentian Great Lakes"
2. "Engaging digital tools for community participation in managing flooding in the Laurentian Great Lakes"
3. "Easy-to-use e-governance tools for monitoring and mitigating water temperature changes in the Laurentian Great Lakes"
4. "Virtual observatories for non-experts to assess water contamination in the Laurentian Great Lakes"
5. "Accessible information communication technology for addressing fish health issues in the Laurentian Great Lakes"
6. "Interactive maps for public engagement in identifying drinking water contamination sources in the Laurentian Great Lakes"
7. "Citizen observatories empowering the public to monitor and report algal blooms in the Laurentian Great Lakes"
8. "User-friendly digital tools for managing and mitigating flooding risks in the Laurentian Great Lakes"
9. "Citizen science initiatives engaging the public in monitoring water temperature and its impacts in the Laurentian Great Lakes using digital technologies"
10. "Open data portals providing information on drinking water contamination and solutions in the Laurentian Great Lakes"

Search Phrases for Google Searches

These included: “Great lakes open water data”, “Environmental virtual observatories great lakes”, “Information communication technology great lakes”, “Interactive map great lakes”, “Digital water tool great lakes”, “Citizen science great lakes digital”.

Appendix II

PRISMA Flow Chart



Appendix III

Final List of Platforms

1. 2012 SPARROW Models for the Midwest: Total Phosphorus, Total Nitrogen, Suspended Sediment, and Streamflow
2. Abandoned Mining Wastes Project: Torch LakeGIS Viewer
3. ABCA Watershed Report Cards
4. Access AIS
5. Access Environment
6. Agroclimate Impact Reporter (AIR)
7. Aqueduct Water Risk Atlas
8. Beach Closings and Advisories Map
9. BEACON 2.0 (Beacon Advisory and Closing On-line Notification
10. BloomWatch
11. Blue Accounting
12. Buffalo Niagara Waterkeeper Water Quality Sampling
13. chronolog
14. Cleveland Water Alliance's Smart Citizen Science Widget
15. Climate and Economic Justice Screening Tool
16. Climate and Hazard Mitigation Planning (CHaMP) Tool
17. Climate Change Tool
18. Climate Explorer
19. Climate Mapping for Resilience and Adaptations Assessment Tool
20. Climate Resilience Evluation and Awareness Tool (CREAT) Streamflow Projections Map
21. Coastal Flood Exposure Map
22. Coastal Inundation Dashboard
23. Coastal Resilience Evaluation and Siting Tool (CREST)
24. Conditional Monitoring Observer Reports
25. County Coastal Snapshots
26. cyanoSCOPE
27. Daily Erosion Project
28. Damage Assessment, Remediation, and Restoration program
29. Drinking Water Mapping Application to Protect Source Waters (DWMAPS)
30. Drop by Drop
31. Drought Impact Reporter Dashboard
32. Drought Impacts Multi Tool
33. Drought Risk Atlas - Hydrology
34. Drought Summary Tool
35. Economics: National Ocean Watch (ENOW) Explorer
36. EcoSpark's Water Quality Dashboard
37. EGLE PFAS IPP Web Page
38. EJScreen (EPA'S Environmental Justice Screening and Mapping Tool)
39. Energy Infrastructure with Flood Vulnerability
40. Enviro Atlas
41. Environmental Response Management Application (ERMA
42. EO Lake Watch: Interactive algal bloom monitoring tool
43. Flood Event Viewer
44. Flood Inundation Viewer
45. FloodHippo
46. Former Lacks Cascade PFAS Investigation Web Map
47. Former Lacks Saranac PFAS Investigation Web Map
48. FreshWater Watch
49. Futures Maps

50. Gelman Sciences, Inc. Site of Contamination Web Map
51. Geographic Information Gateway
52. GeoPlatform.gov
53. Global Flood Monitor
54. Great Lakes Aquatic Habitat Explorer
55. Great Lakes Coastal Forecast System
56. Great Lakes Datastream
57. Great Lakes Mercury Sources Revealed
58. Great Lakes Monitoring
59. Great Lakes NowCast Status
60. Great Lakes Portal
61. Great Lakes Restoration Initiative (GLRI) Edge-of-Field Monitoring
62. Great Lakes Science Center - Data
63. Great Lakes Shoreviewer
64. Hoosier Riverwatch
65. How's My Waterway
66. HydroClient
67. Hydrologic Conditions Map
68. Hydrologic Imagery Visualization and Information System (HIVIS) Dashboard
69. Indiana Springs
70. Indiana Water Balance Network
71. INFOS Apostles ((Integrated Nowcast/Forecast Operation System for the Apostles Islands)
72. INFOS Duluth (Integrated Nowcast/Forecast Operation System for Duluth)
73. INFOS Milwaukee (Integrated Nowcast/Forecast Operation System for Milwaukee)
74. INFOS Port Washington (Integrated Nowcast/Forecast Operation System for Port Washington)
75. INFOS WinGB (Integrated Nowcast/Forecast Operation System from Lake Winnebago to Green Bay)
76. Interactive Catchment Explorer (ICE)
77. Lake Level Viewer
78. Lake Observations by Citizen Scientists and Satellites
79. Lake Observer
80. Lake Partner Program
81. Lake Superior Buoys and Webcams
82. Lake Superior Real-time Data
83. Lake Superior Streams
84. lakestat.com
85. LRCA's Watershed Monitoring Program
86. Map: Great Lakes Guardian Community Fund
87. Marine Debris Tracker
88. Measuring the July 2016 flood in northern Wisconsin and the Bad River Reservation
89. Michigan E. Coli Beach Monitoring
90. Michigan's E. coli Pollution and Solution Map
91. MiCorps Data Exchange
92. Microplastics in our Nation's waterways
93. Midwest Glacial Lakes Partnership (MGLP) Conservation Planner
94. MiEnviro Portal
95. Minnesota Natural Resource Atlas
96. MPART (Michigan PFAS Action Response Team)'s PFAS Geographic Information System
97. MRP Properties Co. LLC PFAS Investigation Web Map
98. National Data Buoy Center
99. National StreamStats Beta Application
100. National Water Dashboard
101. National Water Information System: Map
102. National Water Model
103. National Weather Service

104. Neighborhoods at Risk
105. NEPAssist
106. New York Nowcast Beach Status
107. NOAA Tides and Updates
108. nowCOAST
109. OceansMap
110. Open Litter Data Explorer
111. Paleoclimatology Interactive Map
112. PFAS in US Tapwater Interactive Dashboard
113. PicShores
114. Real Earth
115. Regulated Concentrated Animal Feeding Operations (CAFOs) Web Map
116. Remediation Information Data Exchange (RIDE) Map
117. Risk Factor
118. Seagull
119. Smart Lake Erie
120. Source Protection Information Atlas
121. SPARROW Dissolved Solids Sources, Loads, and Yields for the Conterminous US
122. StreamStats
123. Surface Water Data Access tool
124. Surface Water Data Viewer
125. Swim Guide
126. The Great Lakes Water Level Dashboard
127. Total Maximum Daily Load (TMDL) Watershed Screening Tool
128. Tribar Release Sampling Results Web Map
129. Trout Unlimited Coldwater Conservation Corps Water Quality Monitoring
130. US Climate Extremes Index
131. US Drought Monitor
132. US Hazards Outlook
133. USGS Updated Water Data for the Nation
134. Vegetation Dynamics Viewer
135. Washtenaw Industrial Facility PFAS Investigation Map
136. Water clarity data and trends
137. Water Information for a Safe Coast (WISC) - Watch
138. Water Well Database
139. Water Well Viewer
140. WATERS GeoViewer
141. Watershed Health Assessment Framework
142. Watershed Health Assessment Framework: Lakes
143. WaterWatch
144. What's in My Neighborhood
145. Wisconsin Risk Assessment Flood Tool

Appendix IV

Data Items

Category	Data Item	Categorization
Basic Information	Tool Name	
	Organization's Name	
	Organization's Origin	Canada
		US
		Indigenous
		Bi-National
		Multi-National
		International (Outside of North America)
	Organization Type	Non-Profit
		Government Agency
		Academic
		Watershed Organization
		Research
		Collaborative Project
		Other (*specify*)
Tool Information	Tool Type	Map for locating data
		Map for viewing data
		Map for visualizing data
		Map for analyzing data
		Storymap with integrated platform(s)

		Dashboard with map
		Dashboard, no map
		Data portal with visualizations
		Interactive website
	Tool Intention	Education
		Networking
		Data provision
		Joint decision-making
		Consultation
		Transparency
		Co-creation of knowledge
		Water governance
		Research
		Data Collection/Citizen Science
		Policy decisions/Governance
		Understanding Risks
		Communicating watershed health
		Data accessibility
		Future Planning/Preparedness
Data Information	Spatial Coverage	Global
		National US

		National Canada
		North America
		Great Lakes basin
		Great Lakes US Only
		Great Lakes Canada only
		US National and Canadian Great Lakes
		Lake-Wide: specify lake
		State/Province: specify
		Sub-State/Province: specify
		Midwest US
	Data Category	Water Quality: Broad
		Water Quality: Chemical
		Water Quality: Physical
		Water Quality: Biological
		Water Quantity
		Administrative/Policy
		Geomorphology
		Land Use
		Climatological
		Socioeconomic
		Other

	Data Type, Temporal	Historic
		Updated
		Real-Time
		Projections
	Data Type, Format	Images
		Numerical
		Documents
		Survey

Appendix V

Information Sheet

Project Description and Goals:
This project constitutes part of a Master's thesis aimed at studying the role of online information and communication technology (ICT) tools in participatory water governance in the Great Lakes basin (GLB). These tools include things like dashboards, interactive web maps, virtual simulations, and data viewers. This study comes in response to declines in environmental literacy and ongoing efforts towards open science and public facing environmental Data and Information in the GLB. This project takes a knowledge sciences approach to this topic to explore how ICT tools can move beyond Data provision, and instead share Information and generate Knowledge. The interviews in this study build on a previous systematic review of ICT tools in the GLB according to a knowledge sciences framework. Interviews will be conducted with professionals in the space of digital tools for water governance in the GLB, and seek to understand current uses of, and experiences, with these tools.

