**Alberta Innovates**

# Report: Study of Water Impacts of Hydrogen Development in Alberta

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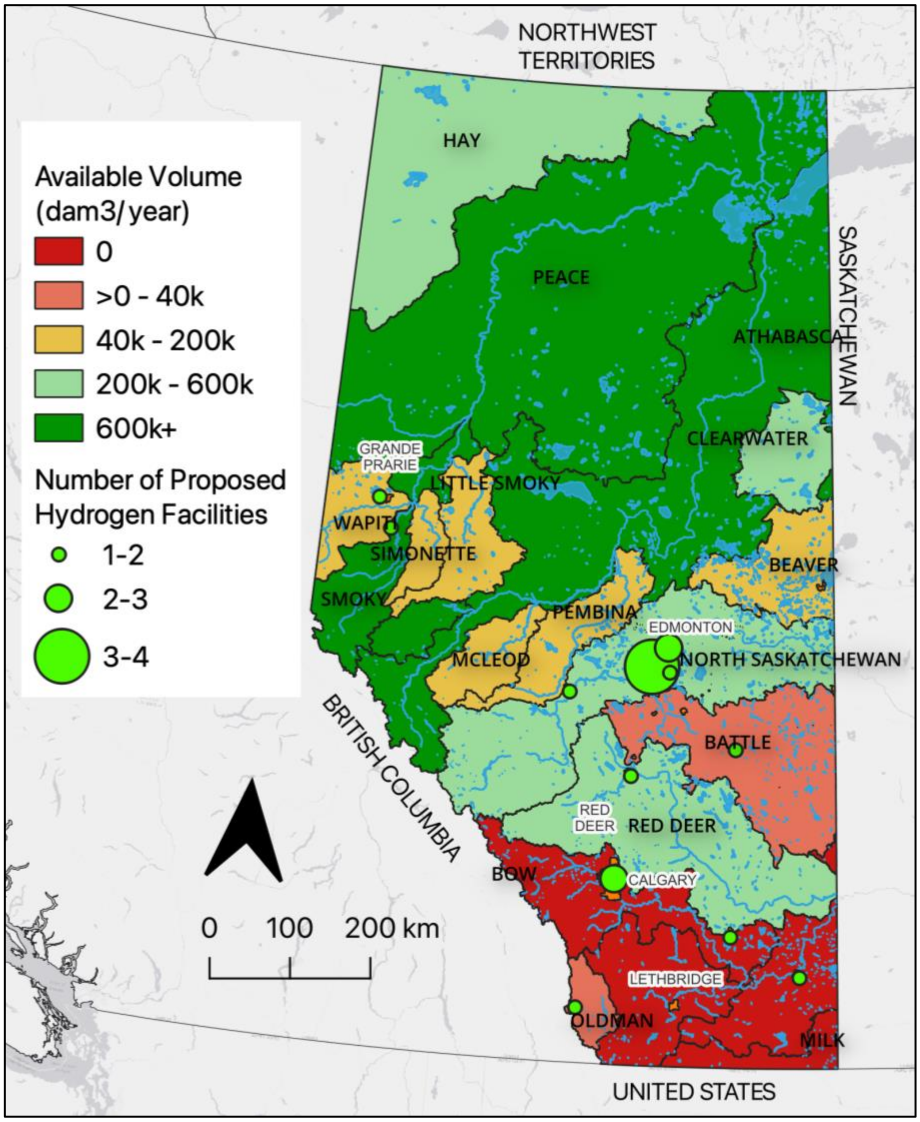
# Executive Summary

Within the context of the global transition to net zero emissions by 2050, there is intense and mounting pressure on Alberta's resource sectors from a wide range of local, national, and international regulators, governments, shareholders, and stakeholders to take concrete and significant action towards achieving this goal. The hydrogen sector is a prominent example of one pathway being pursued within Alberta to achieve net zero 2050 targets. In pursuing emissions reduction and climate change mitigation pathways, it is critical to consider other environmental, social, and economic impacts and trade-offs within the context of the water-energy-food nexus. One of the most important considerations, and the focus of this report, is our shared, and finite, water resources.

WaterSMART Solutions Ltd. (WaterSMART) has prepared this report to assess the potential impacts of hydrogen development on water resources across Alberta, and to highlight locations in which available supply may limit hydrogen development. It is intended to inform policies, regulations, and investments which will best enable the hydrogen sector’s growth, while strategically balancing trade-offs within the water-energy-food nexus context. Project developers and investors in particular should carefully review the analysis in this report on where water supply is likely to be sufficient for hydrogen projects, and where limited water supply will introduce material project risks.

