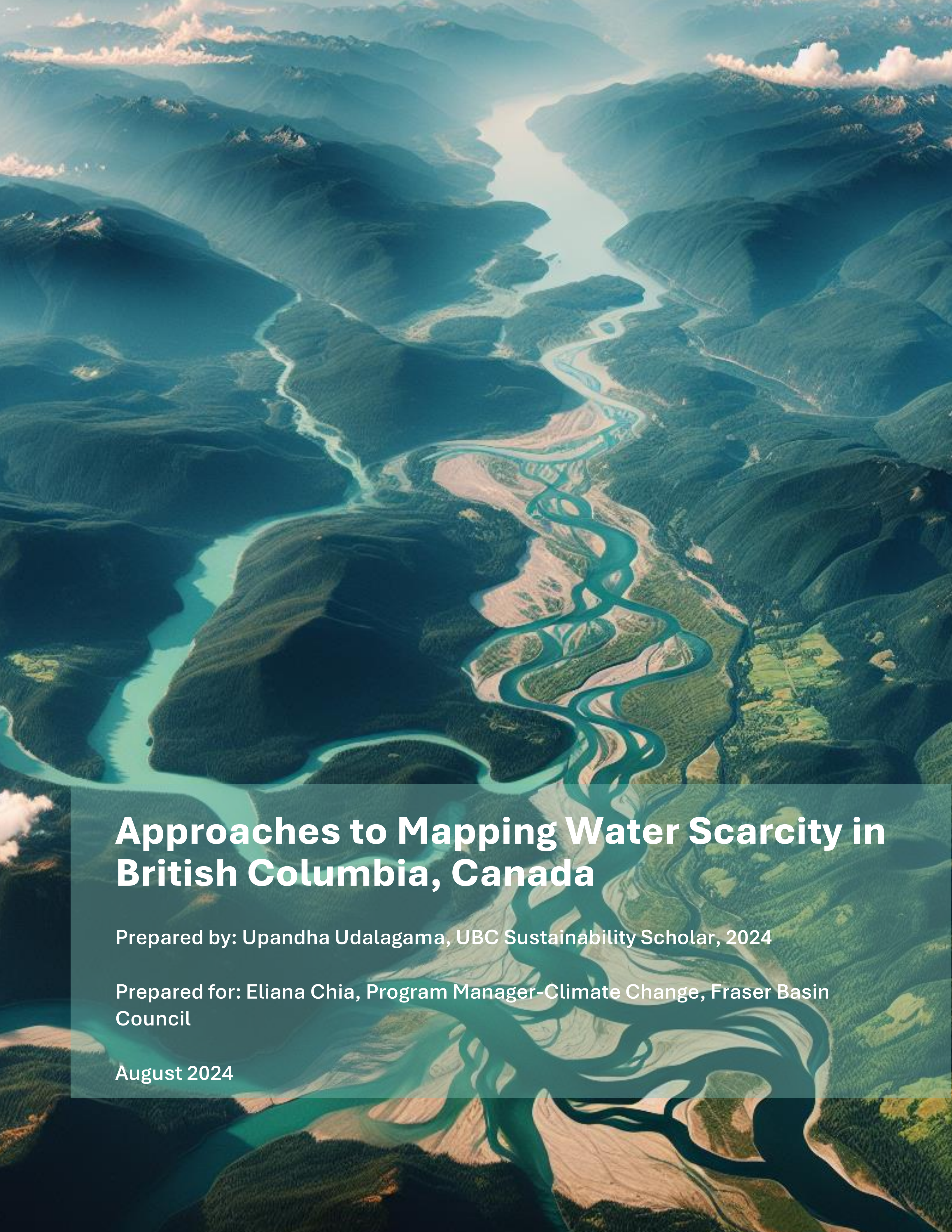

Approaches to Mapping Water Scarcity in British Columbia, Canada

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Disclaimer

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Executive Summary

"Approaches to Mapping Water Scarcity in British Columbia, Canada" addresses the urgent challenge of mapping water scarcity in the province, offering an overview of best practices for local governments, First Nations communities, and other practitioners. This report is a carefully crafted resource, drawing from extensive research and case studies to present best practices, uncover challenges, and extract key lessons tailored specifically to British Columbia's (B.C.) unique climate, geography, and societal context.

Purpose and Objectives

The report aims to facilitate the adoption of effective strategies among diverse partners and actors involved in water scarcity mapping, including communities, researchers, and non-governmental organizations (NGO). By synthesizing insights from environmental science, hydrology, and public policy, it equips decision-makers and practitioners to develop maps that support sustainable water management solutions. The report places particular emphasis on tailoring global best practices to address the unique challenges faced by British Columbia's communities, with a specific focus on Indigenous populations. This approach ensures that the proposed strategies are not only effective but also culturally sensitive and locally relevant.

This report was developed through rigorous research, encompassing a comprehensive review of existing literature and in-depth interviews with experts in water scarcity mapping and water management. Our approach was methodical: we first engaged with academic institutions to establish a robust knowledge foundation. This strategy ensures that any future direct community engagement will be both well-informed and respectful of local dynamics. Consequently, the key strategies presented in this report are firmly grounded in expert knowledge while remaining sensitive to the needs and contexts of affected communities.

Key Strategies

To effectively map water scarcity in B.C., the report highlights the following strategies:

- **Enhancing Community Engagement in the Mapping Process** to ensure that water scarcity maps are inclusive, culturally sensitive, and locally relevant.
- **Investing in Data Collection and Monitoring Infrastructure** to improve the accuracy and resolution of water scarcity maps across the province.
- **Promoting Interdisciplinary Collaboration** in map development to integrate diverse datasets and expertise across multiple fields, including hydrology, climate science, ecology, geology, remote sensing, data science, social sciences, Indigenous Knowledge systems, public health, and urban planning.

Effective water scarcity mapping is crucial for addressing B.C.'s local water challenges. This report provides comprehensive considerations for creating and using water scarcity maps that integrate global best practices with local context. By focusing on accurate, locally relevant mapping techniques, B.C. can better visualize, understand, and manage its water resources for long-term sustainability.

I. INTRODUCTION

Purpose of the Report

The following case study report on "*Approaches to Mapping Water Scarcity in British Columbia, Canada*" is designed to be an invaluable resource for local governments, First Nations communities, and other practitioners throughout British Columbia (B.C.). Its primary aim is to serve as a resource for non-governmental organizations (NGO), researchers, and communities themselves, outlining essential tools, knowledge, and strategies needed to effectively map water scarcity. The report draws on extensive research from both local and international case studies to identify the best practices, challenges, and lessons learned in water scarcity mapping. This wealth of information will be distilled into a guidance framework specifically tailored to the unique climatic, geographical, and societal context of B.C.

Key Objectives

A primary objective of this report is to **enhance the development and implementation of water scarcity mapping** across British Columbia. By synthesizing successful practices, methodologies, and insights from various disciplines—including environmental science, hydrology, geography, and data visualization—the report aims to elevate the quality and effectiveness of water scarcity mapping initiatives. This comprehensive approach to knowledge integration is designed to inform local governments, First Nations, NGOs, and researchers about state-of-the-art tools and techniques for creating accurate, informative, and actionable water scarcity maps.

The report advocates for the equitable development of water scarcity maps in British Columbia, aiming to inform fair and inclusive decision-making processes for water resource management in the province. By incorporating diverse data sources and perspectives, including local knowledge and Indigenous Knowledge, these enhanced mapping capabilities lay the foundation for comprehensive and culturally sensitive water scarcity assessments in B.C. While primarily focused on improving map development, this collaborative approach fosters cooperation among key actors and has the potential to indirectly address broader water management challenges in British Columbia, such as:

- **Ensuring equitable access to clean water for all communities**, especially Indigenous and rural populations that have historically faced barriers (B.C. Assembly of First Nations, 2022)
- **Sustainably managing water resources amid population growth and development pressures**, particularly in water-stressed regions of B.C. where 63% of the population lives (Real Estate Foundation of B.C., 2022)
- **Adapting water management practices and infrastructure to climate change impacts**, including more frequent and severe droughts, floods, and wildfires (Office of the B.C. Ombudsperson, 2022)
- **Protecting aquatic ecosystems and species** already under stress from human activities and further threatened by climate change
- **Improving coordination and collaboration on water governance** among different levels of government, First Nations, stakeholders, and rights holders

By combining Indigenous knowledge and western science through a collaborative process, the development of comprehensive water scarcity maps can help build shared understanding of water challenges. This lays an important foundation for working together on solutions that meet the needs of diverse populations and respect Indigenous rights and jurisdiction over water resources in their territories (B.C. Assembly of First Nations, 2022).

The guidance framework developed from this report is specifically designed to assist local and Indigenous communities in building local capacities for sustainable water management. This framework recognizes the unique challenges and traditional Knowledge of Indigenous Peoples, providing tailored strategies to enhance their ability to create, interpret, and utilize water scarcity maps effectively.

A. Report Context and Methodology

Project Background

The Fraser Basin Council

"Approaches to Mapping Water Scarcity in B.C., Canada" is part of the ongoing efforts of the Fraser Basin Council (FBC) to bolster community resilience against water scarcity challenges in B.C. Established in 1997, FBC is a non-profit, charitable organization that brings together government, First Nations, industry, and non-governmental organizations to address environmental challenges and promote sustainable development in B.C. For the past 27 years, FBC has rolled out collaborative initiatives with a focus on climate change and air quality, watersheds and water resources, and community sustainability and resilience.

The *Best Practices for Extreme Heat and Water Scarcity Hazard, Risk and Adaptation Mapping, and Advancing Disaster and Climate Risk and Resilience Assessments in B.C.* project was initiated in April 2023, with funding and guidance from the Province of B.C.'s Ministry of Emergency Management and Climate Readiness and technical assistance provided by GeoBC. This initiative aligns with the Province of B.C.'s overarching Climate Preparedness and Adaptation Strategy, aimed at anticipating, reducing, and managing climate-related risks across B.C. FBC, as the project lead, was tasked with coordinating activities to enhance climate and disaster risk management capabilities across communities in B.C.

Research Approach

The methodology for this report primarily involved desktop research, grounded in and supplemented by one-on-one interviews with experts in the field of water scarcity mapping and management. This approach allowed for a thorough review of existing literature and best practices while also incorporating current insights from practitioners.

Expert Engagement

For this phase of the research process, a deliberate decision was made to focus on interviewing researchers and academic institutions, exploring their connections to and intersections with water scarcity mapping. This approach was chosen for several important reasons:

- **Avoiding undue burden on communities**: We recognize the importance of not perpetuating the common researcher-research subject dynamic that often places unnecessary demands on local and Indigenous communities (Sabin, 2024). These communities are frequently approached for information without receiving commensurate benefits, leading to research fatigue and potential exploitation (Castleden et al., 2012). Additionally, we considered the seasonal challenges these communities face, particularly during summer months when they are often dealing with wildfires and reduced staff due to vacations.

- **Building a comprehensive knowledge foundation**: By first engaging with academic experts, we developed a thorough foundational understanding of water scarcity in British Columbia. This approach provided interdisciplinary insights from hydrology, climate science, geography, and social sciences, granting access to cutting-edge research and methodologies. The resulting knowledge base enables us to approach future community engagement with informed, relevant questions and a nuanced understanding of local water scarcity issues.

Navigating the Report

This report provides a comprehensive overview of best practices in water scarcity mapping, focusing on their applicability to British Columbia. The main sections are:

I. Introduction and Context to water scarcity in B.C.

II. Best Approaches to Mapping Water Scarcity

III. Challenges and Strategies in Water Scarcity Mapping

Each section builds upon the previous, moving from broad global practices to specific applications in British Columbia. Readers can navigate the report sequentially for a comprehensive understanding or focus on specific sections of interest. Key findings, case studies, and practical examples are highlighted throughout to emphasize important points and provide concrete illustrations of successful water scarcity mapping strategies.

B. What is Water Scarcity?

Water scarcity, a complex global issue, is becoming increasingly relevant in British Columbia. This phenomenon occurs when water resources are insufficient to meet the demands of communities, industries, and ecosystems (Cohen, Neilsen, & Welbourn, 2004). In B.C., water scarcity manifests in various forms, each presenting unique challenges:

Physical Water Scarcity

While B.C. is generally water-rich, certain regions experience physical water scarcity, particularly during dry seasons:

- **Absolute**: In arid areas of the province, such as parts of the Okanagan, where water resources are inherently limited (Moore et al., 2015).
- **Relative**: In regions where seasonal variations or increasing demand temporarily exceed supply, as seen in some coastal areas during summer months (Bakker & Allen, 2015).

Economic Water Scarcity

In B.C., economic water scarcity is less about lack of financial resources and more about:

- Inadequate infrastructure in remote or rapidly growing communities
- Challenges in water governance and equitable distribution, particularly affecting some Indigenous communities (von der Porten & de Loë, 2013).

Ecological Water Scarcity

B.C. faces growing concerns of ecological water scarcity, including:

- Insufficient environmental flows in rivers, impacting salmon and other aquatic species (Gower & Barroso, 2019).
- Water quality degradation from industrial activities and urban runoff (Picketts et al., 2017).
- Groundwater depletion in areas of intensive agriculture or urban development (Holding et al., 2017).

Understanding the multifaceted nature of water scarcity—encompassing physical, economic, and ecological dimensions—is essential for developing effective mapping and management strategies in British Columbia. Climate change is intensifying these challenges, with projections of more frequent droughts, earlier spring runoff, and reduced summer flows (Pike et al., 2010). This evolving landscape underscores the urgent need for adaptive, comprehensive water scarcity mapping tools to inform resilient and equitable water management practices across the province.

❖ Evaluating Water Scarcity through Metrics and Indicators

To effectively assess and monitor water scarcity, researchers and policymakers use various metrics and indicators. These tools provide valuable insights into the severity and extent of the problem, helping to identify unsustainable water usage patterns, reveal complex factors contributing to water scarcity, and inform targeted strategies for sustainable water management and conservation.

Water Stress Index (WSI)

The Water Stress Index (WSI) compares total annual water withdrawals to total available renewable supply. Values above 0.4 indicate high water stress, while values above 0.8 signify severe water stress (Mai et al., 2023).

- **Global Case Study:** A study of the Vu Gia-Thu Bon River basin in Vietnam found WSI values up to 3.4 in downstream areas during the dry season, highlighting the extreme water scarcity faced by communities in the region (Mai et al., 2023).

WSI serves as a critical measure, where high values not only indicate water stress but also highlight regions at risk of severe ecological and human crises.

Falkenmark Indicator

The Falkenmark Indicator, or water crowding index, provides a snapshot of a country or region's overall water situation by measuring annual renewable freshwater availability per person.

Thresholds:

- Less than 1,700 m^3 per person per year: Water stressed
- Less than 1,000 m^3: Water scarcity

- Less than 500 m^3: Absolute water scarcity (Hussain et al., 2022)

This metric has been widely applied to assess water scarcity at national and regional levels, helping policymakers prioritize interventions in the most water-stressed areas.

Water Scarcity Index

The Water Scarcity Index, also known as the Water Exploitation Index, assesses the ratio of water use to water availability, with values above 0.4 indicating severe water stress (Vanham et al., 2018).

- **Global Case Study:** A study of the Mediterranean region found that 13 out of 22 Mediterranean countries face high water stress, with Water Scarcity Index values exceeding 0.4. Cyprus, for example, had a value of 0.7, indicating severe water scarcity due to its semi-arid climate and high water demand for agriculture and tourism (Vanham et al., 2018).

This metric provides a clear indication of the balance between water demand and supply, highlighting areas where water usage patterns are unsustainable.

Note: While the Water Stress Index and Water Scarcity Index are related, they are not exactly the same. The Water Stress Index typically focuses on water withdrawals and renewable supply, whereas the Water Scarcity Index may incorporate additional factors such as environmental water requirements and seasonal variations.

Water Footprint

The Water Footprint measures the volume of freshwater used to produce goods and services, consisting of three components:

- **Blue Water:** Surface and groundwater consumed
- **Green Water:** Rainwater consumed
- **Grey Water:** Freshwater required to assimilate pollutants (Hoekstra, 2017)
- **Global Case Study:** A study of wine production in Spain found that the average water footprint of wine is 3.5 L of water per 125 mL glass. The majority (85%) comes from green water, while blue water accounts for 9%, and grey water for 6%. However, in arid regions, the blue water component can be significantly higher, raising concerns about water sustainability in wine-producing areas facing water scarcity (Bonamente et al., 2016).

This metric helps to identify sectors and practices that contribute the most to water consumption and pollution, informing targeted interventions for sustainable water management.

Virtual Water Balance

The Virtual Water Balance is calculated as the difference between virtual water import and export, providing insights into the embedded water in traded products (Hoekstra & Mekonnen, 2012).

- **Global Case Study:** A comprehensive study of global virtual water flows related to international crop trade found that the United States, Brazil, and Argentina are major virtual water exporters, while Japan, Germany, and Italy are significant importers. For instance, from

1996 to 2005, the U.S. had a net virtual water export of 92 Gm^3/yr, primarily due to crop exports, while Japan had a net import of 92 Gm^3/yr, largely from imported crops and animal products (Hoekstra & Mekonnen, 2012).
- **Local Case Study:** In British Columbia, a study of the Okanagan Basin's virtual water trade revealed that the region is a net virtual water exporter, primarily due to its fruit production. The basin exports approximately 29 million m^3 of virtual water annually through agricultural products, while importing about 14 million m^3 through various goods, resulting in a net export of 15 million m^3 of virtual water per year (Schreier et al., 2007).

This metric underscores the importance of trade in water resource management and can inform policies to promote more sustainable production and consumption patterns, both globally and within water-stressed regions like the Okanagan Basin.

❖ Mapping Water Scarcity in British Columbia

Water scarcity mapping is a critical tool for visualizing and understanding water stress across British Columbia. By leveraging various indicators and creating specialized maps, policymakers, practitioners, and researchers can identify high-stress areas, prioritize interventions, and develop targeted strategies for sustainable water management. Key applications of water scarcity mapping in B.C. include:

1. **Identifying regions of high-water stress**, such as the Okanagan Basin, using Water Stress Index (WSI) maps (Fleming et al., 2015)
2. **Illustrating seasonal water availability fluctuations** through Seasonal Water Scarcity maps, particularly relevant for areas like the Gulf Islands
3. **Assessing groundwater vulnerability** in regions like the Lower Fraser Valley using Groundwater Vulnerability maps
4. **Projecting future water scarcity** based on climate change scenarios to inform long-term planning and adaptation strategies

These mapping tools enable a comprehensive understanding of B.C.'s unique water challenges, facilitating more effective water management policies, infrastructure investments, and conservation efforts across the province.

C. Causes & Consequences of Water Scarcity

Water scarcity in British Columbia has far-reaching consequences that affect environmental, economic, and social aspects of life in the province. These impacts are becoming more pronounced due to climate change and increasing human demands on water resources.

Causes of Water Scarcity

1. **Climate Change**: Shifting precipitation patterns, reduced snowpack, and earlier spring melts are altering the timing and availability of water resources across B.C. (Pike et al., 2010).