The overall findings of this project will aim to reveal best practices for the use and implementation of digital tools for environmental issues around water in North America, which can potentially be extended to other environmental and geographic contexts. This study may also support the identification of means by which data providers can improve digital tools, and subsequently the public may be better-engaged and aware of water-related issues within the Great Lakes Basin. These findings have the added benefit of beginning to address concerns that the public will misinterpret data available online, which has been identified as a current barrier to further investment in open access resources.

Role of Participants:
Should you decide to participate in this study, you will partake in one interview, which will be conducted virtually over Microsoft Teams. It is anticipated that each interview takes an hour at most, and there will be no follow-up interviews.

Your identity, should you decide to participate in this study, will remain confidential, aside from by sector (non-profit, government, etc.). Personal identity and organization will not be disclosed in any reporting of the findings. Results will be disseminated in a Master's thesis, which will be offered through the McGill library, as well as in manuscripts submitted to publications in open-access journals. Further details of confidentiality can be found in the consent form attached below.

If you are interested in participating in this study, please contact the primary researcher (Johanna Dipple) by phone [redacted] or by email [redacted]. Additional contact information on the research team can be found at the top of the consent form attached below.

Appendix VI

Participant Consent Form

McGill

Researchers:
Johanna Dipple, M.Sc. Student, Department of Bioresource Engineering
Macdonald Campus, McGill University
Ph: [redacted], Email: [redacted]

Bryant Serre, Co-Investigator, Graduate student, Department of Natural Resource Sciences
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Dr. Jan Adamowski, Department of Bioresource Engineering
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Dr. Gordon Hickey, Department of Natural Resource Sciences
Macdonald Campus, McGill University
Ph: [redacted], Email: [redacted]

Title of Project: Digital Tools for Participatory Water Governance in the Great Lakes Basin

Purpose of the Study: We are inviting you to participate in an interview as part of a study on public-facing online information and communication technology (ICT) tools concerning water in the Great Lakes basin (GLB). These tools include things like dashboards, interactive web maps, virtual simulations, and data viewers. This study aims to contribute to ongoing efforts to improve data accessibility and findability in the GLB, and seeks to explore the potential of these tools to improve the engagement of the voting public in water-related issues, governance, and overall decision-making. To assess whether these tools are effective, we aim to conduct one-on-one interviews with professionals who work in the Great Lakes basin, and use digital tools for the purpose of engaging the voting public in water-related issues. It is through the collective experience of these professionals in the Great Lakes Basin that we hope to understand the current uses of and experiences with these tools.

Study Procedures*:* Participation in this study involves one interview, which will be conducted virtually, over Microsoft Teams video chat. It is anticipated that each interview takes an hour at most, and there will be no follow-up interviews. The recording feature on Microsoft Teams will be used to record the audio of interviews, which will then be transcribed for content analysis by the research team. If preferred, video can be off, or interviews can be conducted by phone. Interviews will be conducted in English.

Voluntary Participation*:* Participation is completely voluntary, and you may withdraw at any time. Prior to publication, withdrawal means that your data will be destroyed. Following first publication, university policy requires that data be retained for 7 years, but withdrawal will result in your data being removed from further use. At any time, you can 1) skip any question, 2) answer a question in greater or lesser detail based on their comfort, 3) stop an interview, 4) stop participation temporarily (e.g., take a break and rejoin when ready) or 5) withdraw from the study.

Potential Risks: We acknowledge that negative emotions such as feelings of eco-anxiety may surface when recounting personal experiences interacting with the voting public, and current experiences within their institutional roles. That said, the nature of this study is a solutions-oriented approach, and we believe that discussing the promise and ability of digital tools to facilitate public engagement is more likely to elicit positive reactions than negative ones. It is also possible that you may feel social risk or economic risk, when worrying about implications of their participation to their employment and broader network of peers, should anonymity be compromised. The level of confidentiality and measures taken to ensure this confidentiality are described below under 'Confidentiality'. Your rights to skip questions or withdraw, as outlined above, further minimize these potential risks.

Potential Benefits: Participating in the study will have no direct benefit for you, however we hope to learn best practices for the use and implementation of digital tools for environmental issues around water in North America, which can potentially be extended to other environmental and geographic contexts. This study may also support the identification of means by which data providers can improve digital tools, and subsequently the public may be better-engaged and aware of water-related issues within the Great Lakes Basin. These findings have the added benefit of beginning to address concerns that the public will misinterpret data available online, which has been identified as a current barrier to further investment in open-access resources.

Compensation: No compensation will be provided to participants.

Confidentiality: Your confidentiality, security and comfort are our top priority. Thus, steps will be taken throughout the research process to ensure that anonymity is not compromised. During the recruitment process, consent forms will be removed from the email account of the interviewer and instead stored as a hard copy in a locked cabinet in the interviewer's office. During the interviews, a "meeting room" and password-protected login will be used, and there will be the option to call in. After the data collection, a participant code number will be assigned for all interviewees, and the document that links participants' codes with their actual name will also be stored in a locked cabinet. Only the PI (Johanna Dipple) and the Co-Investigator (Bryant Serre) will have access to identifiable materials. Audio recordings of interviews and consent forms of participants will be stored on a secured and encrypted computer (McGill OneDrive). Once transcribed, audio recordings will be deleted. Transcripts will be de-identified, then uploaded and stored on McGill OneDrive. All data on the cloud server is password protected, with access limited to the research team. Data will be stored for a minimum period of seven years after which time it will all be destroyed as we aim for compliance with TCPS 2 (2022) policies. In reports, participants will only be identified by sector (non-profit, government, etc.). Personal identity and organization will not be disclosed in any reporting of the findings.

Dissemination of Results: Results will be disseminated in a Master's thesis, which will be offered through the McGill library, as well as in manuscripts submitted to publications in open-access journals.

Questions: Please contact either the primary researcher (Johanna Dipple) or the supervisors with any questions/clarifications about this study. Their contact information can be found on the first page of this consent form.

If you have any questions or concerns about your rights or welfare as a participant in this research study, please contact the McGill Ethics Officer [redacted] at [redacted] or at [redacted].

Please sign below if you have read the above information and consent to participate in this study. Agreeing to participate in this study does not waive any of your rights or release the researchers from their responsibilities. A copy of this consent form will be given to you and the researcher will keep a copy.

__________________________	______________	__________________________
Name of Participant	**Date**	**Signature**

Appendix VII

Development of an Interview Guide

To develop the interview guide, a methodology by Kallio et al. (2016) was followed. This approach divides the process of creating an interview guide into five distinct phases, explained and applied below:

Phase 1: Identifying the prerequisites for using semi-structured interviews

The first phase assesses whether semi-structured interviews are the appropriate method to answer the research question(s). Semi-structured interviews were chosen for their flexibility and conversational nature, ultimately allowing for follow-up questions to probe further and clarify responses. This aligns with an application Kallio et al. (2016) describe as exploring research topics where perspectives may be complex. Additionally, the authors of this methodology stipulate that there needs to be enough existing information on the topic to formulate questions and guide the interview. In the case of ICT tools for participatory water governance, there is ample research and an abundance of tools, but existing research is disjointed and fails to capture the perspective of practitioners of these platforms.

Phase 2: Retrieving and using previous knowledge

The second phase involves comprehensive research through a literature review to create a conceptual basis for the work. Additionally, the authors emphasize that in the case of fragmented knowledge on the topic, theoretical research can be complemented by empirical research as well as feedback from other researchers. Prior to the development of this interview guide, a literature review of ICT tools for participatory water governance was conducted (Chapter 3). This was complemented with research on the DIKW hierarchy, Open Data and Science Democratization, and theories of change in environmental spaces in order to create the conceptual framework for this research (Chapter 2). Following this research, a systematic review of ICT tools in the GLB was conducted, and these tools were then evaluated through the lens of the conceptual framework, thus providing empirical research in this space (Chapter 3).

Phase 3: Formulating the preliminary semi-structured interview guide

The third phase uses previous knowledge to create an interview guide for flexible,unbiased exploration of main themes, prompted by follow-up questions. Interviews were structured chronologically, moving from the conceptualization and planning stage of platform design, to use in practice, to broader impacts and indicators of success. Following this structure, the main themes were as follows: tool information and planning, tool use and user base, tool outcomes and impacts, measures of success, intersections with other methods of engagement and other platforms, and concluding questions. Both spontaneous and pre-designed follow-up questions were used to guide the interviews.