The figure below overlays the anticipated hydrogen projects throughout Alberta onto a future water availability heat map. Given the significant water demands associated with hydrogen development, future hydrogen projects in some locations, such as the Edmonton region, may constrain other developments by limiting their water access. In addition, the hydrogen projects themselves will be forced to contend with water supply challenges across seasons and years. The Calgary and Medicine Hat regions are noteworthy examples of where hydrogen development ambition may exceed available water supply.



This report demonstrates that full development of the hydrogen sector within Alberta is likely to both cause water supply challenges and be limited by water availability. The extent of water risks varies across the province on a water basin and sub-basin level, and understanding local water context is critical to identifying and managing water risks and water-energy-food nexus trade-offs. When considered in the context of the net zero 2050 transition, which will involve other water-dependent technologies, and future development of all other types, it becomes even more critical to strategically manage our shared, and limited, water resources.

In response to these challenges, the following recommendations are provided for project proponents and investors:

1. Conduct detailed, site-specific analysis of the local water context to better understand how water availability will be impacted by the regulatory framework, stakeholder and Indigenous community concerns, other water users, and seasonal and inter-annual hydrologic dynamics.
    a. This analysis will materially impact project risks and costs and should be completed early

in project development before significant investments are made.

2. Carefully consider climate change risks, informed by location-specific analysis.
3. Develop approaches to manage water supply risks in an increasingly variable and unpredictable climate. These may include:
    a. Constructing water storage with sufficient capacity to supply operations during low flow periods.
    b. Working with other water users in the basin to develop water-sharing agreements, and/or collaboratively manage water on a basin level.
    c. Seeking opportunities to reduce overall consumptive water requirements, for example by using air cooling instead of evaporative cooling.
    d. Seeking alternatives to freshwater use, including saline groundwater and water reuse.

To develop better knowledge and tools for identifying and managing water-related challenges, the following next steps should be undertaken:

1. Utilize collaborative, data-driven processes to identify, understand, and manage water challenges on a river basin scale, while balancing water-energy-food nexus tradeoffs and environmental considerations.
    a. The North Saskatchewan River Basin should be a top priority for this work, given the absence of existing models and tools for this purpose and the abundance of hydrogen development planned for the region.
    b. This work should consider the implications of both consumptive and non-consumptive water use associated with future development.
2. Repeat this study to examine other technologies and sectors which will be involved in the net zero 2050 transition (e.g., carbon capture and storage, small modular nuclear reactors, critical minerals, etc.).
3. Recognizing that net zero 2050 commitments are being made across Canada, repeat this study in the other provinces and territories, which are currently grappling with many of the same challenges documented for Alberta.
4. Develop a better understanding of Alberta's groundwater resources and make this data available publicly in a consistent and usable format.

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# 1.0 Introduction

## 1.1 The transition to net zero 2050 as a project driver

Against the backdrop of the COVID-19 pandemic and recovery, severe supply chain bottlenecks, and the looming climate crisis, there is an intense focus across the globe on the transition to net zero emissions by 2050. In Alberta, this transition has generated a mix of trepidation and excitement, acting as a catalyst for transformative commitments and bold planning. There is intense and mounting pressure on Alberta's resource sectors from a wide range of local, national, and international regulators, governments, shareholders, stakeholders, and rightsholders to take concrete and significant action towards achieving this goal. Meanwhile, governments and regulators are working to both understand and define their evolving roles in the transition as regulators, convenors, enablers, and more.

For Alberta's diverse resource sectors, the transition to net zero 2050 is both an opportunity and a challenge. In this complex and rapidly changing context, it is critical that systems-based thinking and strategic approaches are deployed to identify and manage the water-energy-food nexus trade-offs associated with the energy transition. While much of the discourse about the transition to date has been focused on emissions reduction and climate change mitigation, other environmental, social, and economic impacts and trade-offs must be considered within the context of the water-energy-food nexus. One of the most important considerations, and the focus of this report, is our shared, and finite, water resources.