2. **Population Growth**: Increasing urbanization and population growth, particularly in regions like the Lower Mainland and Okanagan, are putting pressure on local water supplies (Bakker & Cook, 2011).
3. **Agricultural Intensification**: Expansion of water-intensive crops and irrigation practices, especially in areas like the Okanagan Valley, is straining water resources (Neilsen et al., 2006).
4. **Industrial Demands**: Resource extraction industries, including mining and natural gas fracking, compete for water resources in various parts of the province (Gower et al., 2016).
5. **Forest Disturbances**: Large-scale forest die-offs due to pine beetle infestations and wildfires have altered watershed hydrology, affecting water availability and quality (Winkler et al., 2010).
6. **Regulatory Challenges**: Outdated water allocation systems and inadequate groundwater regulations have contributed to unsustainable water use patterns in some regions (Brandes et al., 2015).

Environmental Consequences

1. **Threats to Aquatic Ecosystems**: Reduced streamflows and warming water temperatures pose serious threats to B.C.'s aquatic ecosystems. Pacific salmon populations, which are culturally and ecologically significant, are particularly vulnerable as they require cold, clean water to survive. Continued water scarcity could push some salmon runs to the brink of extinction (Pacific Salmon Foundation, 2021).
2. **Forest Health**: Water stress contributes to forest die-offs and increased wildfire risk, altering B.C.'s landscape and carbon storage capacity. Many watersheds are reaching critical disturbance thresholds that could significantly alter streamflow and water availability (Allen et al., 2015).
3. **Groundwater Depletion**: In areas of intensive agriculture or urban development, such as the Lower Fraser Valley, groundwater resources are at risk of overexploitation (Wei & Allen, 2004).

Economic Impacts

1. **Agricultural Losses**: Water-stressed regions, such as the Peace River region, could face substantial crop yield reductions due to changing precipitation patterns and increased water scarcity (Dierauer et al., 2018).
2. **Forestry Sector Challenges**: Reduced water availability stresses forest ecosystems, increasing vulnerability to pests and wildfires, which could impact B.C.'s crucial forestry sector (Haughian et al., 2012).
3. **Tourism Industry Effects**: Water-based recreational activities, a significant draw for B.C.'s tourism industry, may be affected by lower water levels in lakes and rivers.
4. **Hydroelectric Power Generation**: B.C. relies heavily on hydroelectric power. Reduced water availability could impact energy production, necessitating changes in the province's energy strategy.

Social and Cultural Impacts

1. **Indigenous Communities**: Many First Nations in B.C. are disproportionately affected by water scarcity and quality issues. Some reserves have faced long-term boil water advisories, impacting health, traditional practices, and quality of life (Human Rights Watch, 2016).

2. **Rural-Urban Disparities**: Water scarcity may exacerbate existing inequalities between urban and rural areas in B.C., potentially leading to demographic shifts and increased urbanization.
3. **Water Governance Challenges**: As water becomes scarcer, tensions between different water users (e.g., agriculture, industry, municipalities) are likely to intensify, necessitating more robust water governance frameworks (von der Porten & de Loë, 2013).
4. **Public Health Concerns**: While not as severe as in some global contexts, water scarcity can lead to water quality issues, particularly in rural and Indigenous communities, potentially impacting public health (Dunn et al., 2014).

Infrastructure and Management Challenges

1. **Water Supply Systems**: Existing water infrastructure in B.C. may be inadequate to handle the changing patterns of water availability, requiring significant investments in upgrading and adapting systems (Bakker & Cook, 2011).
2. **Transboundary Issues**: B.C.'s water resources often cross provincial and international boundaries, adding complexity to water management and potentially leading to inter-jurisdictional conflicts (Norman & Bakker, 2010).

The multifaceted consequences of water scarcity in British Columbia underscore the urgent need for adaptive water management strategies, improved conservation efforts, and inclusive policy-making that considers the diverse needs of all stakeholders in the province. Effective water scarcity mapping will be crucial in identifying vulnerable areas and informing targeted interventions to mitigate these impacts.

❖ Future Projections

Climate change and increasing water demands are projected to significantly impact water availability and scarcity in British Columbia and across Canada in the coming decades:

British Columbia Projections

1. **Irrigation Demand**: A study by Brown et al. (2020) projects that irrigation water demand in the Okanagan Basin could increase by 30-100% by the 2050s, depending on crop type and climate scenario.
2. **Snow Water Equivalent (SWE)**: Research by Islam et al. (2017) indicates that spring SWE in coastal British Columbia could decrease by 55-75% by the 2050s under a high emissions scenario.
3. **Seasonal Water Supply Changes**: The B.C. Ministry of Environment and Climate Change Strategy (2019) reports that summer streamflow in snow-dominated watersheds could decrease by 10-40% by the 2050s.
4. **Vegetation Water Demand**: A study by Bonsal et al. (2020) suggests that growing season length in B.C. could increase by 20-40 days by the 2050s, potentially increasing vegetation water demand.

National and Global Context

1. **Economic Impact**: The Canadian Climate Institute (2022) estimates that climate change could cost Canada $25 billion annually by 2025, rising to $78-101 billion annually by 2050 if action is not taken.
2. **Agricultural Sector**: Agriculture and Agri-Food Canada (2022) projects that climate change could lead to both opportunities (e.g., longer growing seasons) and challenges (e.g., increased water stress) for Canadian agriculture.
3. **Nationwide Changes**: A report by Natural Resources Canada (2021) indicates that annual precipitation is projected to increase across most of Canada, but summer rainfall may decrease in southern Canada, exacerbating water scarcity issues.

These projections highlight the critical need for proactive measures to ensure water security for communities, industries, and ecosystems in British Columbia and across Canada as they face climate change and increasing water demands.

D. Water Scarcity Hotspots in British Columbia

❖ Island Regions

East Vancouver Island Basin

- **Communities and Indigenous Groups**: The East Vancouver Island Basin encompasses major urban centers such as Victoria, Saanich, Oak Bay, and Esquimalt, alongside Indigenous communities including the W̱SÁNEĆ Peoples, Songhees, Esquimalt, T'Sou-ke, and Scia'new (Beecher Bay) First Nations. Further north, significant population centers include Nanaimo, Comox Valley, and Campbell River, with First Nations such as the Snuneymuxw, K'ómoks, and Wei Wai Kum Nations (B.C. Assembly of First Nations, 2023).
- **Geographic and Climatic Context**: This region experiences a pronounced rain shadow effect due to the Vancouver Island Ranges, resulting in a markedly drier climate compared to the island's western coast. As of 2022, the area has been designated as Drought Level 4, indicating severe water scarcity that poses significant threats to both ecological systems and socioeconomic stability (B.C. Ministry of Environment and Climate Change Strategy, 2022). Recent climate data shows that annual precipitation in Victoria has decreased by approximately 6% over the past 50 years, further exacerbating water scarcity issues (Pacific Climate Impacts Consortium, 2023).
- **Historical Development and Environmental Impact**: The landscape has undergone substantial transformation due to historical land use practices, particularly extensive logging operations. These changes have had profound impacts on local water systems, increasing the region's vulnerability to water scarcity. The subsequent urbanization and agricultural expansion have further compounded these issues (B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2022). For instance, forest cover in the Capital Regional District decreased by 7.5% between 1986 and 2011, reducing natural water retention capabilities (Capital Regional District, 2022).

- **Demographic Pressures**: Population growth, especially in the Greater Victoria area, has led to a significant increase in water demand, placing considerable strain on the limited supply. The Capital Regional District's population grew by 8% between 2016 and 2021, with projections indicating continued growth of 20% by 2038 (B.C. Stats, 2022). This rapid growth necessitates innovative water management strategies to ensure long-term sustainability.

West Vancouver Island

- **Communities and Indigenous Groups**: The region includes major tourist destinations such as Tofino and Ucluelet, alongside Indigenous communities like the Tla-o-qui-aht and Yuułuʔiłʔatḥ (Ucluelet) First Nations (Clayoquot Biosphere Trust, 2023).
- **Geographic and Climatic Context**: Despite its location within a temperate rainforest, this area faces increasing water shortages. These challenges are exacerbated by climate change impacts and reduced precipitation patterns (Environment and Climate Change Canada, 2023). Recent studies indicate that while annual precipitation remains high, summer rainfall has decreased by 15% in the past three decades, coinciding with peak water demand (West Coast N.E.S.T., 2023).
- **Historical Development and Environmental Impact**: Conservation initiatives, particularly those led by the Tla-o-qui-aht First Nation, have played a crucial role in preserving forests that regulate water flow. These efforts underscore the vital connection between forest conservation and water security (Clayoquot Sound UNESCO Biosphere Region, 2023). The Tla-o-qui-aht Tribal Parks initiative, for example, has protected over 70,000 hectares of land, contributing significantly to watershed health (Central Westcoast Forest Society, 2023).
- **Demographic Pressures**: The region experiences a substantial influx of tourists during the dry summer months, placing additional pressure on already strained water resources. Tourism in the Pacific Rim region has grown by 30% in the last five years, with over 600,000 visitors annually, significantly impacting local water demand (Destination British Columbia, 2023).

Gulf Islands

- **Communities and Indigenous Groups**: The Gulf Islands comprise several populated islands including Salt Spring, Pender, Galiano, Mayne, and Saturna, with Indigenous communities such as the W̱SÁNEĆ Peoples maintaining a strong presence (Islands Trust, 2023).
- **Geographic and Climatic Context**: Situated in the rain shadow of Vancouver Island and the Olympic Mountains, these islands experience a drier climate and rely heavily on rainfall for freshwater replenishment. Climate change has intensified these challenges, with models projecting a 20% decrease in summer precipitation by 2050 (Capital Regional District, 2023).
- **Historical Development and Environmental Impact**: The transition from traditional Indigenous management practices to European settlement patterns has led to increased water demand through the expansion of agriculture, logging operations, and tourism. These changes have placed significant strain on the islands' limited water supplies (Gulf Islands National Park Reserve, 2023). Recent studies estimate that groundwater extraction rates on some islands exceed natural recharge by up to 30% during peak summer months (Salt Spring Island Water Preservation Society, 2022).

- **Demographic Pressures**: The Gulf Islands have a disproportionately older population, with a median age significantly higher than the provincial average. This demographic shift is largely attributed to an influx of retirees and seniors drawn by the mild climate and scenic landscapes. Older demographics tend to exhibit higher per capita water usage, often due to increased landscaping activities and the presence of less water-efficient appliances in older homes (B.C. Stats, 2023).

❖ Coastal Regions

The Central Coast

Case Study: The Kwakshua Watersheds Observatory

Nestled along British Columbia's central coast, the Kwakshua Watersheds Observatory (KWO) encompasses Kwakshua Channel, Meay Inlet, and their surrounding watersheds (Hakai Institute, 2023). This area falls within the traditional territories of Coastal First Nations, including members of the Heiltsuk, Wuikinuxv, and Nuxalk Nations (B.C. Treaty Commission, 2023).

B.C.'s coastal margin watersheds, including those within the KWO, play a crucial role in connecting terrestrial and marine ecosystems. These watersheds are global hotspots for exporting dissolved organic carbon, nitrogen, and iron from land to the coastal ocean (Pacific Salmon Foundation, 2022). This significant flux of organic matter and nutrients supports productive coastal food webs and fisheries, highlighting these systems' ecological importance.

Understanding the origins, pathways, and ecosystem consequences of this terrestrial-to-marine material flux is a key KWO objective. The high yields of dissolved organic matter from these watersheds underscore the need for integrated management approaches that consider both water quantity and quality in addressing water scarcity issues (Hakai Institute, 2023).

Geographic and Climatic Context

Part of the northeast Pacific coastal temperate rainforest (NPCTR), the region is known for high rainfall, with an impressive 3,000-5,000 mm average annual rainfall recorded across its monitored watersheds (Pacific Climate Impacts Consortium, 2023).

The KWO's hydrological regime is mainly pluvial, characterized by rapid runoff responses to intense fall and winter storms (B.C. River Forecast Centre, 2022). However, coastal watersheds in British Columbia have diverse hydrological regimes, including rainfall-dominated, snowmelt-dominated, and hybrid systems influenced by both rainfall and snowmelt (B.C. Ministry of Environment and Climate Change Strategy, 2023).

Despite abundant rainfall, coastal margin watersheds like those monitored by the KWO can experience water scarcity due to several factors:

- **Seasonal Variability**: The pluvial regime leads to high winter flows but can result in critically low summer streamflows, especially in smaller watersheds (B.C. River Forecast Centre, 2022).
- **Rapid Runoff**: The steep, complex terrain and dense rainforest of the NPCTR promote rapid runoff, potentially limiting groundwater recharge and baseflow during dry periods (Pacific Climate Impacts Consortium, 2023).
- **Climate Change Impacts**: As climate change progresses, hybrid and snowmelt-dominated watersheds are projected to face increasing summer water scarcity due to earlier spring melts and reduced snowpack (B.C. Ministry of Environment and Climate Change Strategy, 2023).
- **Population Pressure**: While the KWO region is sparsely populated, it serves as a microcosm for challenges facing many coastal communities that rely on small, isolated watersheds for their water supply (Living Water Smart: British Columbia's Water Plan, 2022).

Navigating the Crisis and Planning for the Future

Established in 2013, the KWO marked a significant leap forward in hydrological monitoring for the region. The observatory fills a critical spatial data gap by providing long-term, high-resolution hydrometeorological monitoring in a remote NPCTR area that was previously sparsely gauged (Hakai Institute, 2023).

The KWO uses advanced automated sensor networks and novel stream gauging methods to continuously monitor weather, soil moisture, streamflow, water quality, and other parameters at high temporal resolution. These sophisticated monitoring techniques allow for:

- Quantification of uncertainty and identification of errors in measurements
- Improved understanding of hydrological processes in complex coastal rainforest environments
- Better-informed water management decisions and policy development

Implications for Water Management and Policy

The insights gained from the KWO and similar studies in coastal margin watersheds have significant implications for water management and policy in British Columbia:

- **Drought Planning**: The Province of B.C. has developed a Drought and Water Scarcity Response Plan to monitor and manage water resources during scarcity (B.C. Drought Information Portal, 2023). However, many coastal communities still lack detailed water supply and demand analyses, drought management plans, and water conservation strategies.
- **Climate Change Adaptation**: The data collected by observatories like the KWO are crucial for developing climate change adaptation strategies. For example, hydrological modeling studies of coastal B.C. watersheds predict significant declines in summer streamflow under future climate scenarios (Pacific Institute for Climate Solutions, 2023).
- **Ecosystem-Based Management**: Recognizing coastal margin watersheds as biogeochemical hotspots emphasizes the need for integrated, ecosystem-based

management approaches that consider both terrestrial and marine systems (Fraser Basin Council, 2023).

- **Data-Driven Decision Making**: The high-resolution data provided by the KWO and similar observatories enable more informed, data-driven decision-making for water resource management in complex coastal environments (B.C. Environmental Flow Needs Policy, 2022).

The Lower Mainland

- **Communities and Indigenous Groups:** The Lower Mainland, encompassing Metro Vancouver and the Fraser Valley, is home to many Coast Salish Peoples, including 14 First Nation communities. As of 2021, it housed nearly 3 million people, about 60% of B.C.'s population (Metro Vancouver, 2023; First Nations Fisheries Council of British Columbia, 2022).
- **Geographic and Climatic Context:** The region faces seasonal water supply-demand mismatches, with most precipitation occurring in winter while demand peaks in summer. The water supply system heavily relies on snowmelt, introducing vulnerability to variations in winter snowfall and spring melt patterns (Greater Vancouver Water District, 2023).
- **Historical Development and Environmental Impact:** Rapid urbanization has led to increased impermeable surfaces, disrupting natural water retention and altering local hydrology. Historical water shortages, such as the 1992 drought and 2015 water restrictions, highlight the region's water supply vulnerability (B.C. Water & Waste Association, 2022).
- **Demographic Pressures:** Projections suggest the Lower Mainland could reach 4 million residents by 2041, placing immense pressure on water resources. In response, Metro Vancouver has implemented conservation programs and infrastructure upgrades to ensure water security (Fraser Valley Regional District, 2023).

❖ Interior Regions

The Peace Region

- **Communities and Indigenous Groups:** The Peace Region, located in northeastern British Columbia, encompasses communities such as Fort St. John and Dawson Creek. It is also home to several Indigenous communities including the Blueberry River, Doig River, Halfway River, Saulteau, and West Moberly First Nations (BCAFN, 2023).
- **Geographic and Climatic Context:** The Peace Region experiences a continental climate with diverse landscapes. As of January 2023, the region faces extreme drought conditions, with its four main water basins at drought level 5, the most severe category. Current snowpack levels are only 72% of historical averages (Peace River Regional District, n.d.).
- **Historical Development and Environmental Impact:** The region's economic development has evolved from the fur trade to agriculture, forestry, and oil and gas industries. The discovery of the Elmworth natural gas field in the 1970s spurred rapid growth in cities like Fort St. John. However, the water-intensive hydraulic fracturing used in gas extraction has strained water resources, with the sector withdrawing an average of 0.004% of the region's total annual runoff each year (B.C. Hydro, 2019).

- **Demographic Pressures:** The Peace River Regional District, spanning 119,200 km^2, is the largest regional district in B.C. but has a sparse population density of only 0.5 people per km^2 as of 2021 (Statistics Canada, 2022) Balancing economic growth with sustainable water management remains a key challenge for the region moving forward.

The Nechako Watershed

- **Communities and Indigenous Groups:** The Nechako Watershed includes communities in the Nechako Valley and is home to the Saik'uz, Stellat'en, and Nadleh Whut'en First Nations. The construction of the Kenney Dam in the 1950s displaced Indigenous communities like the Cheslatta T'En from their traditional lands (B.C. Hydro, 2019).
- **Geographic and Climatic Context:** The Nechako Watershed covers approximately 47,200 km^2. The region's climate varies from coastal influences in the west to more continental conditions in the east, leading to uneven precipitation and localized water scarcity (Nechako Watershed Roundtable, 2023).
- **Historical Development and Environmental Impact:** The construction of the Kenney Dam in the 1950s significantly disrupted the watershed's natural hydrology. As the second-largest agricultural area in B.C., the Nechako Valley places high demands on water resources (Government of British Columbia, 2023c)
- **Demographic Pressures:** The Nechako Watershed faces complex water management challenges, including inadequate groundwater usage tracking, climate change impacts on water availability, and water licensing conflicts. These issues are exacerbated by changing precipitation patterns and competing demands for water resources.