Phase 4: Pilot testing of the interview guide

The fourth phase involves testing the interview guide internally and externally to improve data collection and refine questions. Internal testing was first conducted with the research team to utilize their expertise and reduce bias. This was followed by expert assessment from four external specialists. Two reviewers met respondent criteria but were ineligible due to existing collaboration (from the Great Lakes Observing System and Conservation Ontario), while the other two worked on related topics but were not responsible for ICT tools (from the International Joint Commission and McMaster University). Although comprehensive field testing was limited by time constraints and participant availability, spontaneous questions from the initial interviews were added to the guide.

Phase 5: Presenting the complete semi-structured interview guide

Finally, the fifth phase involves including the completed interview guide in the study paper.

References

Kallio, H., Pietilä, A.-M., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: Developing a framework for a qualitative semi-structured interview guide. *Journal of Advanced Nursing*, *72*(12), 2954–2965. https://doi.org/10.1111/jan.13031

Appendix VIII

Interview Guide

Introductory Questions-

1. Organization name
2. Organization type
3. Role in this organization
4. Water characteristic(s) of interest
5. What is your organization's perspective towards engaging the public?

Introduction of ICT: Provide definition of ICT, lower-level example on DIKW (open data portal) and higher-level example (virtual reality).

6. What kinds of initiatives does your organization implement or plan to implement that fit within this definition of ICT?

Next section: Repeat for each (relevant) tool provided in question 6

7. What was the reason for developing this platform?
    - Was there a specific instance, policy, or other reason why this tool was developed?
    - What are the goals of engagement with this tool specifically?
8. Who is the intended audience of this tool?
    - Do you know who your actual audience is?
    - Are there disparities in the intended and actual audience?
    - Are there any groups who may be less able to access this tool?
    - How is the intended audience reflected in the design of this tool?
9. How is this tool currently used?
    - Has it been successful in meeting its intended use? (why/why not)
    - How do you evaluate the success or the impacts of this tool?
    - Was there anything about the platform's use by the end-user that surprised you?
    - What about by your own use of the tool?
    - Are there any uses or applications of the tool beyond what you originally planned?
10. General question about the outcomes of this tool, may depend on type of tool
    - Is this platform ever used to inform or influence decision-making within your organization(s), or around environmental change, broadly?
    - Is the potential for misinterpretation of data and information a concern with the use of this tool?
11. Is this tool used in tandem with other methods of engagement, digital or other?
    - How would you approach improving collaboration and information sharing with other organizations?

Concluding question

12. Is there anything else you would like to mention about engaging the public through data and information portals?

Appendix IX

Final Codebook

`	**Code:** Definition	**Subcode:** Definition	**Code Occurrence**	**Example of Text**
Tool use: Answering the question of How is this tool used, both intended and actual. Use includes the audience, goals of engagement, link to decision-making, outcomes of the platform, etc. Anything related to how people are intended to use or at using this platform.	**Relatively unknown:** Captures elements with diverse applications across user groups that remain undocumented or underrecognized.		4	"I don't think I understand completely how it's used everywhere." "it's a little challenging to know how it's used."
	Decision-making: This code outlines the use of digital platforms in processes for formulating, applying, and regulating decisions in formal decision-making contexts, not individual actions, including policy applications, local management decisions, and regulation and standard setting.		8	"And so when this when state level decision-making is happening, they you know, they often use our data more as a screening or overview kind of thing [...] sometimes they'll go out and revisit locations that our volunteers have maybe found some kind of impairment or degradation." "So everything that we do is try to create avenues for public participation in governance and management of water resources."
	Legal Uses: This code indicates permission to use data in legal contexts.		5	"we actually have to put a disclaimer [...] that this is not intended for legal purposes."
	Incite action: Encompasses efforts to mobilize collective initiatives, advocate for policy changes, promote local engagement in activities such as testing, and stimulate public demands for concrete measures, leading to tangible actions or responses from communities or authorities.		6	"And you know asking some of those questions of what people want to know but ultimately, you know, it's got to be followed up by action. And so it's been a it's been a marriage of data with community actions, at least in this particular area."
	Joint problem solving: Refers to collaborative efforts that involve integrating data into broader research databases, contributing to external projects, exchanging information among partners, facilitating discussions, and combining various platforms and data to address and resolve issues collectively.		8	"And so [this contaminant] is just one piece of the bigger puzzle, but all of the tools that we have here, all of these GIS platforms are what, that are really helping us to do a better job of managing the resources managing the information, because it is enormous. I mean, we have an enormous amount of information and data here. And we need all of it to be able to make really good sound scientific decisions. And so [we don't] work in a vacuum"
	Group management: Pertains to strategies and practices aimed at efficiently organizing and overseeing citizen science groups, including addressing communication challenges, coordinating community efforts, and handling volunteer involvement.		3	"So it's really intended for those groups to be able to help manage volunteers for employees to put in that data."
	Public engagement: Involves strategies and tools designed to facilitate cost-effective participation from the public, foster communication with community members, and enhance the overall involvement of the public in various initiatives or projects.		4	"So everything that we do is try to create avenues for public participation in governance and management of water resources."
	Further Analysis: Further analysis of the data	**Gap Analysis:** Involves the comparison of existing data and initiatives to identify gaps or deficiencies, aiming to understand the current state of data availability, prevent duplication of efforts, and highlight areas where additional data collection or monitoring efforts are needed to address gaps.	4	"So either existing monitoring programs or new monitoring programs want to understand where monitoring is already happening, so that they don't duplicate efforts. And this is really great, because it just leads to more efficient monitoring overall, and less wasted."

	Internal Analysis: Refers to further analysis of data hosted on the platform done internally, or within the organization, potentially including activities such as flood forecasting and other modeling efforts.	3	"And then, you know, from our perspective, we also use it to look at the climate and watershed drivers of blooms. So we take the bloom indices and analyze them with respect to, to weather events and climate variables and nutrient concentrations to get a better understanding of what the root causes of blooms are and what are driving their, their current and potentially future conditions"
	External Analysis: Refers to additional analysis of data hosted on the platform conducted by entities external to the organization or platform, including academic research, scientific use, and collaborations with researchers or other stakeholders to inform further efforts.	5	"There's been researchers who have done studies and graduate students who have done studies almost entirely based on our database, like looking at it from a regional standpoint or statewide standpoint."
	Program Design: Involves using platform data and insights to guide program design, both internally and externally. This can include guiding monitoring activities, allocating resources, and tailoring engagement to user gaps.	6	"understanding who is sharing their data on data stream and what kinds of data they're sharing and why is really important for us to inform our other programming,"
	Communication tool: Serves as a platform for various communication purposes within the organization and with external stakeholders. This can include creating reports, progress tracking, and consolidating various efforts by the organization.	9	"But we definitely do use it, as I said, to generate like annual reports that go back out to our volunteers, reports that go back to our funders [...] so they can see okay, here's what we've accomplished"
	Collecting data: Explicit intention to collect new data. This includes researching historical information, filling data gaps, engaging in long-term data collection efforts, incorporating data collected through citizen science initiatives, and utilizing crowdsourcing approaches.	5	"And people are generating the data and entering the data. And they're, they're going out in the field and they're interacting with these lakes and these streams, and they're interacting, you know, they're interacting with the data, right. They're responsible for collecting it."
	Data Availability: This code pertains to the efforts to aggregate, store, manage, and enhance the visibility and transparency of raw data (pure symbols, numbers, and potentially sensory inputs as per the expanded definition) within a platform. It involves consolidating disparate data sources, ensuring efficient data management, and promoting open data initiatives to make data more easily discoverable and accessible. The focus here is on the foundational level of the DIKW hierarchy, dealing with data as raw, unprocessed entities that require further processing to acquire meaning.	9	"So the platform is obviously being used to store and share data. Some of that data is being shared for the first time like it wasn't available or open anywhere else before it was stored on [our platform]. And then another one is that the data was already shared elsewhere, but people are sharing it on [the platform] to broaden their reach and audience and that type of thing."
	Data Accessibility: Aligned with the concept of Information, this code focuses on transforming raw data into a format that provides context and meaning. It emphasizes making scientific data more approachable to the public through user-friendly interfaces, visualization techniques, and other means that enhance the ease of access and understanding. By improving accessibility, the initiative broadens the audience and facilitates the transition from raw data to information that informs and is relevant to users.	8	"So these types of platforms [...] making the data more accessible to wider audiences, and making that data easier to use, I think, is a really important piece of public engagement."
	Identification of Threats: Encompasses activities focused on identifying and monitoring various threats to the environment, including local flood monitoring, urban flood monitoring, reporting pollution incidents, and general threat identification within the platform.(Not about the individual).	4	"if water levels drop, how that might impact some of the nearshore fisheries that a tribe might use for subsistence harvesting and so forth."
	Contextualize Conditions: Involves providing additional context or background information to enhance the understanding of current weather events or conditions, including offering historical context for current weather events and providing context for current environmental conditions within the platform.	1	"tools that can help show historical context of water levels on the Great Lakes are extremely useful for communicating to people what, you know, what has happened in the past and what's like, where we are right now? What is, how is that compared to where we've been in the past?"