A prominent example of the potential trade-offs between climate action and water resource management is in the burgeoning hydrogen sector. In Alberta, hydrogen is seen as an exciting opportunity for the province, with a myriad of announcements for world-scale hydrogen projects of all types; the release of the Government of Alberta's Hydrogen Roadmap, which articulates a vision to become a world leader in clean hydrogen production, transportation, and use; the emergence of collaborative initiatives to explore and develop hydrogen hubs and centres of excellence; and more. However, attention must be paid to the potential environmental trade-offs between hydrogen production and water. Given the excitement, opportunity, and potential investment associated with Alberta's expanding hydrogen sector, it is essential to develop a better understanding of the sector's potential impact on Alberta's water resources, as well as how context-specific water availability may limit development.

WaterSMART Solutions Ltd. (WaterSMART) has prepared this report for the benefit of a broad audience of project developers and investors, policy makers and regulators, and hydrogen ecosystem participants. It is intended to inform policies, regulations, and investments which will best enable the hydrogen sector's growth, while strategically balancing trade-offs within the water-energy-food nexus. Project developers and investors in particular will benefit from this report's analysis on where water supply is likely to be sufficient for hydrogen projects, and where limited water supply will introduce material project risks.

The report's focus is on the potential water impacts of hydrogen development in Alberta. However, hydrogen is not the only sector which is evolving in response to net zero 2050 ambitions. Indeed, it is expected that a suite of technologies and sectors will all play a role in decarbonization. While this report focuses on hydrogen, it is acknowledged that the water impacts of technologies and sectors such as carbon capture and storage (CCS), small modular nuclear reactors, and critical minerals mining will also need to be studied. As the transition to net-zero 2050 occurs, this report can serve as a model for how to assess water availability and water risks for other resource sectors that are key to the transition.

## 1.2 Project scope

In this report, the potential water demands of future hydrogen development in Alberta are estimated and compared to Alberta's current and future water availability. As shown in Figure 1, this analysis was completed across Alberta. The investigation, evaluation, and conclusions are summarized in the following report sections:

- Section 2.0 details the net-new water demands expected to be associated with hydrogen development in Alberta. This reflects all currently identified hydrogen projects, including locations and estimated sizes, as well as ranges of per-unit water demands associated with common hydrogen production technologies.
    - A detailed summary of hydrogen project research is provided in Appendix A and Appendix B.
- Section 3.0 summarizes Alberta's present and future water context, with information on how water is regulated and managed within Alberta, as well as the results of water availability analyses completed in key areas throughout the province. A discussion on potential climate change impacts is also included.
    - Detailed, river basin specific information and analysis is provided in Appendix C.
    - An overview of the analysis methodology is provided in Appendix D.
- Section 4.0 presents the combined results of the preceding analyses on hydrogen water demands and Alberta's water availability. This is accompanied by discussion on the water-energy-food nexus tradeoffs which may be required to achieve Alberta's stated hydrogen ambition, highlighted by several locations where hydrogen water demands may exceed available water supply.
- Section 5.0 provides recommendations for how the information contained in this report can be used to support strategic decision making to manage the anticipated water-energy-food nexus tradeoffs associated with the hydrogen sector. Discussion on opportunities for further study within the net zero 2050 transition context is also provided.

Note that this report is focused on surface water supply within Alberta. It is acknowledged that groundwater is a significant source of water for various uses within the province, and groundwater may play a role in supplying technologies and projects associated with the net zero 2050 transition. However, both groundwater usage and available data are relatively limited in Alberta when compared to surface water. Historically, most Alberta projects of the scale contemplated in this report have used surface water. Therefore, a focus on surface water is expected to capture the majority of new water use for hydrogen, while further investigation into groundwater supply is an opportunity for future work.