The Southern Interior

- **Communities and Indigenous Groups:** The Southern Interior region includes the Okanagan and Kamloops areas, with some of B.C.'s fastest-growing urban centers, including Kelowna, Vernon, and Kamloops. This region is the traditional territory of several Indigenous peoples, including the Syilx Okanagan Nation, Secwépemc (Shuswap) Nation, and Nlaka'pamux Nation. Key Indigenous communities in the area include the Westbank First Nation, Okanagan Indian Band, Tk'emlúps te Secwépemc (Kamloops Indian Band), and Lower Nicola Indian Band, among others (B.C. First Nations, 2023; First Nations A-Z Listing, 2023).
- **Geographic and Climatic Context:** The Southern Interior is characterized by a semi-arid climate with extreme temperature and precipitation patterns that contribute to water scarcity. Low spring rainfall and summer heat waves lead to critically low water flows in many areas (Government of British Columbia, 2023e).
- **Historical Development and Environmental Impact:** Historically, a lack of groundwater regulation in B.C. prior to the *Water Sustainability Act* in 2016 resulted in "half a century of neglect" in understanding and managing groundwater. Agricultural irrigation, especially for the Okanagan's tree fruits, vegetables, and vineyards, is the largest water use from April to October (Government of British Columbia, 2023f).
- **Demographic Pressures:** The Southern Interior has some of B.C.'s fastest-growing urban centers, putting pressure on limited water supplies. Studies show the average Okanagan household uses 1,032 liters of water per day, much of it for summer landscaping (Okanagan Basin Water Board, 2023). Despite the Okanagan Basin Water Board being established in 1969 to address water challenges, imbalances between supply and demand persist in the Southern Interior.

II. BEST APPROACHES TO WATER SCARCITY MAPPING

A. B.C.'s Approach to Mapping Water Scarcity

In the face of growing water scarcity challenges, innovative mapping techniques have emerged as critical tools for sustainable resource management. This section delves into cutting-edge approaches that are revolutionizing how we understand, visualize, and address water scarcity issues. We'll explore four key areas that are shaping the future of water management:

1. **Policy Instruments and Governance Frameworks**: The backbone of effective water management, these structures provide the legal and institutional basis for coordinated action.
2. **Community Engagement and Participatory Mapping**: Harnessing local knowledge and fostering stakeholder involvement to create more accurate and actionable water scarcity maps.
3. **Advanced Technologies and Integrated Data**: Leveraging cutting-edge tools like satellite imagery, AI, and IoT devices to gather and analyze water data with unprecedented precision.
4. **Integration of Traditional Knowledge and Modern Technology**: Bridging ancient wisdom with contemporary science to develop holistic water management strategies.

These approaches represent a comprehensive strategy for understanding, visualizing, and addressing water scarcity challenges. They combine top-down policy directives with bottom-up community involvement, cutting-edge technology with time-honored wisdom, and local insights with global perspectives.

Our exploration of these best practices will begin with a detailed look at British Columbia's approach, showcasing how this Canadian province has become a leader in innovative water management strategies. We will then broaden our scope to examine Canada's national efforts in water scarcity mapping, highlighting how federal and provincial initiatives work in concert to address this critical issue. Finally, we will survey global approaches, drawing insights from diverse regions and cultures around the world.

By examining these best practices at local, national, and international levels, we aim to provide a comprehensive understanding of the most effective strategies for mapping and managing water scarcity in various contexts.

1. Policy Instruments and Governance Frameworks

British Columbia has emerged as a leader in developing a comprehensive approach to water management, particularly in addressing water scarcity through innovative mapping and governance frameworks. The province's strategies are tailored to its unique environmental challenges, including diverse climatic zones, from coastal rainforests to semi-arid interior regions, and the impacts of climate change on water resources.

The Water Sustainability Act: A Cornerstone of B.C.'s Water Governance

The *Water Sustainability Act* (WSA), enacted in 2016, represents a paradigm shift in B.C.'s approach to water management (Province of British Columbia, 2016). This landmark legislation introduces several key elements that are crucial for effective water scarcity mapping and management:

1. **Groundwater Regulation**: For the first time in B.C.'s history, the WSA brings groundwater into the regulatory framework, enabling comprehensive mapping and management of both surface and subsurface water resources (Curran & Brandes, 2019).
2. **Water Sustainability Plans**: These plans allow for place-based, watershed-scale approaches to water management, facilitating the integration of water scarcity mapping into local and regional planning processes (Brandes et al., 2017).
3. **Environmental Flow Needs**: The Act mandates the consideration of environmental flow needs in water allocation decisions, necessitating detailed mapping of water resources and ecosystem requirements (ESSA Technologies, 2009).

B.C. Drought and Water Scarcity Response Plan: Proactive Management

The B.C. Drought and Water Scarcity Response Plan exemplifies the Province of B.C.'s (the Province) commitment to evidence-based, proactive water management (British Columbia Ministry of Environment and Climate Change Strategy, 2023). This plan:

- Utilizes advanced mapping techniques to identify areas at risk of water scarcity
- Establishes clear drought levels based on comprehensive hydrological data
- Outlines specific response actions for each drought level, informed by detailed water scarcity maps

B.C. Aquifer Classification System: Mapping Groundwater Resources

Recognizing the critical importance of groundwater, especially in water-scarce regions, B.C. has developed the B.C. Aquifer Classification System (Berardinucci et al., 2002). This system:

- Provides a standardized approach to mapping and classifying aquifers
- Informs land-use planning and water allocation decisions
- Supports the identification of vulnerable groundwater resources in water-scarce areas

Integration of Indigenous Knowledge and Rights

B.C.'s water governance framework increasingly recognizes the importance of Indigenous Knowledge and rights in water management:

- The First Nations Fisheries Council of British Columbia advocates for the inclusion of traditional ecological knowledge in water governance (First Nations Fisheries Council of B.C., 2019).
- Initiatives like the Indigenous Watershed Initiatives program support First Nations in developing watershed governance strategies that blend traditional knowledge with Western science (First Nations Fisheries Council of B.C., 2022).

Collaborative Approaches to Water Scarcity Mapping

B.C. has fostered collaborative approaches to water scarcity mapping, involving multiple stakeholders:

- The Okanagan Basin Water Board collaborates with the Syilx Okanagan Nation to incorporate traditional knowledge into water management strategies (Okanagan Basin Water Board, 2021).
- The Columbia Basin Water Monitoring Collaborative brings together Indigenous communities, local governments, and researchers to develop comprehensive water monitoring frameworks (Columbia Basin Watershed, 2021).
- The B.C.-First Nations Water Table, comprised of representatives from the Province and delegates from First Nations across B.C., is working on co-developing B.C.'s watershed security strategy. This initiative aims to strengthen water management and protection across the province, incorporating both Western science and Indigenous Knowledge in its approach to water governance.

B.C.'s approach to water scarcity mapping and management, grounded in robust policy instruments and governance frameworks, offers valuable lessons for other jurisdictions facing similar challenges. By combining legislative tools, innovative mapping techniques, and collaborative approaches, B.C. is working towards a more resilient and adaptive water management system in the face of increasing water scarcity challenges.

2. Community Engagement and Participatory Mapping

Community engagement and participatory mapping techniques have emerged as powerful tools for addressing water scarcity concerns in British Columbia. By involving diverse partners, including local communities, First Nations, NGOs, and various levels of government, these approaches aim to create a more holistic and inclusive framework for water resource management tailored to B.C.'s unique needs.

Multi-Stakeholder Engagement: The Fraser Basin Council

The Fraser Basin Council (FBC) exemplifies successful community engagement in water management within British Columbia. As a multi-stakeholder non-governmental organization, FBC has effectively employed participatory processes to foster a shared understanding of water issues in B.C.'s watersheds and other regions across B.C. By engaging a diverse array of public and private sector partners, including First Nations communities, FBC has transcended intergovernmental challenges and heightened awareness of the complex interdependencies within the watershed ecosystem (Blomquist et al., 2005).

One of the FBC's notable initiatives is the Nechako Watershed Roundtable, which brings together diverse stakeholders to address water management issues in the Nechako watershed. This collaborative approach has led to the development of a comprehensive watershed strategy that integrates traditional ecological knowledge with scientific data (Fraser Basin Council, 2021).

The Role of Environmental NGOs in B.C.

Environmental NGOs have played a pivotal role in advancing participatory water scarcity mapping efforts in British Columbia. The collaboration between the Pacific Institute for Climate Solutions and researchers to develop the B.C. Water Tool, an innovative interactive online platform, exemplifies the transformative potential of participatory mapping in the province. This tool enables users to explore comprehensive data on water supply and demand across B.C., democratizing access to critical environmental data and catalyzing stakeholder engagement in water planning and management processes (Werner et al., 2019).

Another significant initiative is the Watershed Watch Salmon Society's "Our Water B.C." campaign, which engages communities across B.C. in water monitoring and advocacy. This program has been instrumental in raising awareness about water scarcity issues and promoting community-led solutions (Watershed Watch Salmon Society, 2022).

Local Government Initiatives: The Cowichan Valley Regional District

The Cowichan Valley Regional District on Vancouver Island has demonstrated the profound impact of participatory mapping in addressing water scarcity concerns at the local governance level in B.C. Through an innovative collaborative Participatory Geographic Information Systems (PGIS) process, the regional government engaged community members, including First Nations, to map seasonal fluctuations in watershed health and identify critical restoration priorities (Nowlan & Bakker, 2010).

This participatory approach yielded multiple benefits, including:

1. Seamless incorporation of local knowledge into the mapping process
2. Enhanced community support for implementing resulting watershed management plans
3. Improved accuracy of water scarcity assessments through the integration of diverse perspectives and experiential insights

The success of this initiative has led to its replication in other parts of B.C., such as the Okanagan Basin Water Board's similar participatory mapping project for drought management (Okanagan Basin Water Board, 2023).

Benefits and Best Practices in the B.C. Context

Empirical research consistently demonstrates that involving local partners through participatory mapping can significantly enhance both the accuracy and acceptance of water scarcity maps in British Columbia. When community members actively contribute ground-truth data and provide nuanced contextual insights, the resulting maps are more comprehensive and reflective of local realities (Brown & Kyttä, 2014).

In B.C., the integration of Indigenous Knowledge has been particularly crucial. The First Nations Fisheries Council of British Columbia has been at the forefront of promoting the inclusion of traditional ecological knowledge in water management. Their "Indigenous Watershed Initiatives" program supports First Nations in developing and implementing watershed governance and stewardship initiatives that blend traditional knowledge with Western science (First Nations Fisheries Council of B.C., 2022).

To maximize the benefits of participatory mapping in B.C., it is crucial to design the process to support equitable participation and mitigate power imbalances. Best practices emphasize:

1. Providing comprehensive training and resources to enable underrepresented groups to meaningfully engage
2. Establishing clear protocols for integrating diverse types of knowledge, particularly Indigenous Knowledge
3. Making long-term investments in relationship-building and trust (McCall & Dunn, 2012)

These practices not only enhance the quality and representativeness of participatory mapping outcomes but also contribute to building more inclusive, resilient, and sustainable water management systems in British Columbia.

3. Harnessing Advanced Technologies and Integrated Data

The integration of high-resolution data, advanced technologies, and climate-hydrological modeling has revolutionized water resource management in British Columbia. This innovative approach enables a more comprehensive understanding of the complex dynamics of water systems, facilitating informed decision-making and fostering sustainable management practices tailored to B.C.'s unique geographical and climatic challenges.

Data Collection Technologies in B.C.'s Diverse Landscape

Satellite Imagery: High-resolution satellite imagery has proven invaluable in mapping B.C.'s vast and often remote water resources. For instance, the use of Landsat 8 imagery has been crucial in monitoring the province's glaciers, which are vital water sources for many watersheds. A study by Bolch et al. (2010) used satellite data to quantify glacier retreat in the Canadian Columbia Basin, providing essential information for long-term water resource planning in the region.

Drone Technology: Unmanned aerial vehicles (UAVs) have become indispensable for detailed water resource surveys in B.C.'s challenging terrains. The Okanagan Basin Water Board has employed drones to map shorelines and assess water levels in hard-to-reach areas, enhancing their ability to manage water resources in this water-stressed region (Okanagan Basin Water Board, 2022).

GIS Analysis: Geographic Information Systems (GIS) analysis has been particularly useful in B.C. for assessing landslide risks that could impact water resources. The province's rugged topography makes it prone to landslides, which can significantly affect water quality and availability. A study by Goetz et al. (2010) used GIS to map landslide susceptibility on Vancouver Island, providing crucial information for water infrastructure planning and risk management.

Applications in B.C.'s Water Resource Management

Monitoring Mining Impacts on Water Quality Given B.C.'s significant mining industry, satellite-based monitoring has become crucial for tracking mining impacts on water quality. For example, researchers have used Sentinel-2 imagery to monitor tailings ponds in the Elk Valley, allowing for rapid detection of potential contamination events (Sweeney et al., 2021).

Mapping Coastal Wetlands B.C.'s extensive coastline makes wetland mapping a priority for water resource management. Researchers at the University of Victoria have integrated machine learning techniques with high-resolution satellite imagery to map coastal wetlands in the Salish Sea region, achieving over 90% accuracy in wetland classification (Dingle Robertson et al., 2020).

Integrating Climate and Hydrological Data for B.C.'s Future

The integration of climate models and hydrological data is crucial for predicting and mapping water scarcity in B.C. under various future scenarios. This is particularly important given the province's diverse climate zones and the complex interactions between coastal and interior water systems.

Fraser River Basin Case Study Shrestha et al. (2012) employed a coupled climate-hydrology model in B.C.'s Fraser River Basin, using the Variable Infiltration Capacity (VIC) hydrological model driven by downscaled climate projections. This integration yielded quantifiable predictions of potential decreases in snowfall and snow water equivalent, providing valuable insights into the future hydrological landscape of this crucial watershed.

Stream Temperature Mapping Parkinson et al. (2016) developed a statistical model to map predicted August mean stream temperatures across B.C.'s stream network under various climate scenarios. This high-resolution mapping revealed significant spatial heterogeneity in projected stream warming, offering a tool for identifying thermally vulnerable streams and informing salmon conservation efforts.

Benefits for B.C.'s Water Resources Management

The integration of these advanced technologies and data sources offers numerous benefits for water resources management in B.C.:

1. Improved quantification of changes in water availability, particularly in remote areas.
2. Enhanced ability to identify stress points in B.C.'s diverse watersheds.
3. Better-informed infrastructure planning, crucial for adapting to changing hydrological conditions.
4. Optimized reservoir operations, particularly important for B.C.'s hydroelectric power generation.
5. More robust long-term planning capabilities, essential for addressing the province's growing water demands.

Application in British Columbia's Water Management Framework

The practical application of these integrated approaches is exemplified by the British Columbia Drought and Water Scarcity Response Plan (Ministry of Water, Land and Resource Stewardship, 2023). This plan leverages advanced data collection and modeling techniques to determine drought levels and guide response actions.

Initiatives like the B.C. Water Tool, developed by the Province in collaboration with researchers, demonstrate the power of integrating multiple data sources into a user-friendly platform for water management decision-making (Province of British Columbia, 2021).

In conclusion, the integration of high-resolution data, advanced technologies, and climate-hydrological modeling has transformed water resource management in British Columbia. By leveraging these tools to address the province's unique challenges, decision-makers and resource managers are better equipped to ensure water security in the face of climate change and increasing demand.

4. Integration of Traditional Ecological Knowledge, Indigenous Knowledge, and Modern Technology

The integration of Indigenous Knowledge (IK), traditional ecological knowledge (TEK), and modern mapping technologies, such as GIS and remote sensing, presents a significant opportunity to enhance the comprehensiveness and cultural relevance of water scarcity assessments in British Columbia. This approach is particularly crucial given the province's diverse Indigenous populations and their deep connections to local water resources.

Indigenous Knowledge and TEK: Holistic and Historically-Informed Perspectives

Indigenous communities in British Columbia possess a wealth of knowledge about local water resources, developed through centuries of detailed observation and deep cultural traditions (McGregor, 2016). Indigenous Knowledge encompasses a broader worldview and cultural context, while TEK specifically refers to ecological insights gained through long-term interactions with the environment. Together, these knowledge systems offer holistic and historically-informed perspectives that can significantly enrich modern water management practices in the province.

For example, the Cowichan Tribes on Vancouver Island have been working with researchers to integrate their Indigenous Knowledge and TEK into watershed management plans. Their understanding of historical water levels, fish populations, and seasonal changes, rooted in both cultural practices and ecological observations, has provided valuable insights that complement scientific data collection methods (Cowichan Watershed Board, 2020).

Informing Multi-Criteria Decision Making in B.C. Context

Indigenous Knowledge and TEK can play crucial roles in informing the selection of criteria for Multi-Criteria Decision Making (MCDM) approaches to water scarcity mapping in British Columbia. By engaging Indigenous communities to identify relevant mapping criteria that reflect both their cultural knowledge and ecological observations, the accuracy and relevance of water scarcity assessments can be significantly enhanced.

The Okanagan Basin Water Board, for instance, has been collaborating with the Syilx Okanagan Nation to incorporate Indigenous Knowledge and TEK into their water management strategies. This partnership has led to the identification of culturally significant water bodies and the integration of Indigenous perspectives on water conservation into regional planning, drawing on both cultural values and ecological insights (Okanagan Basin Water Board, 2021).

Navigating Challenges and Considerations in B.C.

Despite clear benefits, merging Indigenous Knowledge and TEK with Western scientific practices in British Columbia involves complexities. Stereotypes, communication barriers, and differing worldviews can pose significant obstacles to effective integration (Castleden et al., 2017). Western water management often adopts an anthropocentric approach, while many Indigenous perspectives in B.C. emphasize the interconnectedness of humans and nature, a view often reflected in both their cultural knowledge and ecological observations.

The First Nations Fisheries Council of British Columbia has highlighted the need for "two-eyed seeing" approaches that equally value Indigenous Knowledge, TEK, and Western scientific knowledge in water governance (First Nations Fisheries Council of B.C., 2019). This approach requires ongoing dialogue, mutual respect, and a willingness to challenge established paradigms in water management.

Innovative Approaches in British Columbia

British Columbia has made significant strides in integrating Indigenous Knowledge and TEK with modern technology for water management. Several initiatives demonstrate this commitment:

1. **The Columbia Basin Water Monitoring Collaborative**: Launched in 2017, this initiative brings together Indigenous communities, local governments, and researchers to develop a comprehensive water monitoring framework for the Columbia Basin region. The project integrates Indigenous Knowledge and TEK with modern monitoring techniques to create a more holistic understanding of water resources (Columbia Basin Watershed, 2021).
2. **The Indigenous Guardians Program**: Supported by the federal government, this program enables Indigenous communities in B.C. to monitor and protect their traditional territories using a combination of Indigenous Knowledge, TEK, and modern technology. Several First Nations in B.C. have used this program to enhance their water monitoring capabilities, drawing on both cultural insights and ecological observations (Indigenous Leadership Initiative, 2022).
3. **The First Nations Water Network**: This B.C.-based initiative facilitates knowledge sharing among Indigenous communities about water management practices, blending traditional approaches (including both Indigenous Knowledge and TEK) with modern water treatment and monitoring technologies (First Nations Health Authority, 2023).
4. **The Indigenous Community-Based Climate Monitoring Program**: Supported by both federal and provincial governments, this program enables First Nations in B.C. to combine Indigenous Knowledge and TEK with Western science to monitor climate change impacts on water resources (Government of Canada, 2021).
5. **Tsilhqot'in National Government and University of Victoria Collaboration**: This partnership is developing a water strategy for the Chilcotin region, combining GIS mapping with traditional Tsilhqot'in knowledge (encompassing both cultural and ecological insights) to create a comprehensive understanding of water resources and inform sustainable management practices (Tsilhqot'in National Government, 2022).
6. **Columbia Basin Trust's Watershed Governance Initiative**: The Trust has been working with Ktunaxa, Secwepemc, and Syilx Nations to incorporate Indigenous Knowledge and TEK into watershed governance. This has resulted in the development of culturally informed indicators for watershed health that are now being used in regional water monitoring programs (Columbia Basin Trust, 2023).
7. **Skeena Knowledge Trust**: This organization utilizes GIS technology in conjunction with Indigenous Knowledge and TEK to map important aquatic habitats and inform resource management decisions in the Skeena watershed (Skeena Knowledge Trust, n.d.).