	Inform Local Populations: This code pertains to individual resource use and decision-making, including informing local users about water health risks and resources to enhance public understanding of their local ecosystems.	9	"it's a way of taking complex scientific data and trying to make it applicable to the average homeowner who might be living next to one of these sites."
	Broader Understanding: This code signifies efforts to deepen public comprehension and awareness of complex environmental issues, including climate change events and resilience, simulating future events, impacts of various factors, and health crises.	5	"these types of tools can be a good way of showing how it complements or works with other types of information, to inform policy decisions or to inform local action and to inspire people's awareness and interest in environmental issues."
	Education: Refers to discussions related to teaching and learning processes within formal or informal settings, encompassing curriculum development, educational methodologies, and practices, as well as efforts to enhance learning experiences, promote environmental education, educate the public, and create interactive learning environments.	5	"We get a lot of praise from teachers about teaching their class and how easy it is for them to see, and we have some lesson plans."
	Utilize new technology: Refers to the use of a platform to adopt and leverage emerging technologies or trends in this space. Includes implementing technological advances, utilizing cloud-based architecture, optimizing for mobile use, and exploring simulation capabilities.	3	"I think just overall trying to get a more modern cloud based architecture in play under the umbrella of the [this initiative]"
	Narrative Shifts: Describes significant changes in the overarching storyline or discourse around ICT tools. It encompasses a pro open data stance, increased openness of data, embracing of technology, increased trust in technology, and efforts to increase transparency.	5	"Well, one thing that we have observed is that, and I don't think [we] can take credit for this. But we've certainly contributed, I think, to, to conversations about the value of open access water data in Canada"
	Unanticipated uses: refers to uses of the platform that were unintended or unexpected by the practitioner.	7	"And so governments who have their own data management systems, we have heard, and this is anecdotally, like I can't provide any evidence for this, but anecdotally, that they like to see their data their own data on [our platform] instead of their own systems just because it's a lot easier to navigate and understand the data in context."
	Create shared identity/vision: Involves the process of fostering a cohesive collective identity and establishing a unified understanding of common goals, aspirations, or objectives within a group or community.	2	"shared desired outcomes for the lakes"
	Data as evidence: Signifies the use of data from platforms as a form of evidence, including instances where incorporating data in the platform adds legitimacy (e.g. citizen collected data)	5	"And they probably kind of know some of this information. But if it's not recorded somewhere, then we don't have examples of them and we can't kind of push decision-making or advocate for water bodies as much. So we all have a role to play is this big lesson."
	Generating and Maintaining Interest: Encompasses activities that stimulate ongoing engagement and enthusiasm among users, including sparking initial interest in data and initiatives, as well as fostering prolonged involvement of volunteers.	6	"And I think that when you get people who don't usually have to go to the water and test it to go and do those things, what we found is that they suddenly take the time to notice what's happening to the water. And that often leads to them taking actions other than just water testing. They want to get more involved and do more to help the water to help the environment. So it's a bit of a snowball effect. So I think it's super important to engage the people and a data platform is an easy first step for them."

	Increasing accessibility of the environment: This code pertains to using digital tools to make natural environments more accessible to individuals who are not geographically close**.**		2	"Because getting back to some of your previous questions about accessibility, not everybody can get to the water's edge, not everybody can get into the water, not everybody can go under the water. And so these types of tools provide new insights and new views that otherwise many people would not have."
	Enhance Equity and Resilience: This code is used when respondents discuss outcomes such as improved fairness, access, and adaptability within local communities, incorporating equity considerations.		2	"And I would say that platforms that are built with users in mind, you know, with a user focus, they can promote equity, I think in the environmental sector more generally, as you asked a question earlier, about sort of, like technical capacity, that people would need to use a system like data stream, so building them to be as user friendly and accessible as possible, I think is is progress, I guess from like an equity lens when working in environmental management."
Audience	**Intended**	**General public:** Refers to a wide-ranging, undefined audience without specific attention to demographics or a subset of the population.	9	"I think this is for the broad public, I think it's for everybody, because there's so many different sects of the public that need to know this information."
		Populations close to waters: Refers to various groups and individuals residing near water bodies, including those involved in property transactions, recreational users, residents, and community members with scientific inquiries.	4	"there are people who either live on the on the lakes or have their recreational boats, you know, that they want to know[...] is this summer higher than last summer water levels"
		Decision Makers: Refers to individuals or entities within legal, policy-making, or governmental frameworks who hold authority to make official decisions impacting policies, regulations, or laws. This category typically excludes actions taken by the general public or individuals, focusing instead on institutional decision-making processes.	9	"in the hands of governors, premiers, members of Congress, Parliament and their staff. So that's the level that we're trying to reach. In terms of the broader Great Lakes decision maker."
		Researchers: Encompasses individuals and institutions engaged in systematic investigation, scholarly inquiry, and scientific study across various fields.	7	"A third audience has also emerged in researchers"
		Community based monitoring groups: Encompasses community-driven initiatives involving collective participation in scientific monitoring and research activities. This includes community science programs that engage volunteers organized into groups, emphasizing collaborative efforts over individual contributions.	3	"In many cases, the intended audience are community members that are associated with some kind of science question. So a watershed group that wants to protect their stream, or say a group that's interested in vernal pools. So there's usually a group of people that are interested in some sort of aspect of nature, and that somehow is associated with how much water is at a location or not."
		Agency partners: Organizations that collaborate with a primary organization to achieve shared goals or objectives, often through formal partnerships or agreements.	2	"our agency partners"
		Nonprofits and Local Stewardship Groups: Includes organizations such as cottagers' groups, lake associations, and ENGOs that are dedicated to environmental conservation and local stewardship efforts.	2	"a lot of nonprofits"

		Fulfilling data needs: Involves addressing various aspects of data communication and sharing related to freshwater. This includes individuals seeking to communicate information about water levels, those searching for relevant data, and those possessing data and aiming to share it with others.	2	"So generally, very generally, the audience is anybody who has data and wants to share it openly. And then the other on the flip side is people who are looking for data to inform research, management, that type of thing."
		Limited Audience: Denotes a deliberate targeting or acknowledgment of a restricted audience, explicitly excluding the general public or individuals not within the specified audience scope.	1	"But I'd say that by and large, the services that we provide, aren't necessarily geared toward a true public sense."
	Actual	**Broad**: Refers to the diversity and range present in various aspects related to the platform's goals, user expertise, audience demographics, and age groups targeted by the platform.	3	"But we have folks we've worked with from like six years old, to like 85 years old kind of thing."
		Populations close to waters: Refers to various groups and individuals residing near water bodies, including those involved in property transactions, recreational users, residents, and community members with scientific inquiries	8	"Most of the people that I meet that use it have some kind of hobby that they're interested in, that resolves around water. So that being someone who likes to fish, someone who likes to kayak, someone who likes to watch birds, those seem to be the people who participate the most, or at least are out participating."
		Decision Makers: Refers to individuals or entities within legal, policy-making, or governmental frameworks who hold authority to make official decisions impacting policies, regulations, or laws. This category typically excludes actions taken by the general public or individuals, focusing instead on institutional decision-making processes.	8	"But our audiences tend to be leaders within the great lakes that have specific roles, whether it's individuals that are in charge of water management through a state or provincial natural resource agency."
		Researchers and Academics: Encompasses individuals and institutions engaged in systematic investigation, scholarly inquiry, and scientific study at universities and higher education institutions.	5	"universities use it as well, when they're doing research projects,"
		Community based monitoring groups: Encompasses community-driven initiatives involving collective participation in scientific monitoring and research activities. This includes community science programs that engage volunteers organized into groups, emphasizing collaborative efforts over individual contributions.	3	"about half of the contributors on [our platform] are community based monitoring programs"
		Private Entities: Organizations and individuals, including consultants, that operate independently of government control and are typically driven by private interests.	2	"I know the consultants who do like environmental research or environmental searches for property transaction for historical information, that kind of stuff."
		Nonprofits and Local Stewardship Groups: Includes organizations such as cottagers' groups, lake associations, and ENGOs that are dedicated to environmental conservation and local stewardship efforts.	2	"So definitely like associations, like I mentioned, cottagers groups"