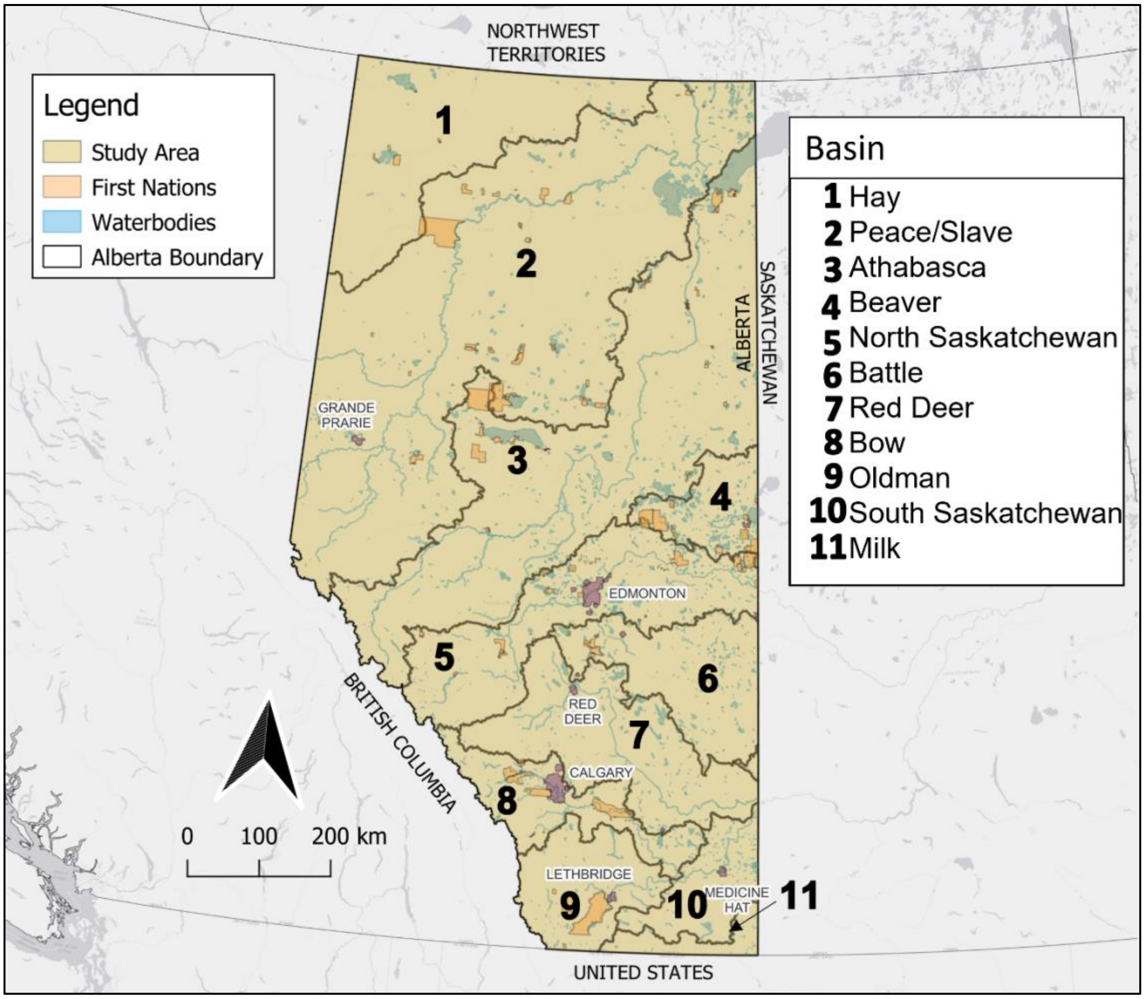

**Figure 1. Map of the study area for this report, which covers all of Alberta.**

# 2.0 Anticipated Hydrogen Water Demands in Alberta

This section documents the research completed to determine the water use intensity of various hydrogen production methods, identify projects within Alberta expected to deploy these technologies, and estimate the water use associated with hydrogen development throughout the province. Section 2.1 provides background on hydrogen as a resource, while Section 2.2 discusses the methodology for estimating project water demands. These projects, and the approach for identifying them, are discussed in Section 2.3. Finally, Section 2.4 presents the estimated water demands of future hydrogen projects in Alberta.

Note that this section and the associated analysis relies upon publicly available information and reasonable assumptions. As such, the results in Section 2.4 and the associated conclusions elsewhere in this report should be reviewed regularly as technologies develop and new hydrogen projects are announced.

## 2.1 Background

Hydrogen (H) is the most abundant element on earth, usually found combined with other elements, like in water ($H_2O$) and methane ($CH_4$). Hydrogen carries energy within its bonds, which is released when it is reacted and can be used for a multitude of purposes. For example, hydrogen fuel has the potential to offset the current use of fossil fuels in sectors such as transportation and heating. Hydrogen is considered a lower emissions alternative to fossil fuels because the only by-product of its combustion is water:

$$2H_2 + O_2 \rightarrow 2H_2O + \text{energy}$$

In addition to being used directly as a fuel, hydrogen can also be used as a feedstock to make other products, such as ammonia and methanol. Ammonia is currently used primarily as agricultural fertilizer, while methanol is a key input for many common products, including plastics, paints, fabrics, fuels, antifreeze, and much more [1].