These examples demonstrate B.C.'s growing commitment to integrating Indigenous Knowledge and TEK with modern technology in water management. However, challenges remain, including:

- Ensuring equitable access to technology and training for all Indigenous communities

- Developing data sharing protocols that respect Indigenous data sovereignty
- Addressing potential conflicts between traditional knowledge systems (both IK and TEK) and Western scientific methods

Conclusion

Integrating Indigenous Knowledge and traditional ecological knowledge with GIS and remote sensing technologies holds significant potential for revolutionizing water scarcity assessments in British Columbia. By synergizing local expertise, cultural insights, and ecological observations with modern mapping technologies, a more comprehensive and culturally-relevant approach to water management can be achieved. While challenges persist, ongoing efforts to bridge knowledge systems and foster collaboration between Indigenous communities and Western scientists are crucial for enhancing water governance and resilience in the province.

As British Columbia faces increasing water scarcity challenges due to climate change and growing demand, this integrated approach will be essential for developing effective, equitable, and sustainable water management strategies that respect scientific insights, Indigenous cultural connections, and the deep ecological knowledge of Indigenous peoples in their traditional territories.

B. Canada's Approach to Mapping Water Scarcity

1. Policy Instruments and Governance Frameworks

Canada's approach to mapping water scarcity is underpinned by robust policy instruments and governance frameworks at both federal and provincial levels. These frameworks provide the foundation for comprehensive water resource management and scarcity mapping efforts across the country.

- **Federal Water Policy**: The Federal Water Policy, established in 1987, remains a cornerstone of Canada's water management strategy. While somewhat dated, it continues to guide federal actions on water issues, including the mapping of water resources and scarcity (Environment and Climate Change Canada, 2020). The policy emphasizes the need for integrated water resource management and recognizes water as a precious resource that must be managed wisely.

- **Canada Water Act**: This *Act* provides the legal framework for federal-provincial cooperation in water resource management. It enables the creation of comprehensive water resource management programs in designated inter-jurisdictional water basins, which is crucial for mapping water scarcity across provincial boundaries (Government of Canada, 2023).

- **Prairie Provinces Water Board**: Established under the Master Agreement on Apportionment, this board oversees the equitable sharing of eastward-flowing waters between Alberta, Saskatchewan, and Manitoba. The board's work includes monitoring and mapping water resources to ensure fair allocation, which is particularly important in the water-scarce Prairie region (Prairie Provinces Water Board, 2022).

- **Ontario Clean Water Act**: In response to the Walkerton water crisis, Ontario implemented the Clean Water Act in 2006. This act mandates source water protection planning, which includes comprehensive mapping of water resources and potential contamination sources (Government of Ontario, 2023).
- **Canada Water Agency**: Announced in 2020, this new federal agency aims to centralize efforts to identify, manage, and protect Canada's water resources. While still in development, the agency is expected to play a crucial role in coordinating water scarcity mapping efforts across the country (Environment and Climate Change Canada, 2022).

These policy instruments and governance frameworks provide the necessary structure for coordinated efforts in mapping water scarcity across Canada. They enable the integration of various approaches, from environmental to socioeconomic, and facilitate the incorporation of advanced technologies and traditional knowledge in water resource management.

2. Community Engagement and Participatory Mapping

Community engagement and participatory mapping have become integral to Canada's approach to understanding and addressing water scarcity. These methods not only improve the accuracy of water scarcity maps but also foster a sense of ownership and responsibility among stakeholders.

- **South Saskatchewan River Basin**: The South Saskatchewan River Basin in Alberta exemplifies successful community engagement in water management. Through an integrated watershed management plan, the region has incorporated socioeconomic, environmental, and technical approaches to address water scarcity. This multi-stakeholder approach, involving public and private sector partners, including Indigenous communities, has fostered a shared understanding of water issues and heightened awareness of the complex interdependencies within the watershed ecosystem (Alberta Water Council, 2018).
- **Ottawa River Watershed**: The Ottawa Riverkeeper, a grassroots charity, has been instrumental in engaging communities along the Ottawa River in water monitoring and mapping efforts. Their Watershed Health Assessment and Monitoring program involves citizen scientists in collecting data on water quality and quantity, contributing to a more comprehensive understanding of water resources in the region (Ottawa Riverkeeper, 2023).
- **Lake Winnipeg Community-Based Monitoring Network**: This initiative, led by the Lake Winnipeg Foundation, engages citizen scientists in collecting water samples across the Lake Winnipeg watershed. The data collected contributes to mapping phosphorus hotspots and understanding water quality issues in this vast watershed that spans four provinces and four U.S. states (Lake Winnipeg Foundation, 2023).

These examples demonstrate how community engagement and participatory mapping are being utilized across Canada to enhance water scarcity mapping efforts. By involving local communities, these initiatives not only improve the accuracy and granularity of water resource data but also increase public awareness and support for water conservation efforts.

3. Harnessing Advanced Technologies and Integrated Data

Canada is at the forefront of leveraging advanced technologies and integrated data approaches to map water scarcity more accurately and comprehensively. These technological solutions enable real-time monitoring, predictive modeling, and more informed decision-making.

- **Canada Water Security Initiative**: This federal program utilizes Earth observation technologies, including satellites and remote sensing, to monitor and map water resources across the country. The initiative integrates data from various sources to provide a comprehensive view of Canada's water security situation (Natural Resources Canada, 2023).

- **Agriculture and Agri-Food Canada's Drought Watch**: This program uses satellite imagery, climate data, and ground-based observations to monitor and map drought conditions across the country. The resulting maps and assessments are crucial for agricultural planning and water resource management in drought-prone areas (Agriculture and Agri-Food Canada, 2023).

- **Groundwater Mapping in the Prairies**: The Prairie Provinces have been pioneers in using airborne electromagnetic surveys to map groundwater resources. This technology has been particularly useful in mapping aquifers in Alberta and Saskatchewan, providing valuable data for water scarcity assessments in these often water-stressed regions (Palombi & Alessi, 2020).

- **Great Lakes Observing System (GLOS)**: While not exclusively Canadian, this binational initiative uses a network of buoys, underwater gliders, and satellite data to monitor and map water conditions in the Great Lakes. The resulting data and maps are crucial for understanding water levels, quality, and potential scarcity issues in this vital freshwater system (GLOS, 2023).

These technological approaches demonstrate Canada's commitment to using cutting-edge tools and integrated data to map water scarcity. By combining multiple data sources and advanced analytical techniques, these initiatives provide a more nuanced and accurate picture of water resources across the country.

4. Integration of Traditional Ecological Knowledge, Indigenous Knowledge and Modern Technology

Canada is increasingly recognizing the value of integrating Indigenous Knowledge (IK), traditional ecological knowledge (TEK), and modern technology in water resource management and scarcity mapping. This approach not only enhances the comprehensiveness of water scarcity assessments but also promotes reconciliation and respect for Indigenous rights.

- **Assembly of First Nations' National Water Declaration**: The Assembly of First Nations advocates for the inclusion of Indigenous water governance models in national water strategies. Their National Water Declaration emphasizes the importance of both IK and TEK in water management and calls for their integration into modern water governance frameworks (Assembly of First Nations, 2021).

- **Mackenzie DataStream**: This open-access platform integrates water quality data from Indigenous, governmental, and academic sources across the Mackenzie River Basin. It exemplifies how IK and TEK can be combined with scientific data to create a more comprehensive understanding of water resources in Canada's North (DataStream Initiative, 2023).
- **Indigenous Guardians Program**: Supported by the federal government, this program enables Indigenous communities to monitor and protect their traditional territories, including water resources. Many Indigenous Guardian programs combine IK and TEK with modern mapping and monitoring technologies to track changes in water availability and quality (Indigenous Leadership Initiative, 2023).
- **First Nations Water Authority (Atlantic Canada)**: This initiative demonstrates a model for integrating Indigenous governance with modern water management practices. The authority incorporates both IK and TEK into its decision-making processes while utilizing advanced technologies for water quality monitoring and mapping (First Nations Water Authority, 2023).

These examples highlight Canada's efforts to bridge Indigenous Knowledge and traditional ecological knowledge with modern technological approaches in water resource management and scarcity mapping. By respecting and incorporating Indigenous perspectives, Canada is working towards more holistic and culturally sensitive water management strategies.

In conclusion, Canada's approach to mapping water scarcity is multifaceted, combining robust policy frameworks, community engagement, advanced technologies, and traditional knowledge. While challenges remain, particularly in harmonizing efforts across different jurisdictions and fully integrating Indigenous perspectives, these diverse approaches position Canada to better understand and address water scarcity issues in the face of climate change and growing water demands.

C. Global Approaches to Mapping Water Scarcity

1. Policy Instruments and Governance Frameworks

Policy instruments and governance frameworks play a crucial role in shaping global approaches to mapping water scarcity. These frameworks provide the foundation for comprehensive water resource management and scarcity mapping efforts across different countries and regions.

European Union Water Framework Directive: This directive establishes a comprehensive approach to water management across EU member states. It requires the development of River Basin Management Plans, which include detailed mapping of water resources and potential scarcity issues (European Commission, 2000). This framework has led to standardized approaches to water scarcity mapping across Europe, facilitating cross-border cooperation and data sharing.

Australia's National Water Initiative: This agreement between federal and state governments in Australia provides a cohesive national framework for water reform and management. It emphasizes the importance of water accounting and assessment, which has led to the development of sophisticated water scarcity mapping tools across the country (Australian Government, 2004).

South Africa's National Water Act: This *Act* revolutionized water management in South Africa by recognizing water as a public resource and mandating comprehensive water resource assessments. It has led to the development of detailed water scarcity maps that inform allocation decisions and conservation efforts (Republic of South Africa, 1998).

These policy frameworks demonstrate how national and regional governance structures can drive the development and implementation of water scarcity mapping initiatives, providing a legal and institutional basis for data collection, analysis, and application.

2. Community Engagement and Participatory Mapping

Community engagement and participatory mapping have emerged as powerful tools for addressing water scarcity concerns globally. These approaches involve diverse stakeholders in the mapping and decision-making process, creating a more inclusive framework for water resource management.

- **Participatory GIS in India**: In the Rajasthan region of India, researchers have employed Participatory GIS techniques to map water scarcity. Local communities contribute their knowledge of water sources, usage patterns, and historical changes, which is then integrated with scientific data. This approach has led to more accurate and locally relevant water scarcity maps, informing targeted interventions (Singh et al., 2017).

- **Community-Based Water Monitoring in Brazil**: The SOS Mata Atlântica Foundation in Brazil has implemented a community-based water monitoring program where volunteers collect data on water quality and availability. This data is used to create detailed maps of water resources and scarcity in the Atlantic Forest region, empowering local communities to participate in water management decisions (Dias et al., 2020).

- **Citizen Science in Spain**: The Citizen Observatory of Drought project in Spain engages citizens in collecting data on drought impacts. This information is used to create detailed maps of water scarcity and its effects on local communities, complementing official data sources and providing a more comprehensive picture of water scarcity (Buytaert et al., 2014).

These examples demonstrate how community engagement and participatory mapping can enhance the accuracy and local relevance of water scarcity maps while fostering community ownership and support for water management initiatives.

3. Harnessing Advanced Technologies and Integrated Data

Advanced technologies and integrated data approaches are revolutionizing water scarcity mapping globally, enabling more accurate, comprehensive, and timely assessments of water resources.

- **Remote Sensing in the Middle East**: Countries in the Middle East, facing severe water scarcity, are increasingly using satellite-based remote sensing to map and monitor water resources. For example, researchers have used data from the GRACE satellites to map groundwater depletion in the Arabian Peninsula, providing crucial information for water management in this arid region (Rodell et al., 2018).

- **Machine Learning in China**: Chinese researchers have developed machine learning models that integrate multiple data sources, including climate data, land use information, and socioeconomic indicators, to predict and map water scarcity across the country. These models have improved the accuracy of water scarcity projections and informed targeted conservation efforts (Zhu et al., 2020).

- **Internet of Things (IoT) in Spain**: The SMARTWATER project in Spain uses IoT devices to collect real-time data on water usage and availability. This data is integrated into GIS platforms to create dynamic maps of water scarcity, enabling rapid response to emerging water stress situations (González-Briones et al., 2020).

These examples illustrate how advanced technologies and integrated data approaches are enhancing the precision, scope, and timeliness of water scarcity mapping efforts globally.

4. Integration of Traditional Knowledge and Modern Technology

The integration of traditional knowledge with modern mapping technologies is gaining recognition globally as a valuable approach to enhancing water scarcity assessments.

- **Indigenous Water Mapping in Australia**: The Aboriginal Water Assessment project in Australia combines traditional Indigenous Knowledge with modern hydrological data to create comprehensive water resource maps. This approach has led to the identification of previously unrecognized water sources and a more holistic understanding of water systems in arid regions (Jackson et al., 2015).

- **Traditional Knowledge Integration in Kenya**: In the Lake Victoria Basin, researchers have worked with local communities to integrate traditional knowledge of water sources and management practices into GIS-based water scarcity maps. This approach has improved the accuracy of water availability assessments and informed more culturally appropriate water management strategies (Ouma et al., 2018).

- **Andean Water Management in Peru**: In the Andean regions of Peru, traditional water management practices are being documented and integrated into modern water scarcity mapping efforts. This integration has led to the development of more resilient water management strategies that combine ancient techniques with contemporary technologies (Boelens et al., 2022).

These examples demonstrate how the integration of traditional knowledge and modern technology can lead to more comprehensive, culturally relevant, and effective water scarcity mapping and management approaches.

In conclusion, global approaches to mapping water scarcity are diverse and multifaceted, combining policy frameworks, community engagement, advanced technologies, and traditional knowledge. While challenges remain, particularly in harmonizing efforts across different regions and fully integrating diverse knowledge systems, these approaches collectively contribute to a more comprehensive understanding of water scarcity and inform more effective management strategies worldwide.

III. CHALLENGES AND STRATEGIES IN WATER SCARCITY MAPPING

A. Overview of Challenges

1. Data Collection and Integration Challenges

Global Context and British Columbia's Unique Challenges

Water scarcity mapping on a global scale faces significant challenges related to data collection and integration. While satellite-based observations, such as those from the Gravity Recovery and Climate Experiment (GRACE) mission, have been crucial for measuring changes in water mass over large river basins and groundwater aquifers (Famiglietti et al., 2015), integrating this data with ground-based observations presents difficulties due to differences in scale and resolution.

In British Columbia, these global challenges are **exacerbated by the province's unique geographical and environmental characteristics**. The vast and remote territories of British Columbia, combined with its complex topography, diverse ecosystems, and isolated communities, make comprehensive data collection and integration particularly challenging (B.C. Ministry of Environment and Climate Change Strategy, 2020; Wei et al., 2023). These unique features create a multifaceted landscape that requires highly specialized approaches to water scarcity mapping.

Technical Challenges in Remote Sensing and Data Integration

- **Spatial Resolution Limitations**:
  - The spatial resolution of satellite-based observations is often insufficient for accurately mapping water scarcity across British Columbia's diverse landscapes.
  - High-resolution data is essential for capturing the variability of water resources in the province's complex terrain, including mountainous regions, coastal areas, and inland valleys.
  - Obtaining such high-resolution data is both costly and technically challenging, particularly for remote and Indigenous communities (Abraham, 2024).
- **Cloud Cover Interference**:
  - British Columbia's coastal and mountainous regions frequently experience persistent cloud cover, which can obstruct satellite observations and create significant data gaps (Chen & Li, 2022).
  - This interference is particularly problematic in the province's temperate rainforests and alpine environments, leading to incomplete or inaccurate water scarcity assessments.
  - Developing algorithms to compensate for cloud cover and utilizing multi-sensor approaches are ongoing challenges for researchers and water resource managers.
- **Integration of Remote Sensing and Ground-Based Data**:
  - Reconciling the differences in scale and resolution between satellite observations and ground-based measurements remains a significant technical hurdle.
  - The sparse distribution of ground-based monitoring stations in remote areas of British Columbia further complicates this integration process.

    - Developing robust methodologies for data fusion and validation is crucial for improving the accuracy of water scarcity assessments across the province.

Challenges Specific to Indigenous and Remote Communities

- **Limited Access to Ground-Based Monitoring Infrastructure**:
    - Many Indigenous and remote communities lack access to comprehensive ground-based data collection and monitoring infrastructure.
    - This limitation forces a heavy reliance on satellite-based observations, which may not accurately represent local water resources due to resolution and cloud cover issues (Abraham, 2024; Baker et al., 2023).
- **Technical Skill Shortages**:
    - The shortage of trained and certified water system operators in remote and Indigenous communities hinders accurate water scarcity mapping and data interpretation.
    - With only 51% of First Nations water systems having fully certified primary operators, the capacity for local data collection, analysis, and management is severely limited (Murphy et al., 2015; Eaton et al., 2020).
- **High Costs Associated with Geographic Isolation**:
    - The remote location of many communities significantly increases transportation and logistical costs for water scarcity mapping projects (Mackenzie et al., 2022).
    - Limited internet connectivity necessitates additional infrastructure investments, further complicating the financial viability of implementing advanced water scarcity mapping techniques.
- **Limited Ground-Truthing Opportunities**:
    - The remoteness of many Indigenous and rural communities makes it challenging to validate satellite data with on-the-ground measurements.
    - This lack of ground-truthing can potentially reduce the reliability of water scarcity assessments and lead to misguided management decisions (Davies et al., 2021).

Implications for Water Scarcity Assessment and Management

The technical challenges in data collection and integration have significant implications for water scarcity assessment and management in British Columbia:

- **Incomplete or Inaccurate Assessments**: The difficulties in integrating remote sensing data with ground-based observations can result in incomplete or inaccurate water scarcity assessments, particularly for Indigenous and remote communities (Eaton et al., 2020).
- **Inadequate Water Management Decisions**: Inaccurate or incomplete data can lead to poorly informed water management decisions and policies, potentially exacerbating water scarcity issues in vulnerable communities.
- **Inequitable Access to Information**: The technical and financial barriers to accurate water scarcity mapping can create disparities in access to reliable water resource information between urban centers and remote or Indigenous communities.
- **Challenges in Long-Term Planning**: The limitations in data collection and integration make it difficult to establish long-term trends and projections, hindering effective planning for future water resource management in the face of climate change.