		Education: Encompasses elementary and secondary schools, educators, and students utilizing the platform for teaching and learning in K-12 settings, including class projects and curriculum integration.		4	"We've definitely had like, a few examples of teachers like at the grade school level, you know, with young students using it as, like real examples in the classroom, whether it's like middle school, elementary, high school, situations like that"
		Indigenous use: Refers to the involvement and engagement of Indigenous groups with the platform, highlighting their unique perspectives, needs, and contributions.		5	"Three of the [monitoring [stations] that were started were started in indigenous communities [...]. And so those communities were provided with tools and resources to collect and share water quality samples."
		Sustained engagement: Refers to mention of maintaining long term involvement and interaction with the platform, characterized by a core set of users who engage in ongoing dialogue and find value in their individual interactions. This may include repeat users who are directly engaged with the platform over time, contrasting with primarily one-time contributors.		3	"And you know, there's, I would say, a set of core and users that are really outspoken about the value of the products and they share it with, you know, they'll post it to all their annual newsletters and share it with local media."
		Unanticipated users: Refers to users of the platform that were unintended or unexpected by the practitioner.		7	"we also got quite a few people, either individuals themselves or their real estate agents that were looking for places to buy property. They wanted to find out where was a nice clear lake or a healthy stream or whatever to, you know, either themselves or for their clients to you know, potentially buy a vacation home or, you know, just to move to so that was a surprise to us."
	Variations: Describes fluctuations or changes in platform usage patterns, which may arise due to factors such as software bugs, increased interest during the school year, or heightened engagement during periods of extreme weather.			5	"So outreach was easy when when water levels are high, because we always needed to be responding to requests for information." "It drops off in the summer because people aren't in school as much during the school year,"
Success: Essentially anything answering questions about whether the tool is successful, how respondents think about and measure success, what may be missing from this picture, etc.	**Magnitude**	Yes		7	"Yes, I would say it has been effective in meeting its goals? If anything, we've exceeded some of our earlier goals"
		No		1	
		Somewhat		4	"I mean, I think it's a it's, it seems to be achieving the goals that I was hoping for. But does it achieve like the goals of what the community would want? Or what the broader public would want? I'm not sure."
	Measures	**Qualitative**	**Direct contact**: Refers to direct interactions between users and the organization that indicate success, including user feedback, webinars, promotions, user-driven expansion, troubleshooting, and receiving questions.	10	"Where we kind of decide whether we're doing a good job or not, is based on you know, the individual interactions we have with users who either say it was great, we found what we wanted, thank you for supporting this program or I'm having trouble like I don't know how to get the information I want out of the database, or I don't understand this"
			Usability: Pertains to the perceived ease of use and user-friendliness of the platform, broadly discussed in terms of its success in facilitating smooth interactions, without necessarily having concrete measures.	1	"I think it should be something that is usable"

			Good relationships: Indicates positive interactions and rapport established with users, contributors, and collaborators, serving as an indicator of the platform's success in fostering meaningful connections and engagement.	1	"That yeah, the relationships are good,"
			Internal feedback: Encompasses feedback provided within the organization, including input from management and internal teams, which serves to inform and improve the platform's success and operations.	2	"we have systems to collect our own team feedback"
		Quantitative	**Known users**: Quantitative measures tracking users and their information within the platform, including registered accounts, subscriptions, group organization, and data collection, indicating the platform's success in user engagement and retention beyond simple analytics.	4	"I know who has subscribed as a user formally, so through that subscription process, we ask for their name, their email, their affiliation, what have you. So we do maintain that database just for our own knowledge of who's using it."
			User Analytics: Focuses specifically on tracking and analyzing user-related data, including user demographics, behaviors, and preferences. This includes metrics such as the geographic locations of users, type of IP addresses, number of users, unique hits, and devices used to access the platform. User analytics provide insights into the platform's user base and their interactions with the platform.	7	"We do generally know what devices they're coming from, whether they're using their iPhone, or Android, or if they're checking in via a desktop app like desktop or if they're using our application because it is a web based platform"
			Traffic Analytics: Involves analyzing user engagement with the platform by tracking metrics related to website traffic and user activity. This includes metrics like hits on the webpage, visits to the platform, user clicks, pages visited, and time spent on the platform. Traffic analytics primarily focus on understanding user behavior and interaction patterns.	11	"I don't know the numbers, but we do keep track of like, hits on the webpage. That's probably the biggest way we keep track of it for this product that I'm aware of."
			Data analytics: Involves analyzing various aspects of data usage and contributions on the platform, including the quantity of data uploaded, the number of monitoring locations, data contributors, and the total number of data points.	4	"we look at things like the number of data contributors, the quantity of data that's uploaded, the number of monitoring locations that are covered in each of the hub regions"

			Tracking downloads: Involves monitoring the usage of the platform's API, including the utilization of tokens for accessing the API. This tracking provides insights into how users interact with and utilize data from the platform externally.	2	“So we have an API that people can use to access and query the database. And so to get access to the API, people need to request a token. So that's how we understand who's accessing the data that way.”
			Tracking external use: Includes monitoring the integration of platform data into other products or systems, its utilization in presentations, and tracking citations or references to platform data. maybe delete: This tracking provides insights into the platform's external impact and reach beyond its native environment.	6	“But there are dozens and dozens of research articles and publications that use data stream, we'll find out if it's published, and we pick up the citation”
			Cost of maintenance: Represents the expenditures incurred in maintaining and supporting the platform, which tend to increase with higher usage. This metric serves as an indirect measure of success, reflecting the platform's scalability and sustainability in meeting growing user demands.	1	“I pay attention to what the cost is. I pay per [input] so I pay attention to what the cost is [...] and that gives me a little idea in a given month, how many people have participated.”
		Service provided: The ability to deliver a reliable service is considered a marker of success. This is evidenced by minimal downtime and interruptions, ensuring continuous access to accurate data.		4	“Yeah, so you know, that major goal of making the data accessible, it's there, right? It works. It exists. It's public, people can get to it. We have very little downtime. It runs as expected, you know that in that way. It's definitely meeting that very basic goal.”
		Tracking outcomes: Involves monitoring the impact of the platform on various outcomes, such as changes in legislation and its influence on programming decisions. These outcomes provide insights into the platform's success in driving real-world changes and influencing decision-making processes.		2	“ And so that's an element of success for us that says that okay, not only did people care about the water quality, they cared enough to get involved and do something about it.”
		Lack of measures: Indicates the absence or limited availability of measures to track platform usage and success, characterized by factors such as lack of user login, minimal analysis of user interactions, anonymous usage, limited direct communication with users, and a general lack of focus on tracking platform use.		10	“Because [it’s] an open access platform, we don't have any specific requirements around use of the data. So we're not always sure how the data is being used and who's accessing it, unless we have some kind of some kind of a dialogue with them.”
		Breadth of Use: References to the extent and diversity of platform usage, including those outside original intentions, as indicators of success.		2	“So we look at platform and hub growth. As I said, we never expected to grow nationally. So as new hubs come online, that is certainly a measure of impact.”
		Sustainability of projects: Refers to an organization’s ability to maintain a project’s operations over time (long-term sustainability) as a measure of success.		1	“ I think especially now that we're running it in a way that feels like you know, we can sustain it. I think it is. Yeah.”

		Missing from success: Highlights aspects that are absent or insufficient in assessing the platform's success, including the desire for more data application, overlooked communities, changes in behavior, absence of a call to action, and discussions surrounding the validity of measures used to evaluate success. These factors reveal areas where the platform's impact may not be fully captured or understood.		7	"The harder piece is where do we then see movement out in the real world, right? Because this is really intended to call people to action within this very small universe, we're trying to reach and drive change [...]. And so that will be a real effort in and of itself, to be able to see [that outcome]. I can't tell you that it's actually happened yet."
Variable: Answering the question of What hinders or facilitates the success of the platform. Includes things like tool design, incorporation of feedback, capacity issues, funding, and other barriers, outreach, misinformation, the presentation of data, prerequisites, etc.	**Resources**	**Overall lack of resources:** Refers to broad and unspecified limitations cause by a lack of resources. (Barriers)		4	"So I think there's huge areas of potential to advance these things, tools and the products that are coming out of them. So, yeah just not enough time. Not enough people, not enough resources to do it."
		Finances:	**Financial resources for providers, Positive**: Refers to strategies specific to this field aimed at overcoming financial barriers, such as direct funding, support from other organizational units, resource reusability, shared costs, and collaborative efforts, which enhance the platform's success.	3	"I think it's, we've been lucky with [this platform] because we [...] get a lot of stuff for free. Because it's a carrot. Because people say, oh, I want to put our data in there. So I'll develop this for you and you can pull it in. So those database owners, all that burden is on them to develop the app. It's been very easy and lightweight."
			Financial resources for providers, Negative: Describes challenges and limitations related to financial support for provisioners, including costs of data management, budget constraints, and concerns about financial sustainability, all potentially hindering the platform's success and growth.	8	"I think one of the biggest barriers is that these these platforms are often created by charities or nonprofits because they're geared towards social impact. And this can provide a barrier for a number of different reasons like because the goal isn't profit, it can be really tricky to make them financially sustainable"
			Cost of use: Refers to the expenses incurred by users when utilizing the platform, which may include considerations such as the availability of free accounts, openness of access, and the absence of login requirements. These factors influence the accessibility and affordability of the platform, impacting its success.	4	"Researchers, managers, the volunteers themselves and basically anyone from the public [...], you don't have to have an account or permission to login. Anyone can go and look at any of that data at any time."
		Human capacity:	**Human capacity, positive**: Describes positive experiences related to human resources available for platform development and management, including having in-house developers and data specialists, as well as experiencing adequate capacity to support platform operations effectively.	4	"And as our team continues to grow, we have higher capacity in house to be able to improve the platform."
			Human capacity, negative: Refers to challenges and limitations regarding human resources available for platform development and management, such as the absence of on-staff developers, being a small organization, constraints related to contract length, limited	10	"Yeah, so we're, like I said, a small team. And I think as the application grows, that's capacity that we're going to need to address I think."