Since hydrogen is rarely found in nature as $H_2$, it must be extracted or “produced” from resources like water and methane. While there are many technologies being explored to produce hydrogen, there are only a few technologies currently considered commercial. These commonly used technologies include steam-methane reforming (SMR), autothermal reforming (ATR), and water electrolysis. Other emerging technologies include methane pyrolysis and biomass gasification. Further discussion on these technologies is included in Appendix A.

## 2.2 Per-unit water demands

Water is required in most hydrogen production technologies, either as a direct process input, for steam generation, for system cooling, for catalyst regeneration, or for some combination thereof. Many technologies which do not use water directly in the chemical reaction(s) to produce hydrogen typically still require water as part of the overall process, such as for system cooling or catalyst regeneration. Cooling is a critical element of hydrogen production because the reactions to produce hydrogen take place at high temperatures and pressures to increase reaction efficiency. In industrial processes, evaporative cooling is often employed, although air cooling is available as an alternative which is more expensive but less water intensive. By some estimates, replacing evaporative cooling with air cooling may reduce cooling water demands by 30 – 40% [2].

A critical factor for evaluating the water intensity of hydrogen production is the distinction between total water use and consumptive water use. Total water use refers to the volume of water which is used in the entire hydrogen production process, including internal recycling of water and water which is used and returned to the river basin from which it was diverted. Consumptive water use is a subset of total use and refers to the volume of water which is removed from a basin and is not returned to it. For hydrogen production, water is consumed primarily through chemical reactions and evaporative cooling. This report focuses on consumptive water use, because this has the largest impact on basin health and other users. Throughout this report, water demand and use are terms which refer to consumptive water use unless otherwise specified.

Building upon previous WaterSMART analysis [3], publicly available data, and input from project funders, the per-unit water demands (i.e., L $H_2O$/kg $H_2$) for the aforementioned hydrogen production technologies were estimated (Table 1). Low, Medium, and High water use scenarios were prepared, recognizing that individual hydrogen processes and facilities are highly variable. For each technology, the stoichiometric amount of water was derived from the relevant chemical equations for the process and used as a starting point, as described below and in Appendix A:

- The stoichiometric amount represents the theoretical minimum water volume which is required based on chemistry first principles.
- Low water use approximates an extremely water-efficient process, starting from the stoichiometric amount and assuming a modest cooling demand and 10 – 15% efficiency losses.
- Medium water use accounts for additional losses through steam generation, water cooling, and other water used throughout various production processes, such as catalyst regeneration in certain technologies.
- High water use accounts for further losses from evaporative cooling and lower efficiency. As more water is introduced to a process, whether it is consumed directly or not, the opportunity for water losses increases. Some allowance for water lost during treatment is also included in this scenario.

The estimates in Table 1 were validated against available literature sources, although they should be reviewed regularly as technologies and processes develop [2] [4]. One of the most important drivers for water use in industrial facilities is cooling since each cooling approach has dramatically different water requirements. For example, flow-through cooling (also called once-through cooling) requires a very high water intake, but most of this water is returned to the environment, which is used as a heat sink. Water-based cooling systems with recirculation consume water by using evaporation as a heat sink, which reduces the total water intake for cooling but increases the consumptive amount compared to flow-flow. Finally, air coolers can be used in place of water-based cooling, typically with higher costs but much lower water use [2] [4]. Larger industrial facilities may invest time and resources into optimizing cooling to reduce water use, although water losses from cooling are impossible to substantially avoid unless air cooling is used [4]. This uncertainty in cooling approach is reflected in the water use scenarios in Table 1. The Medium scenario is expected to reflect a well-optimized system, which is typical of larger industrial processes, although decision-making around water use during plant design is variable. Project proponents should complete detailed analysis for their facilities based on more specific information.

Water treatment is another important driver of overall water consumption, since hydrogen production processes require high quality process water, with specific criteria varying between SMR, ATR, and electrolysis. When raw water is treated, a portion of the total volume is rejected by the process as waste, which can be 40% of the feedwater volume or more, depending on inlet and outlet quality [2] [5]. The High water demand scenario indirectly accounts for some water loss during treatment, although the highly variable nature of raw water qualities and process water quality requirements precludes the estimation of the specific water consumption associated with treatment in this report.

Importantly, the water use associated with CCS was not included in Table 1. Once again, the water demands are highly variable, in the range of 0.50 to 3.16 $m^3/tonneCO_2$ for pre- and post-combustion capture technologies [6]. For hydrogen projects using natural gas feedstock and CCS, this will be an additional water demand which will need to be considered. Project-specific analysis and future aggregated review are recommended.