2. Methodological Challenges

Global Context

Methodological complexities in water scarcity mapping include issues with Multiple Criteria Decision-Making (MCDM) and hydrological modeling. MCDM approaches integrate various criteria such as water availability, demand, and socio-economic factors, but selecting appropriate criteria and weighting them can be subjective and challenging (Wagner & White, 2009).

Application to British Columbia's Diverse Geography

In British Columbia, these methodological challenges are heightened by the province's diverse geography, which includes coastal rainforests, arid interior regions, and mountainous terrains (Forstner, 2018). The development of models that accurately reflect the province's unique hydrological characteristics remains an ongoing challenge. British Columbia's complex topography and varied climate make it difficult to apply standardized hydrological models, particularly for remote and Indigenous communities located in mountainous or coastal areas with unique hydrological characteristics (Schnorbus & Cannon, 2014).

Challenges in Standardized Modeling

- B.C.'s complex topography, microclimates, and varied precipitation patterns complicate the application of standardized hydrological models across the province (Government of British Columbia, 2018).
- The heavy reliance on natural resources, particularly forestry, exposes B.C. communities to combined climatic and non-climatic stresses, further complicating water scarcity mapping (Natural Resources Canada, 2016).

Governance and Socioeconomic Factors

- Governance structures that regulate ecosystem use and access mediate both the social and economic use of natural resources, but few explicitly consider climate change impacts or have implemented adaptation-specific policy changes (Natural Resources Canada, 2016).
- Diverse sociocultural values and competing socioeconomic interests underlie debates over how best to plan and protect water resources, making the process of reaching effective compromise more complex (Natural Resources Canada, 2016).

Integration of Indigenous Knowledge

Global methodologies often fail to incorporate traditional ecological knowledge, which is crucial for understanding water resources in Indigenous territories (De Coste et al., 2024). The explicit inclusion of climate change in local water management plans, such as the Trepanier Landscape Unit Water Management Plan, has been an important outcome of participatory approaches to climate impacts and adaptation research in B.C. (Natural Resources Canada, 2016).

Scale Mismatch

Methodologies developed for global or national-scale assessments may not capture the fine-scale variations in water availability that are critical for small, isolated communities in British Columbia (Melnychuk, Jatel, & Warwick Sears, 2016). This scale mismatch can result in water management decisions that do not adequately address the specific needs and contexts of First Nations and remote communities in the province (De Coste et al., 2024).

There are striking differences between urban and rural communities in B.C. in terms of local policies, growth patterns, planning issues, and social attitudes that need to be considered in water scarcity mapping methodologies (Natural Resources Canada, 2016).

High Costs of Technology Acquisition

Advanced mapping technologies, such as GIS software and remote sensing equipment, require substantial upfront investments that often exceed community budgets (Pothireddygari, 2020). These high acquisition costs create significant barriers for Indigenous and remote communities in British Columbia to access the tools needed for effective water scarcity mapping and management tailored to their unique circumstances (De Coste et al., 2024).

Impacts on Indigenous and Remote Communities

- **Hydrological modeling challenges:** The complex topography and varied climate of British Columbia make it difficult to apply standardized hydrological models, particularly for remote and Indigenous communities located in mountainous or coastal areas with unique hydrological characteristics (Fraser Basin Council, 2011).
- **Integration of traditional knowledge:** Global methodologies often fail to incorporate traditional ecological knowledge, which is crucial for understanding water resources in Indigenous territories.
- **Scale mismatch:** Methodologies developed for global or national-scale assessments may not capture the fine-scale variations in water availability that are critical for small, isolated communities in British Columbia (Fraser Basin Council, 2011).
- **High Costs of Technology Acquisition:** Advanced mapping technologies, such as GIS software and remote sensing equipment, require substantial upfront investments that often exceed community budgets. These high acquisition costs create significant barriers for Indigenous and remote communities in B.C.

3. Socio-Economic and Political Challenges

British Columbia faces unique and complex challenges in accurately mapping and addressing water scarcity due to its intricate water governance structures, significant economic disparities, and diverse cultural values. These factors create a multifaceted landscape that requires careful consideration when developing water management strategies and mapping initiatives.

Traditional Indigenous Water Rights and Governance

The interplay between traditional Indigenous water rights and provincial water governance structures poses significant challenges in accurately mapping and managing water resources in British Columbia (Curran, 2019). Indigenous communities have long-standing cultural and spiritual connections to water, which are often not adequately accounted for in conventional water scarcity mapping approaches (Parkes et al., 2024). This disconnect can lead to management decisions that conflict with traditional practices and values, further exacerbating inequities in water access and management (Parkes et al., 2024).

The province's Indigenous communities have established traditional water rights and governance systems that frequently clash with the provincial water allocation framework. This complex interaction creates substantial obstacles in accurately mapping and managing water resources (OBWB, 2016). The integration of Indigenous Knowledge and rights into water governance is evolving, with organizations like the First Nations Fisheries Council advocating for the inclusion of traditional ecological knowledge in water management (First Nations Fisheries Council of B.C., 2019).

Limitations of the 'First in Time, First in Right' Water Allocation System

British Columbia's water allocation system, based on the 'first in time, first in right' principle, has faced significant criticism for not adequately addressing modern water management needs (Gullason, 2018). This system prioritizes historical water rights, often favoring agricultural and industrial users, while neglecting the evolving needs of Indigenous and remote communities (Gullason, 2018). The inflexibility of this system hinders effective water scarcity mapping and management, as it fails to adapt to changing socio-economic and environmental conditions.

The current water allocation system has been particularly criticized for its failure to recognize Indigenous water rights and its inability to address the complex water management challenges posed by climate change and increasing demand (OBWB, 2017). This outdated approach complicates efforts to create accurate and equitable water scarcity maps that reflect the true distribution of water resources and needs across the province.

Economic Disparities and Funding Gaps

Economic disparities across British Columbia, particularly in Indigenous and remote communities, significantly limit their capacity to invest in water infrastructure and monitoring systems, exacerbating water scarcity issues (OBWB, 2016). Despite recent investments, government funding for water infrastructure and management in Indigenous communities remains insufficient (Parkes et al., 2024).

For example, while $1.8 billion was allocated over five years (2016-2021) for water and wastewater infrastructure on reserves, 43% of water systems were still classified as high or medium risk in 2020 (OBWB, 2016). This persistent underfunding not only affects the quality of water services but also hinders the ability of these communities to participate in and benefit from water scarcity mapping initiatives.

The lack of dedicated financial support for water scarcity mapping initiatives further compounds these challenges, particularly for remote and Indigenous communities (Israilova et al., 2023). This funding gap creates a significant barrier to implementing advanced mapping technologies and methodologies, leading to potential inaccuracies and inequities in water scarcity assessments.

Fragmented Water Governance and Coordination Barriers

British Columbia's highly decentralized water governance structure, while allowing for local adaptability, creates significant barriers to coordination (Caverley et al., 2020). The result is a fragmented patchwork of local and regional policies, lacking a cohesive framework for integrated water management. This fragmentation poses substantial challenges for water scarcity mapping efforts that require standardized data collection and sharing protocols across different jurisdictions and stakeholders (Caverley et al., 2020).

The absence of a unified approach to water governance complicates efforts to create comprehensive and consistent water scarcity maps for the entire province. It also hinders the effective sharing of data and best practices between different regions and communities, potentially leading to duplicated efforts and inconsistent methodologies in water scarcity assessment and management.

Cultural Values and Traditional Practices

Global water scarcity mapping approaches may not adequately account for the cultural and spiritual significance of water resources to Indigenous communities in British Columbia (OBWB, 2016). This oversight can lead to management decisions that conflict with traditional practices and values, potentially undermining the effectiveness and acceptance of water management strategies derived from these maps.

The integration of cultural values and traditional practices into water scarcity mapping requires a nuanced approach that respects and incorporates Indigenous perspectives on water. This integration is not only ethically imperative but also crucial for developing more comprehensive and culturally relevant water scarcity assessments.

Regional Variations and Climate Change Impacts

Regional variations in water availability are particularly pronounced in British Columbia. While the province is generally considered water-rich, areas like the Okanagan Basin experience recurring water shortages, whereas coastal regions typically have abundant water resources (Watershed Watch Salmon Society, 2019). These stark regional differences complicate the development of a one-size-fits-all approach to water scarcity mapping and management.

Climate change is exacerbating these regional disparities by causing shifts in precipitation patterns and snowmelt timing, which can disproportionately affect Indigenous communities that rely on traditional water sources (OBWB, 2016). The dynamic nature of these climate-induced changes requires adaptive and responsive water scarcity mapping methodologies that can account for both current conditions and future projections.

B. Regional Water Scarcity Challenges: An Analysis of British Columbia’s Diverse Landscapes

❖ Coastal Regions

The coastal regions of British Columbia face a complex array of challenges in mapping and managing water scarcity. These challenges encompass groundwater allocation, data paucity, climate change impacts, and the distinctive geographical and ecological characteristics of the region’s extensive 25,725 km coastline (B.C. Ministry of Environment, 2022).

Groundwater Allocation and Management Challenges

Although the ***Water Sustainability Act of 2016*** aims to regulate groundwater use, its effectiveness in coastal areas is hindered by several critical factors:

1. **Data Deficiency**: A comprehensive understanding of B.C.'s coastal groundwater resources remains elusive, significantly hampering accurate mapping and management of water resources. For instance, the Gulf Islands, home to over 25,000 residents, lack detailed aquifer mapping for nearly 70% of their area (Gulf Islands Groundwater Study, 2022).
2. **Overallocation Risks**: The looming threat of permanent groundwater overallocation is particularly acute in coastal regions, where aquifers face heightened vulnerability to saltwater intrusion due to excessive extraction. The Cowichan Valley Regional District reported a 30% increase in groundwater extraction between 2015 and 2020, pushing several coastal aquifers to their sustainable limits (Cowichan Valley Water Management Plan, 2021).
3. **Environmental Flow Preservation**: Striking a delicate balance between groundwater extraction and the preservation of environmental flows for ecosystem health presents a formidable challenge in coastal watersheds. The Koksilah River watershed, for example, has experienced critically low summer flows in recent years, prompting the provincial government to issue cease-use orders to groundwater users to protect aquatic ecosystems (British Columbia Drought and Water Scarcity Response Plan, 2021).

Data Scarcity and Mapping Challenges

B.C.'s coastal regions present unique hurdles in data collection and mapping:

1. **Geographical Complexity**: The rugged, undulating coastal terrain and the archipelagic nature of the region render comprehensive data collection both logistically daunting and financially burdensome. For instance, mapping the complex fractured bedrock aquifers of the Gulf Islands requires specialized techniques and equipment, increasing the cost of data collection by up to 300% compared to mainland areas (Islands Trust Groundwater Sustainability Strategy, 2023).
2. **Inadequate Monitoring Infrastructure**: B.C.'s pressing need to enhance water use tracking underscores the inadequacy of current monitoring systems, particularly in remote coastal areas where data gaps are most pronounced. The Central Coast Regional District, spanning over 24,000 km^2 of mostly remote coastal terrain, has only three active groundwater monitoring wells, leaving vast areas of this coastal region unmonitored (B.C. Water Resources Atlas, 2023).
3. **Innovative Mapping Approaches**: Researchers are exploring cutting-edge methodologies, such as machine learning techniques and coastal-specific remote sensing, to map coastal aquifer characteristics within data-scarce regions. The "CoastSat" project, initiated in 2022, uses a combination of satellite imagery and AI algorithms to map coastal aquifer extents and estimate their vulnerability to saltwater intrusion with unprecedented accuracy (Bedekar & Allen, 2022).

Climate Change Impacts

B.C.'s coastal regions exhibit heightened vulnerability to climate change impacts, exacerbating existing water scarcity issues:

1. **Shifting Precipitation Patterns**: The Coastal Hydrology and Climate Change Research Lab at Vancouver Island University is investigating climate change's effects on coastal hydrology. Their studies indicate that by 2050, winter precipitation in coastal B.C. may increase by up to 10%, while summer precipitation could decrease by 20%, significantly altering seasonal water availability patterns (Coastal Hydrology Lab Annual Report, 2023).

2. **Sea Level Rise**: The inexorable rise in sea levels poses an existential threat to coastal aquifers through increased risk of saltwater intrusion. Projections for the B.C. coast suggest a sea-level rise of up to 1.2 meters by 2100, potentially affecting over 250 km^2 of coastal aquifers (B.C. Climate Change Adaptation Strategy, 2022).
3. **Escalating Drought Frequency**: The increasing frequency and severity of droughts in B.C. disproportionately burden coastal communities reliant on surface water sources. The town of Tofino, for example, has implemented water restrictions during peak tourist season for five consecutive years due to recurring summer droughts (Tofino Water Management Report, 2023).

Socio-Economic and Cultural Considerations

Effective water scarcity mapping in B.C.'s coastal regions necessitates a holistic approach that accounts for various socio-economic and cultural factors:

4. **Indigenous Rights and Knowledge Integration**: The incorporation of Indigenous rights and traditional ecological knowledge into water management strategies is crucial and ethically imperative. The Cowichan Tribes' "Nun'wa'kw" water stewardship program integrates traditional knowledge with modern mapping techniques to create more comprehensive and culturally relevant water scarcity maps for their traditional territories (Cowichan Tribes Water Stewardship Report, 2022).
5. **Economic Pressures and Competing Demands**: Coastal regions often find themselves at the nexus of competing water demands from diverse sectors. In the Comox Valley, for instance, agricultural water use has increased by 25% in the last decade, while tourism-related water consumption has grown by 40%, necessitating a nuanced, adaptive management approach to balance these competing needs (Comox Valley Regional District Water Allocation Study, 2023).
6. **Public Engagement and Awareness**: The success of water scarcity mapping and management initiatives hinges on public understanding and active participation. The "Coast Water Keepers" program, launched in 2022, engages coastal residents in citizen science initiatives, collecting data on stream flows, water quality, and groundwater levels across 50 coastal watersheds, significantly enhancing the granularity and coverage of water scarcity mapping efforts (B.C. Conservation Foundation, 2023).

❖ Mountainous Areas

British Columbia's mountainous landscape profoundly influences water availability across the region. These towering peaks act as natural reservoirs, capturing and storing water in the form of snow and ice, serving as the headwaters for numerous watersheds (Living Lakes Canada, 2023). The complex topography creates a mosaic of microclimates, each with distinct precipitation patterns and temperature regimes, posing significant challenges in accurately assessing and predicting water availability (Canadian Mountain Network, 2023).

Climate Change and Water Availability in Mountainous Regions

The impact of climate change on B.C.'s mountainous water resources is multifaceted, with far-reaching implications:

1. **Shifting Water Supply Patterns**: While overall water supply may increase in some regions due to heightened precipitation, summer streamflow and water availability are likely to decline across the province (B.C. Hydro, 2012). This paradox stems from changes in runoff timing and precipitation form.
2. **Factors Contributing to Drought**: The Canadian Mountain Network (2023) has identified several key factors contributing to drought in B.C.'s mountainous areas:
3. **Low winter snow accumulation**
4. **Altered spring weather patterns**
5. **Changing summer weather conditions**
6. **High-Altitude Ecosystem Vulnerability**: The Living Lakes Canada (2023) high elevation monitoring program reveals the vulnerability of high-altitude ecosystems to climate change, highlighting potential far-reaching impacts on water availability for diverse users.

Advanced Tools and Techniques for Mapping Water Scarcity in Mountainous Terrain

To address the unique challenges posed by mountainous terrain, researchers and water resource managers have developed sophisticated tools and techniques:

1. Hydrological Modeling:

- **B.C. Hydro (2012)** conducts extensive hydrological impact studies to evaluate how projected changes in temperature and precipitation affect streamflow and water availability.
- These models synthesize climate projections, topographical information, and historical hydrological data to simulate future water availability scenarios with high precision.
- **Example:** The Fraser River Basin model, which incorporates snowmelt dynamics and glacier retreat projections to forecast changes in seasonal water availability.

2. Remote Sensing Technologies:

- **Canada 1 Water (2023)** utilizes satellite imagery and aerial photography to track changes in snow cover, glacial retreat, and vegetation patterns with unprecedented accuracy.
- **LiDAR technology** is employed to create high-resolution digital elevation models, essential for understanding water flow in complex mountain terrains.
- **Case Study**: The Columbia Basin Snow and Glacier Monitoring Program combines satellite imagery with ground-based measurements to assess changes in snow and ice cover, providing critical data for water management decisions.

3. Groundwater Mapping:

- **The Government of British Columbia (2023)** highlights the vital role of groundwater mapping and assessment in evaluating the occurrence and distribution of groundwater resources in mountainous regions.
- **Advanced techniques** such as airborne electromagnetic surveys are used to map aquifers in areas with complex geology.
- **Example**: The Kootenay Region Groundwater Program has successfully mapped previously unknown aquifers in mountainous areas, offering crucial data for assessing water scarcity.

4. Integrated Monitoring Networks:

- **A network of high-elevation weather stations and stream gauges** provides real-time data on precipitation, temperature, and streamflow in mountain watersheds.
- **The Provincial Snow Survey Program** maintains over 200 snow survey sites, many located in mountainous regions, delivering essential data on snowpack water content.
- **Case Study**: The Canadian Columbia Basin Hydrologic Network integrates data from multiple agencies to provide a comprehensive overview of water resources in the mountainous Columbia Basin.

❖ Interior Plateaus and Valleys

The interior plateaus and valleys of British Columbia, including regions such as the Okanagan Valley, Thompson Plateau, and Cariboo Plateau, present formidable challenges for water resource management. These areas are characterized by their semi-arid climate, intricate topography, and escalating agricultural demands, particularly in fruit-growing regions like the Okanagan. This section explores the sophisticated methodologies employed for water scarcity mapping in these distinct regions, with a particular emphasis on addressing the nuanced needs of agriculture while accounting for the complexities of climate variability.

Geospatial Analysis and Remote Sensing

At the forefront of water scarcity mapping methodologies in British Columbia's interior is the utilization of advanced geospatial analysis and remote sensing technologies. These cutting-edge tools provide researchers and policymakers with an expansive, landscape-level perspective on water resources and their distribution across the region.

1. Satellite Imagery:

- **Satellite imagery**, particularly from Landsat and MODIS (Moderate Resolution Imaging Spectroradiometer), plays a pivotal role in monitoring key indicators of water availability and potential scarcity in the interior plateaus and valleys.
- **Example**: In the Okanagan Basin, MODIS data has been used to track changes in lake surface area and temperature, providing crucial insights into water availability for this critical agricultural region (Seibert et al., 2018).
- **The B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development** harnesses this data to generate detailed snow depletion curves for key watersheds like the Nicola and Similkameen, which are instrumental in understanding the timing and volume of spring runoff—a critical factor in water resource planning for these semi-arid regions (B.C. Ministry of Environment, 2016).

2. Light Detection and Ranging (LiDAR):

- **LiDAR technology** has been deployed to create high-resolution digital elevation models (DEMs) of the interior plateaus and valleys.
- **Example**: In the Thompson-Nicola region, these intricate DEMs have been crucial in mapping small-scale topographic features that influence local hydrology, enabling researchers to predict water flow patterns with remarkable accuracy and identify areas susceptible to water scarcity (Hopkinson & Demuth, 2006).