			human capacity, and lack of time, all of which may hinder the platform's success and growth.		
			External Human Capacity Influence: Refers to the impact of external factors, such as the burden on data providers and the capacity of partner organizations, on the human capacity of the organization. This includes considerations of how data management responsibilities are distributed among different groups and organizations.	3	"But to be the people that we're getting the data from, is definitely hard. And sometimes they can't do everything we want them to do. And a lot of it will require putting a new module in their database to allow us to pull in a whole other aspect of their data."
	Limited by organization type: Describes limitations that come from the type of organizations operating the platform, including structural capacity and security requirements.			5	"Yeah, I think from a government perspective, I think, you know, the whole process of developing this platform highlighted areas of our own policy that are in desperate need of updating in terms of data policies and web policies and you know, updating our ability to adapt to new tools and new information."
	Technology needed for use	**Technology needed for use:** Specifies the technological requirements essential for utilizing a service or product efficiently, encompassing general usage and considerations for mobile accessibility. This includes having a cellphone for data submission, considerations for internet speed, cell phone access, the necessity of a computer to create an account, compatibility with web browsers, internet access, and availability of a mobile application. Add: spoken about neutrally		7	"it's basically if you have access to the internet, and can, you know, use a web browser, then you should be able to use this tool. That's the other beauty about this tool is it's all online. It doesn't require you to download any special software. As long as you've got an internet browser, you can see and use this tool as well."
		Technology as Facilitator: Describes the positive role of technology in supporting platform use, including the accessibility facilitated by cellphones and other devices. This highlights how technology enhances user access and engagement with the platform, contributing to its success.		4	"And it's a matter of barriers of entry, right? You would need some more technology on people's phones in terms of an app or some kind of web based interface. And right now, everyone can text message. So it's very easy. The barrier of entry is very, very low"
		Technology as Barrier: Encompasses challenges related to technology hindering platform access and use, including barriers stemming from both technological knowledge, particularly among older participants, and technological access, including obstacles like limited internet access and the requirement for specific devices like laptops, which impede user access to the platform.		5	"I'm sure there's a few people that we aren't catching, obviously, the people who don't have good internet access or or, you know, potentially in some of our EJ communities, something like that. That might not be able to be reached because they don't have the tools. They don't have the computer or they don't have the internet."
	Knowledge needed for use	**Knowledge needed for use, positive**: Indicates a low level of required knowledge for utilizing a product or service effectively, emphasizing simplicity and accessibility. This includes basic technological literacy, with no specialized knowledge necessary and no assumptions of prior expertise.		7	"But we work with data contributors who fall along every spectrum, I guess a sort of like technological literacy. So we work with people who don't actually know how to save their data in the CSV format. People who, yeah, so that's, that's one example. So yeah, we work with people along a pretty wide spectrum of having that technological kind of competency and literacy."

		Knowledge needed for use, negative: Denotes the level of required expertise or understanding that may pose barriers to effectively utilizing the platform. Includes a certain level of education or specialized knowledge to extract meaning from platform/utilize the full potential of the platform.	10	"But if they really want to get into what does the data mean, then they kind of have to either have that basic knowledge or they have to reach out and ask somebody more specific."
	Language: Mention of language relative to platform use and success, both in reference to scientific language and jargon, and linguistic differences and translation.	**Scientific language**: Involves the process of simplifying scientific language by providing definitions and using controlled vocabulary, aiming to avoid academic language and jargon to facilitate comprehension by a non-specialized audience.	6	"And one thing we try to do is use very simple language. We don't want there to be any jargon"
		Language barrier: Refers to challenges arising from linguistic differences, particularly in translating scientific concepts or content between languages such as English and French.	3	"when you're communicating science, the translation of the science and policy into French makes me really nervous to know, did we get this right? So we'd not only need, you know, an actual human to do the translation. But we'd then need to make sure that they were also available to do the updates for us. So we know there's a language barrier."
	Data Interpretation	**Misinterpretation:** Encompasses factors contributing to misinterpretation of data, like varying health standards and uncertainties, along with solutions such as clear disclaimers, involving the audience, and strategic outreach during tool launches.	11	"Yes, I think it's always a concern. I think there's various ways that it can be misinterpreted. So like, you [...] see the lake wide average water levels. A common misunderstanding I think could be that you would think that's the level that you're gonna see at your location on Lake Michigan on a given day, during that month, but there's a lot more variability in water levels both day to day and across a lake. And so I think that's a potential misinterpretation."
		Messaging: This code encompasses efforts to present data neutrally, avoid politicization, and align messaging with public concerns, aiming to effectively communicate information while maintaining objectivity and addressing public interests.	4	"You know, when you try to convince people of your story or of your state of affairs, you really need a non bias scientific way to show data that's not going to create division hard feelings or and or some sort of, you know, political tension, and so far we've been able to keep [...] out of the politics part of it. But I don't know how much longer we'll be able to do that to be honest."
		Information Balance: This code pertains to the contextualization of data and the balance between providing information and maintaining clarity. It includes considerations such as finding the right balance between context and raw data, determining the appropriate level of detail, and contextualizing data to facilitate correct interpretations.	7	"And so trying to find that line to walk, where people feel brave in presenting the information, but users actually access the information because it isn't surrounded in the scrum of stuff that they don't want. That's really going to be the magic trick that we're trying to pull off."
	Design Elements: Encompasses the visual and functional components integrated into the platform's interface and user experience, aimed at enhancing usability,	**Simplicity**: Refers to the design and functionality of a system, emphasizing intuitiveness, accessibility to uneducated users with additional detail as required, ease of use, utilization of simple language, straightforward navigation, and presenting limited data on maps to avoid overwhelming users.	10	"So we tried to design the platform to be as easy to use as possible. Obviously, not everybody will have an easy time of it. But so that's one of our first design principles is that it's accessible. I mean, not just from an open access standpoint, but that it is easy to use."
		Data trends and summaries: Encompasses various methods for summarizing and visualizing data trends, including hydrographs, scoring mechanisms, sparklines, summary reports, and graphs, which provide concise representations of data patterns and insights.	6	"when you go see the summary of that location, you'll see little spark graphs that form and like kind of show you how the data is moving through time"

	accessibility, and aesthetic appeal.	**Interactive data:** Involves dynamic data representations on digital platforms that users can interact with, allowing users to click, compare, distinguish layers, and hover to view numbers for enhanced exploration.	7	"But we have interactive data visualizations. And so those enable comparison between monitoring programs"
		Images: Refers to the use of images within digital platforms, including snapshots and pictures, utilized for illustration or representation purposes.	3	"And then you can look at those dots. And each one of those docks has been a landing page that has, in the best case scenario, a picture of the site, and then it has the hydrograph."
		Visual elements: Refers to design components that contribute to the aesthetic appeal and usability of the platform, including universal visual elements that enhance accessibility and overall visual appeal.	6	"So it's designed to take that complicated information, take the numbers and just assign a visual elements like something that is universal. Green means go red means stop."
		Search capacities: Functionalities within digital platforms enabling users to locate relevant data. This includes features such as searching by geography, activating geolocation, applying filters, and exploring data through interactive maps or explorer tools.	10	"And then, you know, people can view the data online, they can search by location, county, you know, water body, watershed, you know, a timeframe that they're interested in"
		Customize interface: Enables users to tailor their experience on digital platforms, including saving preferences such as favorite platforms and pinning parameters for convenience.	1	"Pin parameters, counts, view preferences, stuff like that, you know, just just a lot of little things that can make the workflow through the website easy."
		Accessibility measures for disabilities: Encompasses various strategies implemented on digital platforms to ensure inclusivity for users with disabilities, including considerations for color blindness and other accessibility needs.	5	"We and of course we look at you know, it helps us that we build this all under [our organization's] platforms and so there are enforcement's of, you know, accessibility standards and stuff, everything from color schemes, to the way hyperlinks work and all of that so, so we feel good about that."
		Linked information: Refers to supplementary data or resources connected to the main content on digital platforms, including partner details and data descriptors for comprehensive understanding and context.	8	"People saying, like, all of this data is great, but what the heck does it mean? So the science explainers were developed and integrated into the platform as well to meet that need"
		Instructions on tool navigation: Additional guidance provided to navigate the tool, including textual instructions, screenshots illustrating features, and prompts to assist users in overcoming technical knowledge gaps for seamless interaction.	3	"And then, of course, too like, you know, we encourage people when, if they're just starting out with the tool, to use the help information to familiarize themself with the navigation so that it minimizes that misunderstanding or misuse of the tool itself."
	Outreach: Discussion of diverse strategies and initiatives aimed at raising awareness, disseminating information, and engaging with various stakeholders to	**Presentation and Meetings**: This category includes both in-person and online group communication and engagement activities that serve as a means for outreach. In-person examples consist of in-person presentations, conferences, town meetings, town halls, meetings, STEM outreach events, seminars, workshops, public meetings, and code sprints. Online examples comprise Zoom presentations to groups and webinars.	11	"In-person engagement likely only at those those meetings, so everything from technical science driven conferences to public engagements that the department does with local communities so, so we do do presentations,"
		Through partners: Involves outreach efforts facilitated by partnering with external organizations or groups, including	8	"Our partners, who are watershed groups, do 100% of the outreach at this point. So we don't do any outreach. So they'll send out newsletters explaining what we're doing."