**Table 1. Per-unit, consumptive water demands of different hydrogen production methods compared to the stoichiometric amount. See Appendix A for more details.**

| Technology | Stoichiometric amount (L $H_2O$/kg $H_2$) | Water consumed (L $H_2O$/kg $H_2$) | | |
|---|---|---|---|---|
| | | Low | Medium | High |
| **ATR** | 3.9 | 4.8 | 11.3 | 21.7 |
| **SMR** | 4.5 | 5.5 | 13.0 | 25.0 |
| **Electrolysis** | 9 | 10 | 15.0 | 45.0 |
| **Pyrolysis*** | 0 | 1.0 | 8.5 | 16.3 |
| **Gasification**** | *Variable* | 8 | 18.9 | 36.4 |

*Table notes:*

**Water consumption depends on the specific methane pyrolysis technology. Method of system cooling and catalyst regeneration affects water demand.*

***Water consumption for gasification is highly dependent on the biomass feedstock and can vary greatly. Moisture content and biomass carbon to hydrogen ratio influences water demand.*

Water demands were also estimated for ammonia and methanol, which are expected to be produced by many of the projects identified in Section 2.3. As detailed in Appendix A, these demands were estimated by computing a hydrogen equivalency for ammonia and methanol on a mass basis. That is, a coefficient was calculated to convert kilograms of ammonia and methanol to kilograms of hydrogen. The water demands in Table 1 were then applied to these hydrogen-equivalent production rates to estimate the water demands of specific projects (see Section 2.4).

## 2.3 Alberta hydrogen projects

The projects considered in this study are for production of hydrogen and hydrogen-related products (e.g., ammonia and methanol) which are in the construction, proposal, or planning phase at the time of writing. They are all either completely new projects or expansions of existing facilities which would require net new water demands in the basins in which they are located. Other projects within the hydrogen ecosystem, such as research, transportation, and consumption projects were identified but are not included in the analysis because they do not directly represent a net new use of water.

Projects meeting these criteria were identified through a combination of research, engagement with project funders, and leveraging WaterSMART's industry knowledge. The most robust source was provided by the Government of Alberta, with information about publicly announced projects as well as several confidential projects which were noted but for which no information was provided [7]. Efforts were made to corroborate project details with multiple sources where possible, and to compare projects on a consistent basis. Where data was not available for certain projects, assumptions were made using the average of known values. A detailed summary of this research is provided in Appendix B.

Figure 2 shows the locations of new, announced hydrogen and hydrogen-related projects throughout Alberta. Variably sized circles are used to indicate where multiple projects are located within the same area (e.g., in the Edmonton region). Because only the announced projects are included in the figure (i.e., where a project location was identified), there are several projects which were included in the water demand analysis, but which are not displayed in the figure. Specifically, nine projects were included in the Government of Alberta source with the location redacted. These confidential projects are not on the map below but are included in subsequent numeric analysis.