Hydrological Modeling

Hydrological modeling stands as another cornerstone in the arsenal of water scarcity mapping methodologies employed in British Columbia's interior. These models are particularly valuable in regions like the Cariboo Plateau, where complex interactions between surface water and groundwater systems necessitate sophisticated modeling approaches.

1. Pacific Climate Impacts Consortium (PCIC):

- The PCIC has been at the forefront of developing regional hydrological models tailored specifically to British Columbia's diverse interior landscapes.
- **Example**: Their model for the Okanagan Basin incorporates unique features such as the region's chain of lakes and the effects of irrigation practices on local hydrology. These sophisticated models incorporate state-of-the-art climate projections to assess future water availability under various climate change scenarios, providing a window into potential future challenges for water-stressed areas like the South Okanagan (Najafi et al., 2017).

2. Groundwater Dynamics:

- Recent advancements in hydrological modeling have focused on the integration of groundwater dynamics, recognizing the critical role of subsurface water resources in the overall water balance of interior regions.
- **Example**: The Geological Survey of Canada has conducted extensive geological mapping to characterize aquifers and groundwater systems in areas like the Kettle River watershed, providing a crucial foundation for understanding the complex interplay between surface water and groundwater resources in these semi-arid environments (Hamblin, 2012).

On-the-Ground Monitoring Networks

While remote sensing and modeling provide broad-scale insights, on-the-ground monitoring networks serve as the ground truth in the interior plateaus and valleys, validating satellite and model-derived data while providing real-time information on water availability.

- **Stream Gauges**:
  - The Water Survey of Canada maintains an extensive network of stream gauges throughout British Columbia's interior, with a particularly dense network in critical watersheds like the Okanagan and Thompson Rivers.
  - These gauges meticulously measure river discharge and water levels, providing invaluable data for identifying immediate water scarcity issues in these drought-prone regions (B.C. Ministry of Environment, 2016).

- **Snow Survey Sites:**
  - Complementing the stream gauge network, a comprehensive array of snow survey sites is maintained across the interior plateaus and valleys.
  - **Example:** In the Cariboo and Chilcotin regions, these sites diligently track the water content of the snowpack, providing crucial information for predicting spring runoff volumes and potential water scarcity during the arid summer months when agricultural demand peaks (B.C. Ministry of Environment, 2016).

Agricultural Water Demand Modeling

Given the paramount importance of agriculture in British Columbia's interior plateaus and valleys, particularly in regions like the Okanagan and Creston Valley, methodologies for water scarcity mapping must necessarily account for agricultural water demands with a high degree of precision.

- **B.C. Ministry of Agriculture:**
  - The B.C. Ministry of Agriculture has developed a sophisticated Agricultural Water Demand Model specifically calibrated for the unique crops and climate conditions of the interior.
  - **Example:** This model estimates water requirements for crops such as tree fruits, vineyards, and forage, based on a complex interplay of climate data, soil information, and crop types specific to each sub-region of the interior (B.C. Ministry of Agriculture, 2013).

- **2. Integration with Other Data:**
  - In the Okanagan Valley, this model has been instrumental in creating detailed maps that highlight areas where agricultural water demand may exceed available supply, pinpointing potential hotspots of water scarcity in this crucial fruit-growing region.
  - The integration of this agricultural water demand data with hydrological models and remote sensing information provides a comprehensive, multidimensional picture of water scarcity unique to the interior plateaus and valleys.

Climate Variability and Change Considerations

Recognizing the profound impact of climate variability and change on water resources in the semi-arid interior, contemporary methodologies for water scarcity mapping increasingly incorporate sophisticated climate projections and scenario analyses.

- **1. Pacific Climate Impacts Consortium (PCIC):**
  - The PCIC has developed downscaled climate projections specifically for interior regions like the Thompson-Okanagan and Cariboo-Chilcotin.
  - **Example**: These projections are utilized to assess potential changes in precipitation patterns, temperature regimes, and the frequency and intensity of extreme weather events, such as the prolonged droughts that have affected the region in recent years (Najafi et al., 2017).

- **2. Integration with Hydrological Models:**
  - These climate projections are seamlessly integrated into hydrological models and agricultural water demand assessments to create forward-looking water scarcity maps for the interior plateaus and valleys.
  - **Example**: In the Nicola Valley, these integrated models have been used to project future water availability for both agriculture and endangered fish species, allowing for proactive water management and the development of robust adaptation strategies in the face of climate uncertainty (ESSA, 2021; Fraser Basin Council, 2021; ESSA Tools, 2021).

C. Overview of Strategies

1. Improving Data Collection and Monitoring

Enhancing data collection and monitoring is crucial for addressing water scarcity challenges in British Columbia, particularly for Indigenous, and remote communities. This section outlines key strategies and initiatives to strengthen water resource management across the province.

Expanding and Integrating Water Monitoring Networks

Successful initiatives demonstrate the potential of comprehensive monitoring networks:

- The Columbia Basin Water Monitoring Framework (CBWMF) has effectively tracked climate change impacts on water supply across 12,500 square kilometers in five operational areas (Living Lakes Canada, 2023).
- The Horn River Basin Aquifer Characterization Project in northeastern B.C. has deployed hydrometric and climate stations to collect precise water flow, quality, and climatic data (Golder Associates Ltd., 2015).

Potential options to improve data collection and monitoring include:

- **Accelerating groundwater licensing**: Streamline application procedures and offer incentives for early adoption to broaden understanding of groundwater usage patterns.
- **Mandating actual usage reporting**: Implement robust metering systems and regular reporting protocols to transition from maximum limits to actual consumption data.
- **Expanding the groundwater observation network**: Follow the Columbia Basin's model of increasing observation wells from 2 to 30 since 2017, aiming for province-wide expansion.
- **Supporting open access data hubs**: Extend initiatives like Living Lakes Canada's approach to aggregating water data from diverse sources.

Leveraging Advanced Technologies

Integrating cutting-edge technologies can significantly enhance water resource monitoring:

- **Remote sensing**: Utilize satellite imagery (e.g., Sentinel-2) for mapping submerged habitats in coastal waters and monitoring inland water bodies and wetlands (Nahirnick et al., 2019).
- **Drones and high-altitude balloons**: Deploy for higher-resolution imagery of specific areas, particularly useful for monitoring culturally significant sites for Indigenous communities (Lowman & Barros, 2020).
- **GIS and data analytics**: Employ advanced spatial analysis tools to process and interpret the collected data, providing deeper insights into water resource dynamics.

Positive Impact for Indigenous and Remote Communities

These improvements in data collection and monitoring could have significant positive impacts:

- Enable active participation in water management decisions affecting traditional territories
- Facilitate the integration of traditional ecological knowledge with western scientific approaches

- Enhance access to accurate, timely, and comprehensive water data
- Support the development of targeted interventions and adaptation strategies tailored to each community's unique needs and challenges

By implementing these strategies, British Columbia can create a more robust, inclusive, and responsive water management system that addresses the diverse needs of its communities while ensuring long-term water security in the face of climate change and increasing demand.

2. Refining Water Scarcity Mapping Methodologies

Integrating Physical and Socio-Economic Water Scarcity Factors

To address the complex water scarcity challenges in British Columbia, particularly for Indigenous and remote communities, mapping methodologies must incorporate both physical water availability and socio-economic factors:

- **Physical water availability data**: Integrate surface and groundwater data, including seasonal variations and long-term trends (Wei et al., 2023).
- **Socio-economic indicators**: Incorporate population density, economic indicators (e.g., income levels, infrastructure investment), and institutional factors (e.g., water rights, governance structures) (Curran, 2019).
- **Case study application**: The Cheslatta Carrier First Nation case exemplifies the intricate relationship between water rights, economic development, and resource access, highlighting the need for nuanced mapping approaches (Mehta, 2014).

Incorporating Climate Change Projections

Integrating climate change projections is critical for long-term planning and adaptation:

- Utilize the Watershed Security Strategy to enhance tools for monitoring water demand and supply under changing climate conditions (Government of British Columbia, 2023).
- Incorporate projections of temperature and precipitation patterns, snowmelt timing, evapotranspiration rates, and extreme weather events frequency.
- Leverage climate adaptation funds, such as the federal Disaster Mitigation and Adaptation Fund and the First Nations Adapt Program, to support these initiatives (Infrastructure Canada, 2022; Crown-Indigenous Relations and Northern Affairs Canada, 2022).

Strengthening Water Withdrawal Regulations

In response to intensifying climate change impacts, as evidenced by severe drought conditions in 2023, implement the following regulatory enhancements:

- **Proactive risk assessment**: Develop a comprehensive system for early identification of vulnerable water sources, integrating climate projections, historical data, and real-time monitoring (B.C. Energy Regulator, 2024).
- **Tiered water use restrictions**: Implement a three-tier system with clear thresholds for graduated water use restrictions:
    - Tier 1 (Yellow): Voluntary conservation measures
    - Tier 2 (Orange): Mandatory restrictions on non-essential water use

- Tier 3 (Red): Severe restrictions and potential curtailment of commercial operations

- **Enhanced Environmental Flow Needs Policy**: Develop specific, enforceable regulations to protect essential human and ecosystem needs during scarcity periods, including mandatory minimum flow requirements based on ecological needs (B.C. Energy Regulator, n.d.).

Validating Maps with Ground-Truth Data and Indigenous Knowledge

Ensure the accuracy and cultural relevance of water scarcity maps through:

- Comparison of satellite-derived data with in-situ measurements.
- Incorporation of traditional ecological knowledge from First Nations and Indigenous communities.
- Field surveys to verify mapped water bodies and their characteristics.
- Case study example: The Stellat'en First Nation study demonstrates the value of combining western science with traditional knowledge in understanding local water resources (Alrushoud et al., 2022).

Respecting Indigenous Data Sovereignty

To integrate traditional Indigenous Knowledge while respecting data sovereignty, it's crucial to adhere to the principles of OCAP® (Ownership, Control, Access, and Possession). These principles, developed by the First Nations Information Governance Centre (FNIGC), provide a framework for how Indigenous data should be collected, protected, used, and shared. In the context of water scarcity mapping, this involves:

- Acknowledging the context and seeking permission for knowledge utilization (Province of British Columbia, 2020).
- Building respectful relationships with Indigenous nations and knowledge holders.
- Applying Indigenous Knowledge throughout environmental assessments to gain a holistic understanding of watersheds (Mena, 2019).
- Ensuring Indigenous nations retain control over how their knowledge is collected, accessed, and utilized through data sharing agreements and collaborative water tables (Owen, 2024).
- Recognizing that Indigenous communities own their cultural knowledge, traditions, and practices related to water management.
- Providing Indigenous communities with access to the data collected about their territories and resources.

By following these OCAP® principles, water scarcity mapping initiatives can ensure ethical and respectful use of Indigenous Knowledge while promoting Indigenous data sovereignty (First Nations Information Governance Centre, 2022).

Positive Impact for Indigenous and Remote Communities

These refined methodologies could:

- Provide a comprehensive picture of water scarcity challenges, considering both physical and socio-economic factors.
- Enable better anticipation and preparation for future changes in water availability.

- Ensure water scarcity maps are grounded in local realities and incorporate traditional ecological knowledge.
- Empower communities to actively participate in the validation and refinement of water scarcity maps.

By implementing these refined methodologies, British Columbia can develop more accurate, culturally relevant, and effective water scarcity mapping tools that address the unique needs of its diverse communities and landscapes.

3. Engaging Communities and Decision-Makers in Water Scarcity Mapping

Effective engagement of communities and decision-makers is crucial for developing accurate, culturally appropriate, and actionable water scarcity maps in British Columbia. This section outlines strategies to involve local communities, build capacity, communicate effectively with policy-makers, and leverage various funding sources to support these efforts.

Community Involvement and Capacity Building

Engaging Indigenous and remote communities in water scarcity mapping is essential for developing locally relevant and culturally appropriate information. Key strategies include:

- **Collaborative research partnerships**: Foster partnerships between academic institutions, government agencies, and Indigenous communities to combine scientific methods with traditional ecological knowledge.
- **Indigenous-led education initiatives**: Support programs like the Indigenous Mapping Workshop to train a skilled Indigenous workforce in geospatial technologies, promoting self-determination and sustainable management of traditional territories.
- **Local capacity-building**: Implement training programs for data collection, analysis, and interpretation, empowering communities to actively participate in and lead water scarcity mapping efforts.

Case Study: The Gitga'at First Nation's involvement in monitoring environmental contaminants demonstrates the value of incorporating local knowledge into scientific monitoring programs (Living Lakes Canada, 2023). This approach can be adapted for water scarcity mapping across B.C.

Effective Communication with Policy-Makers

Translating complex water scarcity data into clear, actionable recommendations is crucial for informed decision-making. Strategies include:

- Developing concise summaries of key findings and implications
- Creating visually compelling representations of water scarcity data
- Highlighting high-risk areas and priority intervention zones

The Okanagan Basin Water Board's use of visual storytelling techniques to communicate water issues to local governments serves as a model for effective stakeholder engagement (Okanagan Basin Water Board, 2022).

Innovative Mapping Tools and Platforms

Developing user-friendly, interactive mapping platforms can empower stakeholders to explore different scenarios and contribute to water management solutions:

- **Interactive web-based platforms**: Allow users to overlay various data layers, conduct scenario analyses, and provide community-level input.
- **Tailored regional tools**: Expand initiatives like the Columbia Basin Water Hub to other B.C. regions, addressing unique water scarcity challenges faced by diverse communities.

Funding and Resource Allocation

Securing adequate funding is critical for implementing comprehensive water scarcity mapping initiatives. Strategies include:

- **Advocacy for targeted government funding**: The British Columbia Assembly of First Nations' successful advocacy has led to significant federal commitments, including $918 million over five years for Indigenous community infrastructure (Government of Canada, 2024).
- **Leveraging existing programs**:
    - The First Nations Water Management Strategy has invested over $6.3 billion since 2015 in water infrastructure for First Nations communities (Government of Canada, 2024).
    - The B.C. Investment Agriculture Foundation's Beneficial Management Practices program offers funding for water-related projects on First Nations agricultural lands (Investment Agriculture Foundation of B.C., 2024).
    - The Watershed Security Fund, which received an initial investment of $100 million from the Province in 2023, is working towards establishing a permanent fund that is co-developed and co-managed with First Nations, supporting more resilient watersheds across B.C. (Watershed Security Fund, 2024).
- **Academic research partnerships**: Utilize funding streams like NSERC's Indigenous community-based research grants to support water scarcity mapping projects (NSERC, 2022).

Positive Impact for Indigenous and Remote Communities

By implementing these engagement strategies, Indigenous and remote communities in B.C. will benefit from:

- Empowerment through active participation in water resource management
- Enhanced local capacity for data collection and analysis
- Improved communication of water challenges to policy-makers
- Access to user-friendly tools for exploring water management scenarios
- Increased funding and resources for community-driven water initiatives

This comprehensive approach to community engagement in water scarcity mapping will foster more resilient, sustainable, and equitable water management practices across British Columbia.

C. Emerging Technologies and Methodologies for Enhancing Water Scarcity Mapping

British Columbia faces significant challenges in managing its water resources due to climate change, population growth, and industrial development. A suite of emerging technologies and methodologies offers promising avenues for enhancing water scarcity mapping across the province's diverse landscapes, with particular benefits for Indigenous and remote communities.

1. Surface Water Mapping Technologies

Airborne LiDAR Data: Transforming Surface Water Detection

Airborne LiDAR data utilizes laser scanning to capture three-dimensional coordinates of the Earth's surface, offering a novel way to discern water bodies. A groundbreaking, fully automated method leverages 3D coordinate observations to map surface water bodies with remarkable accuracy (Anon, 2023). Key advantages include:

- Enhanced detection of small water bodies (under 1 hectare), crucial for understanding B.C.'s complex hydrological systems.
- Elimination of extensive data preparation and calibration needs.
- Comprehensive 3D topographic mapping, integrating water and terrain features.

For First Nations and Indigenous communities, this technology enables more accurate identification of small water bodies on traditional territories, improving understanding of seasonal changes and mapping of culturally significant areas.

RPAS Photogrammetry: High-Resolution Mapping at Local Scales

Remotely Piloted Aircraft System (RPAS) photogrammetry complements LiDAR by providing detailed mapping of water resources at local scales. In B.C., this technology has shown remarkable promise for creating high-resolution digital imagery and 3D models of water features (Milidragovic et al., 2022). Benefits include:

- Unparalleled spatial detail for precise mapping of water bodies and associated features.
- Flexibility and cost-effectiveness for frequent monitoring and updating of water resource maps.
- Advanced 3D modeling capabilities using Structure-from-Motion (SfM) photogrammetry.

This technology empowers First Nations and Indigenous communities to manage their water resources with greater autonomy and insight, offering a cost-effective solution for regular monitoring in remote areas.

2. Satellite-Based Mapping Techniques: Province-Wide Monitoring

Adapting Sentinel-2 Satellite Data for Water Resource Mapping

Recent advancements in processing Sentinel-2 satellite data present new opportunities for comprehensive water scarcity mapping across B.C.'s vast terrain (Anon, 2021). Advantages include:

- High spatial resolution (20-meter) for detailed mapping of water bodies and associated land cover.
- Extensive area coverage suitable for province-wide assessments.
- Frequent updates enabling near real-time tracking of water resource dynamics.

This technology provides Indigenous communities with a clearer understanding of how environmental changes impact water resources on traditional lands.

3. Groundwater Mapping and Assessment

Quantifying Aquifer Stress with Groundwater Footprint Analysis

Innovative methods now allow researchers to quantify aquifer stress in areas with scarce data by calculating annual volumes of groundwater withdrawal, recharge, and environmental flow contributions (Klassen & Allen, 2022). Benefits include:

- Screening-level estimates of aquifer stress across B.C.
- Improved water scarcity assessments incorporating both surface and groundwater resources.
- Data-driven decision making for sustainable water management policies.

This analysis is particularly beneficial for Indigenous communities relying on aquifers, supporting informed decision-making for sustainable water use on traditional lands.

Integration of Technologies: A Synergistic Approach

The integration of these technologies (airborne LiDAR, RPAS photogrammetry, satellite imagery, and groundwater footprint analysis) enables B.C. to develop a comprehensive and dynamic water scarcity mapping system. This integrated approach offers:

- Multi-scale mapping from local to province-wide assessments.
- Comprehensive water resource assessment incorporating both surface and groundwater.
- Regular updates for proactive management and early identification of water scarcity issues.
- Capacity building and sovereignty strengthening for Indigenous and remote communities.
- Improved decision support for water managers and policymakers.

Case Study: Okanagan Basin Water Board

The Okanagan Basin Water Board (OBWB) exemplifies the successful integration of these technologies in water scarcity mapping. The OBWB has implemented:

- LiDAR and high-resolution aerial imagery for detailed mapping of the Okanagan watershed.
- A network of real-time hydrometric and climate stations for continuous data collection.
- Groundwater monitoring wells equipped with data loggers for aquifer level tracking.
- Collaboration with the Syilx Okanagan Nation to incorporate traditional ecological knowledge.