	promote the use, relevance, and impact of the platform within relevant communities or target audiences.	engaging organized groups, leveraging existing networks, and promoting collaboration with other platforms		
		Through users: Involves outreach strategies centered around users' active involvement, including relying on users to reach out or self-organize, promoting initiatives through user-driven efforts, and leveraging word-of-mouth recommendations to expand outreach.	5	"And you know, there's, I would say, a set of core and users that are really outspoken about the value of the products and they share it with, you know, they'll post it to all their annual newsletters and share it with local media. And so it's grabbed a lot of attention and they've been kind of really helpful in spreading the word of the value of the products."
		Communication Channels: Includes various communication methods such as email subscriptions and newsletters used for disseminating announcements and updates about the platform.	7	"And then we also have monthly newsletters, with reminders to go test to upload data."
		Promoting Use During Crisis: Involves leveraging environmental and health crises to highlight the utility and relevance of the platform.	2	"If there are major events [...] we will often issue a public safety statement in response to that and then promote the awareness of the [...] platform"
		Targeted outreach: Involves focused efforts to reach specific user groups, such as direct outreach to key user bases and targeted initiatives within certain sectors.	5	"A big part of what we do on some campaigns is reach out to swim groups. [...] And from like, anecdotally, we know that they're using it we just don't know if it's a large contingent of open water swimmers or if it's predominantly recreational water swimmers, or just beach goers who are looking for a place to swim."
		Social media: Utilizes various social media platforms such as YouTube, live streams, and general social media channels to disseminate information, engage with users, and promote platform use. It involves actively managing and sharing content on social media platforms to reach a wider audience and foster interaction with users.	6	"Social media channels certainly are used pretty predominantly here in terms of sharing information about what we do."
		Media and Press: Refers to increases in the platform's visibility and findability through press releases, articles, news channels, and media calls initiated by external organizations.	4	"Because water quality is often top of mind for municipalities who run beaches, oftentimes there are news articles that come out. And so we're often found as local experts that can speak to beach water quality, and we promote the use of [our platform] through those channels"
		Outputs: Relies on users accessing the outputs of the data platform, which may include publications, summary reports, and fact sheets for utilization.	4	"And then at the end of the bloom monitoring season, we send out an kind of annual summary report to those same subscribers"
		Overall passive: Denotes a passive approach or lack of active outreach initiatives.	2	"I don't, it's passive. I'm not doing I'm not doing active outreach with people, other than when someone wants to put in a gauge I'll give a talk and explain to a watershed group what it does."
		Issues Voiced: Refers to concerns or feedback raised by participants regarding outreach efforts or strategies.	4	"As much as we try to include the personal element, at the end of the day, it is the user alone that has to go online and put in that data and choose to do it. So keeping people motivated, is always an I think will always be an issue."

		Brand recognition: Refers to the acknowledgment or familiarity that practitioners seek to achieve regarding their platform or organization among the general public, influencing user engagement.	4	"Just take us a little bit of branding from from the start and make sure that the products are recognizable stuff"
		Sharing uses of data: This involves leveraging instances or examples of how data from the platform has been utilized to promote new uses, encourage continued engagement, and sustain interest among users.	2	"And we love that we love knowing that the data is being used and is trusted and our volunteers love it too. Because they are like wow, not only did I learn something about my own stream, I'm contributing to real research and real science and you know, improving what we know and how we manage our lakes and streams."
	Intersections with other methods of engagement	**Program Partnerships:** Encompasses initiatives such as affiliate programs, local hubs, and educational partnerships, aiming to foster collaborations with external entities to expand outreach, enhance engagement, and promote the platform's use within targeted communities or sectors.	3	"So we work with regional partners in each of those regions to deliver [data] to communities just because people have different monitoring and data needs across the country"
		In-person engagement: Combines the use of digital platforms with in-person methods such as hybrid trainings and citizen science.	9	"And so I went to those locations, and I shook people's hands, and I talked to people and that's how, and that's also one of the reasons because I like seeded that, that is one of the reasons why there's so many gauges."
		Citizens upload data: Involves citizens directly contributing to the platform by reporting pollution, conducting self-assessments of water resources, and submitting data.	2	"As I mentioned, we asked our volunteers if possible to enter their own data. So we'd walk them through that process as well."
		Additional information: Encompasses supplementary materials such as background material, linked information and science explainers, and testing guidance and training materials, aiming to provide users with comprehensive resources to enhance their understanding and utilization of the platform.	9	"And also, we have lesson plans. We have [...] a lot of environmental education stuff going on so we have a middle school lesson plan. We have a university lesson plan. We have aspirations to do an elementary school one"
	Collaboration	**Existing Network**: Refers to collaboration with established connections and partnerships within the platform's network, including government entities and other partners.	8	"So as a small nonprofit, we do take a very collaborative approach. So we'll work essentially with other orgs that have aligned missions, or goals. And oftentimes, we'll work with universities who have research projects that they want to with us"
		Type of Collaboration: Describes the nature of collaborative efforts within the platform, including linkage with other platforms, data sharing agreements, and joint problem-solving initiatives.	12	"we occupy a very specific niche, but there are other systems that we collaborate with, because people want to develop sort of a more comprehensive understanding of, of water quality health, and they're not just going to get that by looking at at water chemistry, for example."
		Finding a Niche: Refers to discussions where participants identify overlap and redundancies in the space, highlighting the need to carve out a distinct niche. Strategies to overcome this issue include generating unique data and addressing gaps in disconnected platforms.	7	"I think one of the things that we hear from people not just related to this product, but in general is that there's so many tools out there, that it becomes difficult to know where to go for what and so I think we do probably sometimes get lost in the fray"

	Data	**Interoperable and Reusable Data**: Encompasses practices aimed at ensuring data interoperability and reusability within the platform, including metadata standardization, consistent data formats, and ease of access through APIs. These measures enhance the platform's success by promoting efficient data sharing, interpretation, and reuse across different systems and users.	8	"And so that's everything that's gone in here is you can find all the data you can use it, it. It works with different systems, we follow data standards. You can, it's really, you can build other apps with the data, you can go to GitHub and use our code. So that, those are all the technical principles behind it"
		Quality Assurance: Encompasses various practices related to quality assurance, including protocols like real-time error detection, transparency in data handling, and collective responsibility for interpretation, fostering confidence in the platform's data integrity.	7	"we ensure that when data is collected and shared, it's shared with source information so that the user understands how the samples were collected under what methods they were collected and how they're then shared."
		Issues with Data: Encompasses various challenges related to data quality and management, including issues such as outdated or incompatible data, difficulties in maintaining and updating content, missing information, delays in data delivery, and limitations in data collection and analysis scale.	6	"think work that needs to be done in some areas in terms of data accuracy, you know, the need to publish quickly and the balancing the need for quality control, I think, is still tough in some examples"
		Data as Collaboration: Encompasses discussions on integrating external data sources and collaborating with other platforms or organizations through data sharing. Includes both being open or closed to data sharing with external entities.	4	"that's one area of work that we've really expanded on quite a bit in the past few years is this concept of integrations."
	User feedback	**User Feedback, Positive**: Reflects the organization's proactive approach in facilitating and encouraging user feedback, including providing responsive assistance, maintaining open communication channels, prioritizing user needs, collaborating with citizen groups, and ensuring user comfort with tools.	9	"We did a whole usability. I did a lot of usability interviews last year, we're gonna redesign it a little because we got some good feedback on how to make it even easier to use"
		User Feedback, Negative: Indicates shortcomings in facilitating user feedback, such as limited opportunities for interaction, lack of personal connection, or absence of training resources.	2	"The only thing we have is our general assistance stuff. So we really don't have a way for people to give feedback on this website, other than under the About tab. There's you know, my name and email and everybody else's on my team, their names and emails that they could contact us. [...] I've never seen anybody specifically contact us because of the website. The contact is for other things, but not for that at least."
	Story: Involves incorporating storytelling elements into platforms.		3	"I think there's there's transparency, there is information, but it also tells a story and so I think like all good information, it should tell the story of what's going on"
Changes	**Drivers of change**	**Overall Adaptability:** Describes the importance of the platform and organization's capacity to adapt to evolving needs and goals.	6	"But ultimately, I think what the public wants or needs does shift over time. And then having that flexibility to be able to anticipate what people need is, you know, is going to be a challenge for state government especially. So those kinds of, you know, transitioning needs will be something that we will have to work on in the future."