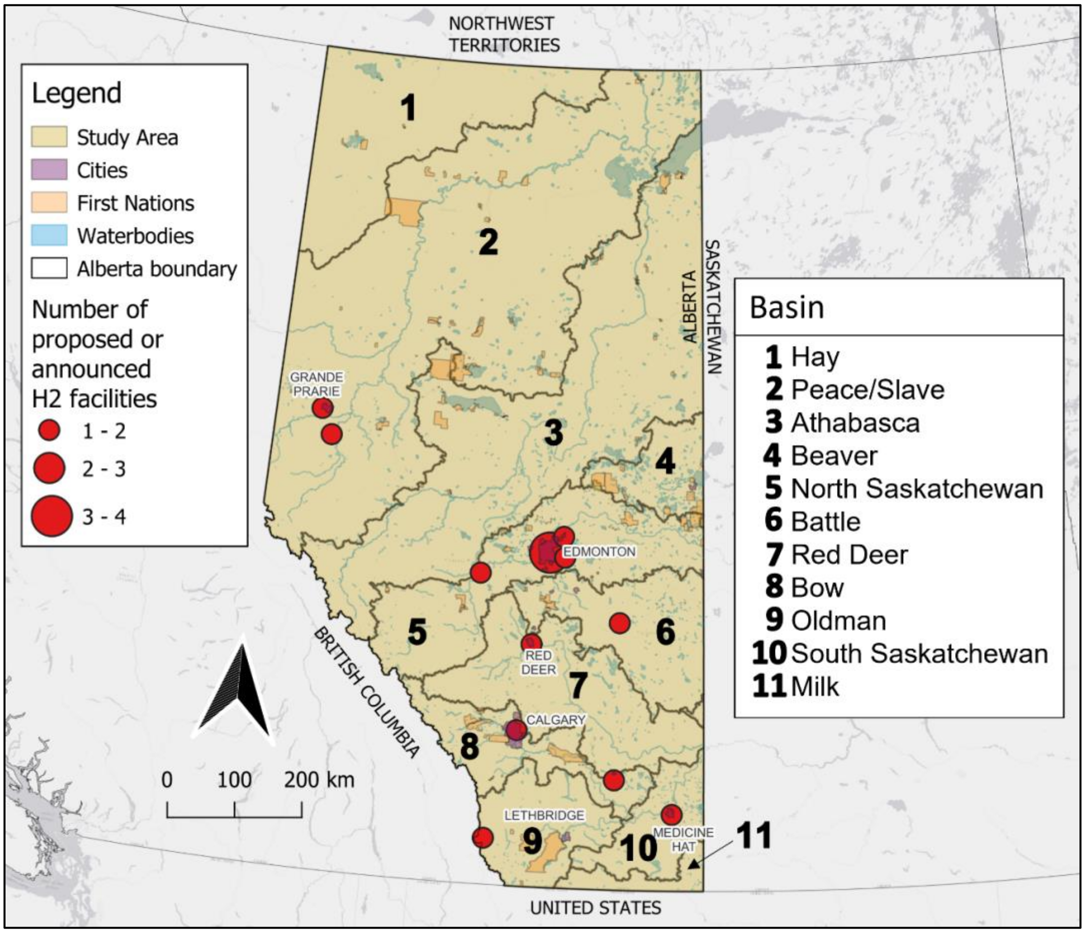

**Figure 2. Locations of announced new hydrogen projects throughout Alberta. Note that the nine confidential projects discussed above are not reflected in the numbers included in this figure as their locations have not been disclosed. The actual count of hydrogen projects in the future could be higher across the province.**

## 2.4 Potential hydrogen water demands

To estimate the water demands of hydrogen production throughout Alberta, the per-unit water demands from Section 2.2 were applied to the hydrogen production rates from Section 2.3. Table 2 summarizes the estimated hydrogen demands within each river basin in Alberta, in some cases divided into sub-basins where relevant (see Section 3.0). The estimated total water demand from new hydrogen projects across Alberta is between 121,100,000 $m^3$/yr and 500,360,000 $m^3$/yr, depending on the water demand scenario used. This demand is distributed across several basins, with a concentration in the Peace, North Saskatchewan, Bow, and South Saskatchewan basins. A value of zero in Table 2 does not mean that hydrogen production is not currently happening, nor will ever happen, in that basin. Rather, this indicates that publicly available information about new hydrogen projects in the region does not exist. As noted in Section 2.3, not all hydrogen projects have announced locations. To address this uncertainty, the estimated water demand associated with these projects was proportionally divided across the river basins with known hydrogen projects, based on the number of projects in each. Thus, the demand scenarios in Table 2 account for all potential projects announced, while the project count reflects only those projects with known locations, consistent with Figure 2.

Per Section 2.3, this analysis reflects a snapshot in time, with many projects in various stages of development. Depending on the selected size of a reference facility, the estimated hydrogen production represents between dozens and hundreds of future facilities, representing a massive investment. Not all of these projects will proceed to actual development, while more will likely be announced. It also takes many years to develop a project from announcement to operations. Given these development timelines and uncertainties, as well as the possible ranges in water demand per project, a specific “future” demand for hydrogen was not estimated in addition to the aforementioned water demand scenarios. The future will depend on many factors, such as hydrogen’s continued role for decarbonizing energy systems, local and global demand, and the economics of production compared to competing jurisdictions. Instead, Table 2 illustrates, within the ranges documented, the potential water demands of future hydrogen development in different scenarios. Over time, as projects begin operating, new projects are announced, and the water demands of these projects are better understood and optimized, the water demands across Alberta should be re-evaluated.