This comprehensive approach has enabled the OBWB to create highly accurate water scarcity maps, inform water management decisions, and develop targeted conservation strategies. The success of this initiative demonstrates the potential for similar integrated approaches across B.C., particularly in regions facing water scarcity challenges.

By leveraging these emerging technologies and methodologies, British Columbia can revolutionize its approach to water scarcity mapping, ensuring more effective, equitable, and sustainable water management practices that benefit all communities, with particular emphasis on addressing the unique needs of Indigenous and remote populations.

D. Conclusion and Key Strategies

British Columbia's water scarcity mapping efforts face a multifaceted array of challenges, from complex data collection issues to intricate socio-economic and political barriers. However, the convergence of cutting-edge technologies and innovative methodologies offers unprecedented opportunities to revolutionize water management practices, particularly for Indigenous and remote communities.

Examples of Key Challenges and Strategic Solutions

- ❖ **Data Collection and Integration**
  - **Challenge:** B.C.'s diverse geography and limited infrastructure in remote areas hinder comprehensive data gathering.
  - **Potential Strategy:** Implement a province-wide program fusing LiDAR, RPAS photogrammetry, and satellite imagery with Indigenous ecological knowledge. Establish a centralized, open-access data hub to ensure information accessibility for all communities.
- ❖ **Methodological Complexities**
  - **Challenge:** Developing standardized models that account for B.C.'s varied landscapes and cultural contexts.
  - **Potential Strategy:** Create holistic mapping approaches integrating physical water availability data with socio-economic indicators and climate change projections.
- ❖ **Socio-Economic and Political Barriers**
  - **Challenge:** Integrating traditional Indigenous water rights with provincial governance structures and addressing economic disparities.
  - **Potential Strategy:** Foster collaborative research partnerships between academic institutions, government agencies, and Indigenous communities. Support Indigenous-led education initiatives in geospatial technologies and water resource management.

Comprehensive Recommendations

1. **Technology and Knowledge Integration**
   - Develop a seamless fusion of advanced technologies with traditional ecological knowledge.
   - Establish collaborative research partnerships to create culturally appropriate mapping methodologies.
2. **Enhanced Monitoring and Data Management**

- Expand and integrate water monitoring networks, drawing inspiration from successful models like the Columbia Basin Water Monitoring Framework.
- Accelerate groundwater licensing and mandate actual usage reporting for improved water consumption insights.

3. **Refined Mapping Methodologies**
    - Incorporate climate change projections and socio-economic indicators into water scarcity mapping.
    - Implement adaptive management strategies for groundwater allocation based on comprehensive data analysis.
4. **Community Empowerment and Engagement**
    - Develop user-friendly, interactive mapping platforms allowing stakeholders to explore scenarios and contribute local knowledge.
    - Implement targeted training programs in remote and Indigenous communities for data collection, analysis, and interpretation.
5. **Policy Communication and Implementation**
    - Create visually compelling summaries of water scarcity data for decision-makers.
    - Establish regular knowledge exchange forums between researchers, community representatives, and policymakers.
6. **Sustainable Funding and Partnerships**
    - Advocate for targeted government funding and leverage existing programs to support community-driven water initiatives.
    - Explore innovative public-private partnerships and academic collaborations to diversify funding sources.
7. **Institutional Reform and Coordination**
    - Review and update water governance structures to ensure seamless coordination across jurisdictions.
    - Align water scarcity mapping efforts with broader water security initiatives and watershed management plans.

Innovative Case Studies and Future Directions

Recent initiatives showcase the transformative potential of these recommendations:

- **The Cowichan Watershed Board's** partnership with local First Nations exemplifies a "whole-of-watershed" approach, seamlessly integrating traditional knowledge with modern mapping techniques. This collaborative governance partnership between Cowichan Tribes First Nation and the Cowichan Valley Regional District aims to protect and enhance the health of the Cowichan and Koksilah watersheds. The Board provides a space for people to come together with their respective authorities, integrity, and humanity—in the spirit of Nutsamat (one heart, one mind)—to share information, make consensus recommendations, and then work to implement those recommendations within their own organizations (Cowichan Watershed Board, 2023).
- **The B.C. Water Tool** is evolving into a comprehensive platform, incorporating real-time data from IoT sensors for up-to-date information on water levels and quality across the province. The Real-time Water Data Tool (Aquarius Time-Series database) serves as the primary repository for continuous surface, groundwater, and snow data from monitoring stations

throughout British Columbia (Miller, 2023). This browser-based system allows timely access to snow and water monitoring data (Government of British Columbia, 2023). The Provincial Hydrology Program manages the collection of provincial surface water quantity data, focusing primarily on river levels and surface water flow (Government of the Northwest Territories, 2020). Sharing this water data supports a greater understanding of B.C.'s water resources, enables sound, science-based decisions, and helps track changes to water resources over time (Government of the Northwest Territories, 2020).

By implementing this integrated approach, British Columbia could position itself as a leader in sustainable water resource management. The synergy of cutting-edge technologies, traditional knowledge, robust community engagement, and aligned policies aims to foster a more resilient and equitable water management system. This holistic strategy could not only address the immediate challenges faced by Indigenous and remote communities but also support efforts towards long-term water security for all residents in the face of climate change and increasing demand.

As we move forward, it is important to recognize that water scarcity mapping extends beyond technical challenges—it is a societal concern. By fostering collaboration, embracing innovation, and respecting diverse knowledge systems, communities across British Columbia may develop mapping tools that serve as a model for sustainable water management. This approach has the potential to set a new standard for integrated, equitable, and forward-thinking water resource stewardship, potentially influencing practices globally.

IV. APPENDIX

❖ Contextual Framework for Water Scarcity Mapping in British Columbia

Water scarcity is a complex global issue with unique challenges in British Columbia (B.C.). The province's diverse geography, climate, population distribution, historical water management practices, and current policies shape its water resource challenges (Bakker & Allen, 2015). To effectively map water scarcity and develop robust management strategies, we need a nuanced framework that combines geographic, historical, and governance dimensions, with intersectionality playing a crucial role.

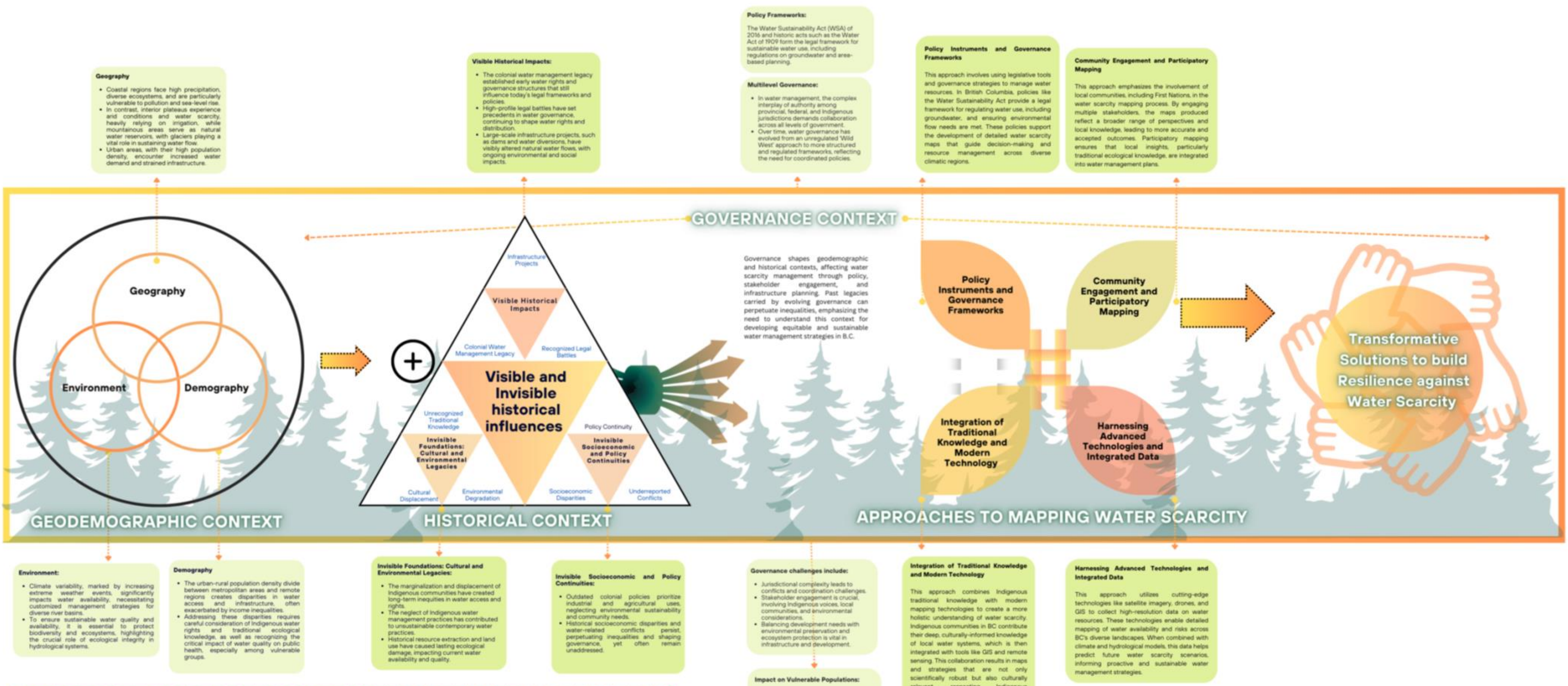
This intersectional context is vital for a comprehensive water scarcity mapping project in B.C. due to the complexities each dimension brings and their intricate interactions:

1. **Geodemographics:** B.C.'s varied topography creates diverse microclimates and hydrological regimes (Moore et al., 2010). Uneven population distribution leads to different water demands and infrastructure needs in urban and rural areas (Bakker & Cook, 2011). An intersectional approach reveals how these factors interact with social identities to create unique water access challenges.
2. **Historical context:** B.C.'s water management has been shaped by colonial practices, Indigenous water rights, and changing economic priorities (Simms et al., 2016). This history influences current water access and distribution (von der Porten & de Loë, 2013). Intersectionality helps us understand how these historical factors interact with current social structures to perpetuate or worsen water inequities.
3. **Governance:** B.C.'s water policies have evolved from a "Wild West" approach to more structured strategies, but still face challenges in areas like groundwater regulation (Brandes & Curran, 2017). The interplay between provincial, federal, and Indigenous jurisdictions complicates the policy landscape (Simms & Brandes, 2018). An intersectional lens is crucial for understanding how these governance structures may disproportionately impact certain communities.

The interplay of these dimensions creates a complex water scarcity context in B.C. that requires an intersectional approach to mapping. This approach can capture the nuanced realities of water availability, access, and management across the province.

By embracing intersectionality, we can develop more nuanced, equitable, and effective solutions that address the complex realities of diverse communities in B.C. This approach enhances our understanding of water scarcity issues and promotes more inclusive and just water governance practices.

Figure 1: **Contextual Framework for Approaches to Mapping Water Scarcity in British Columbia, Canada**



This contextual framework illustrates the intricate interplay of geodemographic, historical, and governance factors in addressing water scarcity in British Columbia, Canada. It highlights how the province's diverse geography and population distribution influence water availability and infrastructure needs. The historical context examines both visible and invisible legacies, including colonial water management practices and the often-overlooked knowledge of Indigenous and First Nation communities, which continue to shape current water practices.

At the heart of this framework, governance acts as the central force, influencing and integrating all other aspects. It determines how water scarcity is managed across different regions and communities. The framework emphasizes the importance of an intersectional approach, acknowledging that effective, equitable, and context-sensitive solutions can only be developed by considering the interconnectedness of these factors. This comprehensive analysis supports the creation of tailored strategies that best meet the water needs of vulnerable, local, remote, Indigenous, and First Nation communities, ultimately aiming to build resilience against water scarcity in British Columbia.

This contextual framework integrates geodemographic, historical, and governance dimensions to better anticipate the feasibility, effectiveness, and equity implications of potential interventions (Curran & Brandes, 2019).

A robust synthesis should directly link specific challenges with governance and policy recommendations. For example, adapting the *Water Sustainability Act* to better address the unique challenges faced by Indigenous communities in water-scarce regions could be a key step towards more equitable and sustainable water management (Joe et al., 2017).

Note: Going forward, this report will refer to this contextual framework as the 'Framework.'

A. Geodemographic Context: Understanding Environmental and Demographic Interactions

Geographic Diversity and Water Scarcity Challenges

British Columbia's diverse topography, from coastal rainforests to arid interior plateaus, creates a complex mosaic of microclimates and localized water availability patterns (Moore et al., 2010; Standish, 2022). This diversity challenges water resource managers and researchers, requiring a nuanced approach to water scarcity mapping that captures local hydrological details while providing a coherent overview of regional trends (Standish, 2022).

Impact of Mountainous Terrain on Water Availability

The province's mountains shape precipitation patterns, creating areas of water abundance and scarcity (Barlow et al., 2021). This variability affects communities, ecosystems, and economic activities. Climate change-driven glacier retreat compounds these challenges, as glaciers have historically regulated water storage (Halseth & Markey, 2019).

Climatic Contrasts and Regional Water Management

British Columbia's geographic diversity extends to its climate, with significant differences between humid coastal and arid interior areas impacting water availability (Arsenault et al., 2024). Arid regions, with less coarse woody debris, are more susceptible to water depletion during forestry activities like clearcutting, necessitating tailored water management strategies for each region.

Population Patterns and Water Demand

British Columbia's geography influences population patterns and water demand. Over half the province's population lives in the Vancouver metro area (Province of British Columbia, 2023), pressuring local water resources. Some water-stressed areas also have higher-than-average population growth rates, exacerbating the challenges (Watershed Watch Salmon Society, 2019).

Approximately 63% of British Columbia's population (2.9 million people) live in water-stressed areas (Watershed Watch Salmon Society, 2019). This underscores the urgent need for sustainable water management strategies that meet current and future needs while protecting ecosystems.

Intersectional Water Access Challenges

Uneven population distribution creates different water demands and infrastructure needs between urban centers and rural areas (Bakker & Cook, 2011). An intersectional approach reveals how geography intersects with social identities to create unique water access challenges for different communities, particularly affecting marginalized groups.

Economic and Industrial Pressures on Water Resources

As British Columbia's population and industries grow, water demand intensifies. Unsustainable practices, especially in mining, can worsen water scarcity through increased effluent discharge, water extraction, and fish habitat degradation (Skuce & Kuyek, 2022).

Understanding the interplay between demographic pressures, environmental impacts, and social identities is crucial for developing sustainable policies that balance economic growth, water conservation, and equitable access. An intersectional approach to water scarcity mapping and management can help British Columbia develop nuanced, equitable, and effective solutions for diverse communities across the province.

B. Historical Context: Navigating the Colonial Landscape

Colonial Legacy and Indigenous Rights

The current water landscape in British Columbia is deeply rooted in historical practices that often prioritized industrial and agricultural uses over environmental concerns and Indigenous rights (Mattison & Moore, 2005). While dams and water diversions brought certain economic benefits, they significantly altered natural flow regimes, profoundly impacting First Nations communities by disrupting traditional water sources and subsistence economies (Allen & Gleeson, 2023).

These large-scale projects often flooded Indigenous lands and disrupted vital fishing practices (Mining Sick, 2020). For example, the 1950s construction of the Kenney Dam flooded vast areas of the Nechako River watershed, forcing the Cheslatta T'en First Nation to relocate and submerging their traditional hunting and fishing grounds (Sandborn, 1999).

This historical context continues to shape water access, rights, and management in the province today. The legacy of these colonial practices underscores the need for a comprehensive approach to water scarcity mapping that acknowledges this history and recognizes the importance of more equitable and sustainable practices that respect Indigenous rights and traditional knowledge.

Evolving Priorities and Competing Demands

The management of water resources in British Columbia has undergone significant changes over time, reflecting shifting societal values and emerging challenges. This evolution is evident in both early water management priorities and modern challenges.

Early Water Management Priorities

Water management in B.C. has evolved significantly over the past century. The *Water Act* of 1909 established many fundamental principles guiding the province's approach to water resources (Government of British Columbia, n.d.). In the early 1900s, efforts in areas like the Okanagan Valley focused primarily on improving navigation between lakes. However, other interests soon emerged, including maintaining minimum lake levels for navigation in shallow areas, reducing flood levels in low-lying areas, and recognizing lakes as storage reservoirs for irrigation during droughts (Symonds, 2000).

Modern Water Management Challenges

This evolution demonstrates the growing complexity of water management issues and the need for a more holistic approach. B.C.'s diverse aquatic ecosystems rely on effective water management for survival and health. The Fraser River and its tributaries support major salmon runs that are ecologically, economically, and culturally significant (Macdonald et al., 2010). These salmon populations are highly sensitive to factors like water temperature, flow, and quality, all influenced by watershed management practices (Macdonald et al., 2010; Macisaac, 2010; Blomquist et al., 2005). The province's water resources face numerous competing demands requiring careful balancing, including hydroelectric power generation, agricultural needs, industrial uses, growing urban populations, and recreational uses.

Indigenous Water Management and Cultural Significance

Traditional Water Management Practices

Indigenous communities in British Columbia have a long history of sustainably managing water resources. Their traditional knowledge offers valuable insights into effective and holistic water management practices. As Haida elder Guujaaw states, "We have to have a relationship with the land and water. Our people have lived here for thousands of years, and we have an understanding of how to live in balance with nature" (Native Women's Association of Canada, n.d.).

Cultural and Spiritual Significance of Water

For First Nations in B.C., water holds immense cultural and spiritual significance. It's viewed as far more than a resource; water is considered sacred, a living entity to be respected and protected. Anishinaabe elder Josephine Mandamin explains, "Water is the first thing that the Creator made, and it's the water where we were born. We pray for that water because water is a living thing. It's not a commodity. We look at it as a spiritual element" (CBC Radio, 2023). This perspective contrasts sharply with Western conceptions of water as a commodity to be exploited (Simms, 2015).

The Erosion of Indigenous Women's Water Stewardship

The role of Indigenous women in water stewardship has been profoundly affected by colonial policies and practices in British Columbia. Historically, Indigenous women held significant authority and responsibility in water management within their communities. However, this traditional role has been systematically undermined through various colonial interventions.

Colonial Impact on Indigenous Women's Authority

The *Indian Act* of 1876 marked a turning point in the erosion of Indigenous women's water stewardship. This legislation stripped Indigenous women of fundamental rights and excluded them from crucial decision-making processes. Indigenous women were barred from voting in band council elections or running for leadership positions until the 1960s (Environment and Climate Change Canada, 2022). This exclusion from formal governance structures severely limited their ability to influence water management decisions.

Displacement and Environmental Degradation

Land dispossession and forced relocation have severed ties between Indigenous communities and their ancestral waters. Confinement to reserves often meant separation from traditional water sources and watersheds (B.C. Assembly of First Nations, n.d.; von der Porten, 2012). British Columbia's water licensing regime, established in the early 1900s, favored settler interests while disregarding Indigenous water rights (von der Porten, 2012).