		Users: Describes users as drivers of platform change, including mention of incorporating user feedback, establishing working groups, and accommodating specific group needs to both maintain priority audiences and expand the user base.		10	"So it's really important that we are close to the community and that we listen to them and what they're telling us and we integrate their feedback into what we do."
		Collaborators: Describes collaborators as drivers of platform change, including input from data providers and internal comments.		5	"So we have we have we have a wide span of data providers. Some are more sticklers than others to make sure that their data do or do not get out there."
		Funders: Describes funding sources as drivers of platform change. These funding dynamics influence the direction of platform development and priorities, shaping adaptations and initiatives to align with funding requirements and objectives.		6	"The problem at the end of the day is funding is linked to really answering fundamental questions in hydrology. And these are not fundamental questions in hydrology, what is the water level? Is not a fundamental question."
		Field: Describes changes in the field as drivers of platform change, including developments in watershed and ecosystem management, understandings of health risks, and changes to data requirements in response to climate change.		2	"The current levels your you know visualizes plus six feet and minus six feet from the long term average. In the new tool because we're experiencing water levels that sometimes even exceed those. We are now visualizing a plus 10 feet and minus three feet from the low water data."
		Technological Change: Describes technological advancements as drivers of platform change, the rapid pace of technological change, and adaptations to ensure the platform remains relevant.		5	"And then, of course, like I said, digital, it's gotta stay fresh, or it gets lost."
		Priority Users: change code name, essentially comments that say that they weigh the input of certain stakeholders more than that of others.		3	"We have the occasional back and forth with the casual user, we have a lot of back and forth with our collaborators and people within the oceanographic operational research realm and stuff like that."
	Pace of Change: Reflects the actual rate of developments within the platform and any misperceptions held by the public that underestimate the speed or complexity of these changes.			4	"I think that from from working in this space, I think that often, this is probably not unusual across a lot of different technical programs and projects, is that you know, all of these systems take a lot longer to build if you want to build them well than people realize"
	Future	**Catering to Key User Groups:** Emphasizes an emphasis on creating tools that cater to specific categories of users who are already using the platform.		2	"I think one of the main things is that there's a lot more focus on managing groups, instead of individuals joining the platform. So we're really focusing more on creating easy tools for groups to manage different volunteers and different projects that they have."
		Broadening Scope	**Decision makers:** Practitioners articulate wanting to expand engagement with formal decision makers, including congress and government entities.	3	"we're still advocating for, like community based water monitoring on a bit more of a government level. We're seeing in some places [...]. But on a small scale, and on the larger scale, the government side I think there could be more collaboration there that we're always working towards."
			Geographic scope: Practitioners express wanting to expand the geographic scope by engaging stakeholders from other states, international partners, and overall beyond the Great Lakes basin.	8	"There's a lot of collaboration to still be done with Canada. There's still a lot of collaboration to be done within the US. We don't have all 50 states engaged yet. And so I think that's going to be necessary"

			Specific Groups: Practitioners identify specific groups for further collaboration, including industry stakeholders, managers of drinking water intake, conservation authorities, water intake managers, marina owners, entities affiliated with parent companies or related agencies, and non-profit organizations.	3	"I'd like to work more closely with kind of regional maybe conservation authorities and drinking water intake"
			EJ Communities: Practitioners emphasize the significance of engaging environmental justice (EJ) communities, such as Indigenous and tribal groups, along with other EJ communities.	5	"And so thinking about the tribal and indigenous community perspective and insight, that's definitely one of the things I feel that we need to have more involvement with, in this realm of, of water science and data visualizations, and, and meaningful engagement as well."
			Expand User Base: Practitioners recognize the platform's overall potential for growth in users, highlighting publicity and outreach efforts to improve overall public recognition.	3	"I think there's a lot of room for growth, and it could have grown faster."
			Collaboration and Coordination: Practitioners foresee enhancing collaboration and coordination between platforms, highlighting opportunities to combine or integrate with other platforms and coordinate efforts.	5	"And I mean, as an organization, we're not competitive. It's all collaborative. What we're trying to do is fuel a movement and we've recognized early on that it can't be just us. It's the power of the movement that shapes the environmental future. And so we'd love just more collaboration in general."
		Nature of Communication	**Nature of Communication, Information:** Practitioners identify changes to communication mechanisms within the platform that fall under Information, such as improved ways of presenting Information to users.	4	"And this is something also that I've known for years, the idea of gamification, making it so there's some kind of leaderboard"
			Nature of Communication, Knowledge: Practitioners identify changes to communication mechanisms within the platform that fall under Knowledge, such as incorporating in-person elements and personal experience.	2	"I was just in a meeting today about [...] bringing together all of our tools and resources in one place [...] to give end users a series of actions that they can undertake [...]. Because if someone is saying that [a beach] is so important to them, and someone else is saying that there's pollution here and someone over here saying we want to do something about it, suddenly the power of that movement, those three people can come together and enact environmental change on the ground level. And so that's really what we want to turn the platform into next."
		Technological change	**Emerging Technologies:** Practitioners anticipate leveraging advancements in artificial intelligence (AI), machine learning, and augmented reality (AR) technologies to enhance the platform's capabilities.	8	"And then yeah, the move towards AI tools as well. You know, how much can we make use of machine learning approaches for filling data gaps for forecasting applications for better understanding drivers of blooms and integrating different datasets?"
			Changes in data storage and management: Practitioners anticipate adopting new ways of storing, managing, and processing data.	8	" So if we have continuous or real time data, there's got to be cheaper ways to store that data and maintain that data because it's expensive, it's expensive to store a bunch of data, where does it go to or where do you archive it to? And so, yeah, the technology has to catch up with us"

			Data Collection Technologies: Practitioners foresee advancements in technologies used for data collection.	1	"but then also just improvements in the technologies that are being used to collect the data on the ground, we're seeing lots of new types of equipment and tools that people are using. And so it's just like, keeping pace with those, the bit the needs that people have is they're using more and more advanced tools to collect data"
		Improving Usability: Practitioners aim to enhance the platform's usability, focusing on refining the user interface to facilitate easier navigation, management, and product generation.		8	"we're actually in the active process of updating the tool itself. So a new user interface, a new layout, kind of cleaning up based off of user feedback to us."
		Improving Understanding Piece: Refers to efforts aimed at enhancing users' comprehension of the data the platform presents, recognizing the importance of understanding in fostering continued user engagement and utilization.		2	"We are re envisioning it because we think we can do better at some of the more you know, finer goals of helping people understand what it means. [...] You know, we want people to have a better understanding of what it means and make it easy, as easy as possible for folks to come to that knowledge"
		Improving Outcomes: Encompasses efforts to enhance the practical use and impact of the platform, including its linkage to decision-making processes, facilitating the transition from data to actionable outcomes, and fostering increased utilization of data.		4	"I can point to lots of really practical examples of how the data is being used by data contributors, really specific local examples. But whether it's being used and being fed into like formal sort of regulatory policy decisions, there's still a little bit of a lack of transparency around that."
		Data	**Adding Data**: Involves efforts to augment the quantity of data available within the platform, emphasizing efforts to increase the volume of data accessible to users.	2	"So the data is just going to continue to explode."
			Data Formats: Encompasses changes related to the format and nature of data within the platform, including the incorporation of continuous and real-time data streams, inclusion of images, and efforts to align with established data standards.	4	"Someday we would love to have real time data for everything but the technology is not there yet to be able to do that."
			Data Topics: Encompasses efforts to expand the breadth and depth of data coverage within the platform, including the addition of data in various topical areas and potentially incorporating more personal experiences to enrich the dataset.	4	"Well, one of the anticipated uses we're going to try to get done is we just loaded up all of the fish contaminant monitoring program information from all of the fish sampling across the state."
		Improving User Metrics: Involves actions aimed at enhancing the measurement and analysis of user engagement and behavior within the platform, which may include the addition of user profiles and increased tracking of user interactions and usage patterns.		5	"And that's one of the things I think, and that's what we're working on right now is to to see if we can start to understand why people participate and who they are. Because right now, we're just guessing"
	Past	**Reduced Scope:** Indicates a past reduction in the breadth or functionality of the platform, potentially due to limitations in capacity or resources, manifesting as fewer datasets being shared and a narrowing of the target audience.		2	"So because we're not there, 24/7 we don't always have somebody to troubleshoot if there's a bug and keeping the datasets up to date isn't like a routine responsibility. So because of that, more recently, we've reduced the functionality of the dashboard a little bit, or quite a bit, I guess in terms of showing the like the number of data sets that we show."

		Adapting to technological advances: Involves evolving with new technologies like APIs and mobile applications	2	"But nobody had an API before. Maybe one database had an API that people were using when we first started doing this. And I had to meet with the owners and explain to them what it was and they we needed it to pull the data and have to design it to pull in the data. And so yeah, so you have to work with people where they are to get their data and some of it took years to get in there."
		Changes in Design: Denotes alterations made to the platform's design, including a shift towards user-centered design principles and enhancements to facilitate access, data findability, and overall understanding.	2	"Just to make it easier for people to query the database, find and use the data. So that includes a custom download tool that we developed, release, release of the public API, and things like that, oh, as well as the introduction of science explainers"
		Changes in Data: Refers to additions and modifications made to the data available on the platform.	6	"But the only thing that we've done to it to date is actually update the underlying base elevation data because as new elevation data was made available to us, we were able to expand the coverage and show even larger portions than what we had previously,"
		Discontinued Technological Advances: Refers to technological changes or tools that were previously implemented but not continued, often due to issues of longevity or obsolescence, highlighting the challenges associated with maintaining and sustaining digital solutions over time.	3	"We've taken a few detours and tried like building a smartphone application, which was hard to convince people to download a smartphone application [...]. We've tried the image processing, like I said, we've tried temperature. What else have we tried. We tried building some inexpensive sensors that would send in text messages of water levels. All of those things were fine, but they were kind of just like, they didn't develop into new branches within the project. "