Environmental degradation from resource extraction projects has further undermined Indigenous women's ability to protect their waters and communities. Mining, oil and gas development, and hydroelectric dams have polluted and degraded many Indigenous water sources (Union of B.C. Indian Chiefs, 2022; Native Women's Association of Canada, 2023).

Disruption of Cultural Knowledge Transmission

The residential school system and other colonial efforts to eradicate Indigenous cultures have severely impeded the intergenerational passing down of Indigenous women's water knowledge and practices (Environment and Climate Change Canada, 2022). This disruption in cultural continuity has had lasting impacts on Indigenous communities' relationship with water and their ability to maintain traditional stewardship practices.

Resilience and Revitalization Efforts

Despite these challenges, Indigenous women continue to assert their roles as water protectors. Ongoing efforts to revitalize and exercise Indigenous authority over land and water demonstrate cultural continuity and resilience (Arsenault et al., 2023). These initiatives are crucial in reclaiming Indigenous women's traditional roles in water stewardship and promoting more sustainable and culturally appropriate water management practices.

C. Governance Context: Understanding Policy and Administrative Structures in British Columbia's Water Management

British Columbia's water governance framework has experienced significant evolution in recent years, reflecting a concerted effort to modernize and enhance water management practices across the province. This transformation underscores the growing recognition of water as a vital resource that demands careful stewardship and comprehensive management strategies.

Historical Context and Legislative Foundations

Pre-20th Century Water Management

Prior to the 20th century, B.C.'s water management regime was anchored in the common law system of riparian rights, an approach that inextricably linked water access to land ownership adjacent to natural watercourses. However, the limitations of this system were thrown into sharp relief during the Cariboo gold rush, which underscored the pressing need for a more flexible and comprehensive water management framework.

The Gold Fields Act of 1859 and the Water Act of 1909

The 20th century marked a transformative period in B.C.'s water management history. This era witnessed a confluence of technological innovation, legislative reform, and shifting societal needs that profoundly shaped the province's approach to water resources for generations to come.

The *Gold Fields Act of 1859* marked a significant departure from the riparian rights system, introducing the concept of appropriation, establishing rental payments to the Crown, and instituting the non-transferability of rights. The *Water Act of 1909* drastically changed B.C.'s water management, shifting from traditional uses to a regulated, rights-based approach. This landmark legislation established many of the foundational principles that would guide water management in the province for decades to come.

Principles Introduced and Implications for Water Access

The *Water Act of 1909* introduced a water allocation regime based on the principle of "first in time, first in right." This principle had far-reaching implications for water access and distribution across the province. The *Act* also introduced a formal licensing system, which allowed for more efficient allocation of water resources, particularly in areas remote from natural watercourses.

Federal and Provincial Frameworks

Federal Policy on Water Management

The National Policy on Water Resources, established by Law 9433/97, serves as the cornerstone of Canada's sustainable water management strategy. This policy recognizes water as a finite and vulnerable resource essential for life, development, and environmental preservation. It promotes integrated water resource management, fostering collaboration among diverse stakeholders to achieve sustainable water use (Global Water Futures, 2019).

The policy encourages shared responsibility, creating a foundation for a resilient and adaptive water management system. It sets the stage for the development of complementary guidelines and initiatives that reinforce its principles.

Guidelines for Canadian Drinking Water Quality: Safeguarding Health

Building upon the National Policy, the Guidelines for Canadian Drinking Water Quality set fundamental standards for all water systems, aiming to ensure Canadians have access to clean, safe, and reliable drinking water (Rivera, 2005). These carefully crafted guidelines undergo regular updates to reflect the latest scientific knowledge and technological advancements.

Beyond serving as a water quality benchmark, these guidelines help identify potential water scarcity issues, informing policy decisions and resource allocation (Rak-Banville, n.d.). This proactive approach enables policymakers to anticipate and address water-related challenges before they escalate.

Federal Government's Role in Water Management

The federal government plays a key role in Canada's water management, especially in matters concerning First Nations, Inuit, and trans-boundary waters (Rivera, 2005). It is responsible for surveying federal contaminated sites and implementing remediation plans, demonstrating a commitment to addressing historical environmental challenges.

Moreover, the federal government publishes authoritative reports and policy documents that elucidate best practices for water scarcity mapping. These publications are invaluable resources for provincial and territorial governments, as well as local communities, in developing effective water management strategies (Global Water Futures, 2019).

Collaborative Research: Bridging Science and Practice

Canada's water management approach is strengthened by collaborative research initiatives that bridge adaptation science and stakeholder needs. These collaborations bring together natural and social scientists, government agencies, and boundary organizations to integrate cutting-edge research with practical applications (Plummer et al., 2019).

The resulting publications and reports advocate for best practices in water scarcity mapping and sustainable management. By nurturing interdisciplinary cooperation, Canada ensures its water management strategies are informed by the latest scientific findings and aligned with diverse stakeholder needs (Global Water Futures, 2019).

Aquifer Mapping: Illuminating Groundwater Resources

A critical component of Canada's water management framework is the comprehensive aquifer mapping undertaken by Natural Resources Canada (Rivera, 2005). This thorough mapping follows best practices and guidelines, guaranteeing consistent and reliable groundwater data and highlighting potential water scarcity.

The aquifer mapping initiative provides valuable information for policymakers, researchers, and local communities. It enables more accurate assessments of water availability, identifies vulnerable areas, and supports the development of targeted conservation strategies (Rak-Banville, n.d.).

Provincial Policy on Water Management

British Columbia, Canada's westernmost province, has emerged as a leader in developing a comprehensive approach to water management. This case study delves into the province's multifaceted strategies, guidelines, and best practices, with a focus on water scarcity mapping and groundwater protection. By examining these initiatives, we gain valuable insights into how a jurisdiction can effectively address the complex interplay between water scarcity, groundwater preservation, and sustainable resource utilization.

The B.C. Drought and Water Scarcity Response Plan: Evidence-Based Approach

The British Columbia Drought and Water Scarcity Response Plan exemplifies the province's commitment to evidence-based decision-making. This plan represents a paradigm shift in addressing water scarcity, moving beyond reactive measures to proactive, data-driven strategies (British Columbia Ministry of Environment and Climate Change Strategy, 2023).

The plan's emphasis on robust data collection, continuous monitoring, and thorough evaluation underscores the importance of accurate, timely information in effective water management. By prioritizing the development of comprehensive water system profiles and establishing clear data requirements, the plan equips decision-makers with the tools necessary to navigate the complex landscape of water resource management (British Columbia Ministry of Environment and Climate Change Strategy, 2023).

Pioneering Integrated Management

The *Water Sustainability Act* (WSA) stands as a testament to British Columbia's forward-thinking approach to water governance. This landmark legislation introduces groundwater licensing and area-based tools, heralding a new era in watershed planning, regional water management, and watershed governance (Province of British Columbia, n.d.).

The WSA's introduction of Water Sustainability Plans (WSPs) and WSA Objectives enables a holistic, whole-of-watershed approach that transcends traditional sectoral boundaries. These tools allow for tailored solutions to address region-specific challenges, from resolving conflicts between water users to mitigating risks to water quality and ensuring the vitality of aquatic ecosystems (Province of British Columbia, n.d.).

Implementation Challenges: Despite the progressive objectives of the WSA, its implementation has encountered notable challenges. A significant issue was the failure of approximately 12,000 users to apply for groundwater licenses by the 2022 deadline, resulting in the forfeiture of their legal water rights. This situation highlights the complexities and difficulties involved in translating policy into effective practice.

B.C. Aquifer Classification System: Mapping the Invisible Resource

Recognizing the critical importance of groundwater resources, British Columbia has developed the B.C. Aquifer Classification System. This innovative system provides a methodical approach to identifying and categorizing aquifers based on their use, vulnerability to contamination, and importance for management and protection (Wei, 2000).

The resulting aquifer classification maps serve as invaluable resources for land-use planners and resource managers. These maps provide crucial information on groundwater vulnerability, development levels, and ranking values, enabling more informed decision-making in land-use planning and resource management (Wei, 2000). By bringing this invisible resource to the forefront, the B.C. Aquifer Classification System ensures groundwater becomes an integral part of comprehensive water resource management.

Environmental Protection and Management Guideline: Balancing Development and Conservation

The Environmental Protection and Management Guideline, issued by the B.C. Energy Regulator (2023), reinforces the province's commitment to integrated water resource management. This guideline exemplifies British Columbia's efforts to strike a balance between economic development and environmental protection.

By requiring project proponents to develop robust rationales and mitigation strategies to address potential impacts on critical environmental values, the guideline ensures water resources are considered holistically within the context of broader resource management decisions (B.C. Energy Regulator, 2023). This approach recognizes water as a fundamental component of ecosystems that require careful stewardship.

Government Reports

The strategies and guidelines outlined above are informed by comprehensive reports from the Ministry of Environment and Climate Change Strategy. The "Ground Water Mapping and Assessment in British Columbia" report, for instance, highlights the crucial role of local involvement in groundwater management (Kohut, n.d.).

This report emphasizes the importance of integrating groundwater considerations into local land-use planning, developing well-head protection plans, and implementing measures to protect aquifer recharge areas. It also recommends that the provincial government, with federal support, establish standards for groundwater mapping and data collection (Kohut, n.d.). These recommendations underscore the need for consistent, high-quality data to inform decision-making at all levels of governance.

Governance Challenges

Jurisdictional Complexity

Effective water governance in B.C. faces several ongoing challenges, including **jurisdictional complexity**: Authority over water resources is shared among various levels of government, including federal, provincial, local, and Indigenous, leading to potential conflicts and coordination issues.

Stakeholder Engagement

There is a recognized need for improved **stakeholder engagement** and public debate around contentious water issues.

Integrated Watershed Planning

The development of institutions and processes for **collaborative, integrated watershed planning** remains a key challenge.

Infrastructure and Development

Early 20th Century Infrastructure Projects

Parallel to these legislative developments, the early 20th century witnessed a boom in water infrastructure projects across B.C. The construction of dams and irrigation systems played a pivotal role in reshaping the province's landscape and economy. These projects were driven by the imperative to support agricultural expansion, particularly in the province's interior regions.

The Columbia River Treaty: A Case Study in Large-Scale Water Management

The Columbia River Treaty, signed in 1961 between Canada and the United States, serves as a prime example of the scale and complexity of water management projects that had their roots in early 20th century water management philosophy. The treaty led to the construction of three major dams in B.C., which provided significant benefits in terms of flood control and hydroelectric generation for both countries. However, they also exemplify the complex trade-offs inherent in large-scale water management projects, including the displacement of communities, the loss of productive agricultural and forestry areas, and significant impacts on fish and wildlife habitats.

Conclusion

The governance dimension of water management in British Columbia is multifaceted and dynamic. It requires ongoing evaluation and refinement to address the complex interplay of environmental, social, and economic factors affecting water resources. As the province continues to grapple with issues of water scarcity and sustainable management, the evolution of its governance structures will play a crucial role in shaping the future of water resources in British Columbia.

British Columbia's approach to water management, particularly in water scarcity mapping and groundwater protection, stands as a testament to the power of comprehensive, integrated strategies. By combining legislative tools, classification systems, and evidence-based guidelines, the province has developed a robust framework for addressing current and future water management challenges.

This approach recognizes the complex, interconnected nature of water resources and seeks to balance various needs and interests within a framework of sustainable management. As climate change continues to exert pressure on water resources globally, British Columbia's comprehensive and integrated approach may serve as a valuable model for other jurisdictions facing similar challenges.

The province's emphasis on data-driven decision-making, local involvement, and holistic watershed management provides a strong foundation for adaptive and resilient water management in the face of evolving environmental conditions.

D. Case Study: The Legal Context of Indigenous Water Rights in British Columbia

Historical Context and Early Legal Battles

The struggle for Indigenous water rights in British Columbia (B.C.) is deeply rooted in colonial history, marked by the systematic displacement of First Nations' traditional water governance systems. This case study examines the complex journey towards reconciliation and justice in water governance, exploring the historical context, legal milestones, and ongoing challenges faced by Indigenous communities in B.C.

Landmark Legal Decisions

Early Acknowledgments and Federal Legislation

The fight for Indigenous water rights began during the colonial era when European settlers displaced First Nations' traditional water governance systems. An early, albeit limited, acknowledgment of Aboriginal title came with the 1888 St. Catharine's Milling decision by the Judicial Committee of the Privy Council in London (Phare, 2009). However, progress was stifled in 1927 when federal legislation made it illegal for First Nations to pursue land claims, effectively halting legal challenges for decades (Phare, 2009).

Key Supreme Court Decisions

The modern era of Indigenous water rights in B.C. dawned with the groundbreaking 1973 Calder v. Attorney-General of British Columbia case. This pivotal decision saw the Supreme Court of Canada recognize Aboriginal title's existence prior to colonization, prompting the federal government to establish a comprehensive land claims policy (Phare, 2009).

Subsequent court decisions further solidified the recognition of Aboriginal title and rights, including water rights:

- The 1984 Guerin v. The Queen case affirmed the federal government's fiduciary duty to First Nations regarding reserve lands and resources (Laidlaw & Passelac-Ross, 2010).
- The 1987 Sparrow decision affirmed First Nations' Aboriginal right to fish for food, social, and ceremonial purposes, intrinsically linking water rights to cultural practices (Laidlaw & Passelac-Ross, 2010).
- The 1997 Delgamuukw v. British Columbia ruling confirmed Aboriginal title in B.C. and established inherent limits on land use to preserve resources for future generations (Laidlaw & Passelac-Ross, 2010).
- The 2014 Tsilhqot'in decision further strengthened Aboriginal title by confirming the Tsilhqot'in Nation's title to a specific area of their traditional territory (Curran, 2020).

These legal victories marked significant progress in recognizing Indigenous water rights, paving the way for Indigenous communities to assert their rights and take a more active role in water governance.

Persistent Challenges and Indigenous Advocacy

Despite legal victories, many First Nations in B.C. continued to face significant challenges in accessing safe drinking water. A 2005 report by the Assembly of First Nations revealed that 75% of water systems on reserves in Canada posed significant health risks (Assembly of First Nations, 2005). Boil water advisories remained a common reality for many Indigenous communities, highlighting the gap between legal recognition and practical implementation of water rights.

Role of Advocacy Groups

Indigenous advocacy groups have played a crucial role in the ongoing fight for water rights. The First Nations Health Authority in B.C. has been a vocal advocate, releasing reports highlighting the ongoing water crisis facing Indigenous communities (First Nations Health Authority, 2020). Similarly, the B.C. Assembly of First Nations has worked to hold the government accountable and secure investments in water infrastructure on reserves (B.C. Assembly of First Nations, 2021).

UNDRIP and Its Implications for Indigenous Water Rights

The United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) has emerged as a critical framework for advancing Indigenous rights, including those related to water. In 2019, the B.C. government passed the *Declaration on the Rights of Indigenous Peoples Act* (DRIPA), enshrining UNDRIP into provincial law and establishing it as the province's framework for reconciliation (Declaration on the Rights of Indigenous Peoples Act, SBC 2019, c 44).

Shift Towards Collaborative Water Management

Collaborative Approaches in Recent Years

Recent years have seen a notable shift towards more collaborative approaches to water management between First Nations and local governments in B.C. The 2015 Cowichan Watershed Board exemplifies this trend, representing a partnership between Cowichan Tribes and the Cowichan Valley Regional District to co-manage the watershed (Curran & Brandes, 2019).

Water Sustainability Act and Indigenous Participation

The 2016 *Water Sustainability Act* requires decision-makers to consider Aboriginal water uses and includes provisions for delegating authority to local entities, potentially enabling greater Indigenous participation in watershed governance (Joe et al., 2017). This *Act* has facilitated the development of Water Sustainability Plans that can be co-governed by First Nations and the province (Centre for Indigenous Environmental Resources, 2020).

Despite positive developments, many argue that significant work remains. The First Nations Fisheries Council has criticized the *Water Sustainability Act* for not adequately recognizing Indigenous water rights and jurisdiction (First Nations Fisheries Council, 2020). Ongoing boil water advisories on reserves underscore the persistent inequities in access to safe drinking water.

The Need for Holistic and Culturally Informed Approaches

Recent reports emphasize the need to center Indigenous laws and knowledge in water management and decision-making (Brandes & Curran, 2019). This approach calls for a paradigm shift towards a more holistic and culturally informed approach to water management.

Conclusion

The history of First Nations' water rights in B.C. is characterized by hard-fought legal battles, powerful Indigenous advocacy, and gradual shifts towards collaborative watershed governance. While significant progress has been made, there remains a pressing need for continued work to fully recognize and implement Indigenous water rights in the province. The path forward requires ongoing Indigenous leadership, continued legal and policy reforms, and a steadfast commitment to addressing persistent inequities in water access and management. True reconciliation in water rights necessitates a fundamental reimagining of our relationship with water, guided by Indigenous wisdom and stewardship practices.

E. Integrated Understanding: An Intersectional Approach to Water Scarcity in British Columbia

Importance of an Integrated Understanding

A comprehensive understanding of the complex interplay between geodemographic, historical, and governance factors is crucial for developing effective water conservation and allocation strategies in British Columbia. This integrated knowledge must consider the intersectional relationships between these factors, acknowledging how they intersect and impact different regions and communities in unique ways. The province's economy, which heavily relies on renewable resources such as forestry, agriculture, and fisheries, can be threatened by water scarcity, with disproportionate impacts on marginalized communities, including Indigenous peoples and rural populations (Marsh, 2006).

Balancing Economic Development with Environmental Protection

Balancing economic development with environmental protection requires a nuanced understanding of the multifaceted factors contributing to water stress, including the historical and ongoing legacies of colonialism, patriarchy, and racism. This integrated knowledge can inform the development of policies, regulations, and incentives that promote sustainable water use across various sectors while also addressing the specific needs and vulnerabilities of diverse communities (Rak-Banville, 2023).

Targeted Interventions for Effective Water Management

By recognizing the intersectional nature of water scarcity, policymakers can craft targeted interventions that address local challenges while contributing to broader provincial water management goals. This ensures that water management strategies are not only effective but also equitable and sustainable in the long term.

Conclusion

In conclusion, understanding the specific geographic, demographic, and environmental factors that contribute to water scarcity in British Columbia is of paramount importance for effective water resource management. This comprehensive knowledge enables the development of tailored strategies that address the unique challenges faced by different regions and communities within the province, fostering resilience in the face of increasing water stress. By acknowledging the intersectional relationships between these factors, stakeholders can develop informed, targeted solutions that prioritize the needs of marginalized communities and promote sustainable water use, protecting diverse ecosystems, and adapting to the challenges posed by climate change in this dynamic and diverse province.

As British Columbia continues to grapple with water scarcity issues, the importance of this integrated understanding cannot be overstated. It forms the foundation for resilient water management practices that can safeguard this precious resource for current and future generations, balancing human needs with environmental preservation in this unique corner of Canada, and promoting justice and equity for all communities.

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