Note that Table 2 includes both major river basins (e.g., the Athabasca River Basin) and select sub-basins (e.g., the Smoky River and the Wapiti River). This differentiation will be explored further in Section 3.0, and in the results in Section 4.0, the water demands are aggregated at a basin level without duplication. For example, the Smoky River has anticipated water demand and is a tributary of the Peace River, which does not have any expected hydrogen demands on the mainstem of the river and is not explicitly included in Table 2. In this report, the Smoky River’s demand also appears in the Peace River’s demand for visualization purposes, because the Smoky River is within the Peace Basin. However, these do not represent unique demands and are not duplicated in the total water demand noted above.

**Table 2. Summary of the Low, Medium, and High hydrogen water demand cases, reflecting all announced new hydrogen projects, per basin. The anticipated water demands for projects announced without a location have been proportionally allocated to basins based on the number of projects with known locations in each. Note that the Wapiti is a sub basin of the Smoky, therefore the anticipated water demand of the Smoky includes that of the Wapiti. The Wapiti has been highlighted on its own, while some other sub basins have not, due to the highly constrained nature of the area.**

| *Basin* | *Sub-basin* | *New hydrogen projects* | *Anticipated water demand (1,000 $m^3$/yr)* | | |
|---|---|---|---|---|---|
| | | | *Low* | *Medium* | *High* |
| Peace | Smoky | 2 | 17,090 | 29,350 | 47,110 |
| | Wapiti (incl. within Smoky) | 1 | 1,650 | 3,910 | 7,520 |
| | Little Smoky | 0 | 0 | 0 | 0 |
| Athabasca | | 0 | 0 | 0 | 0 |
| North Saskatchewan | | 7 | 52,660 | 111,400 | 220,740 |
| Battle | | 1* | 1,430 | 3,390 | 6,520 |
| South Saskatchewan | Red Deer | 1** | 20 | 50 | 90 |
| | South Saskatchewan Sub-Basin | 1 | 28,470 | 52,660 | 128,650 |
| | Bow | 3 | 21,290 | 47,780 | 96,620 |
| | Oldman<br>Upper Oldman | 0<br>1*** | 0<br>140 | 0<br>210 | 0<br>630 |
| Hay | | 0 | 0 | 0 | 0 |
| Beaver | | 0 | 0 | 0 | 0 |
| Milk | | 0 | 0 | 0 | 0 |

*Table notes:*

**Battle River: The project is Heartland Generation's Battle River Carbon Hub (BRCH)* [8]. *The BRCH is a planned conversion of the existing natural gas-fired power plant to run on hydrogen, paired with CCS. On a conservative basis, this project is included as a new hydrogen-related water demand. However, Heartland Generation already has significant water licenses for their existing facility which may be utilized for this purpose. The potential water impacts of both hydrogen production and CCS will need to be better* *understood as the BRCH is developed.*

***Red Deer: The project is the Cvictus Mannville Enhanced Hydrogen Recovery Project, which is understood to be a demonstration of an underground coal-gasification project* [9]*. The technology proponents do not expect that a significant net new diversion of water will be required for their process, since the gasification process produces formation water. Until the demonstration project results can verify this prediction, a water demand associated with the Cvictus project has been included to be conservative.*

****Oldman: As discussed in Appendix C.7, the Oldman River Basin has a small volume of water available for new allocations upstream of the Oldman Dam. The Tent Mountain Renewable Energy Complex has been announced within the headwaters of the Oldman River Basin and may therefore be able to access this available water* [10]*. No projects were identified in the Oldman River Basin downstream of the Oldman Dam*.

# 3.0 Alberta's Water Context

Across Alberta, there is a high degree of variability in both the volume of water which is present in specific locations and how this volume is managed by regulators to meet ecological and human needs. This variability is especially apparent when comparing the southern and northern parts of the province. While 80% of Alberta's water resources are in the north, 80% of the population is in its south [11]. This dynamic has created significantly more competition for water in the southern river basins than the northern ones, as visualized in the Figure 6 water availability heat map below.

Another important water dynamic is the time variability of the water supply, both seasonally and year over year, which will be explored further in Section 3.1. Because of this variability, water users must diligently assess and manage water supply risks within the context of the prevailing regulatory regime for water (Section 3.2), regardless of where in the province they are located. This report provides a high-level water availability assessment (Section 3.3) and relevant background information (Appendix C) for the rivers identified in Figure 3. These rivers were highlighted within the study area because they satisfied one or more of the following criteria:

- Currently a water-short region, wherein water risks for new projects of any kind will be significant.
- Likely to be a water-short region in the near future, meaning the water risk environment is dynamic and must be understood by project developers.
- Likely to host future hydrogen projects, based on those already announced (Section 2.0).

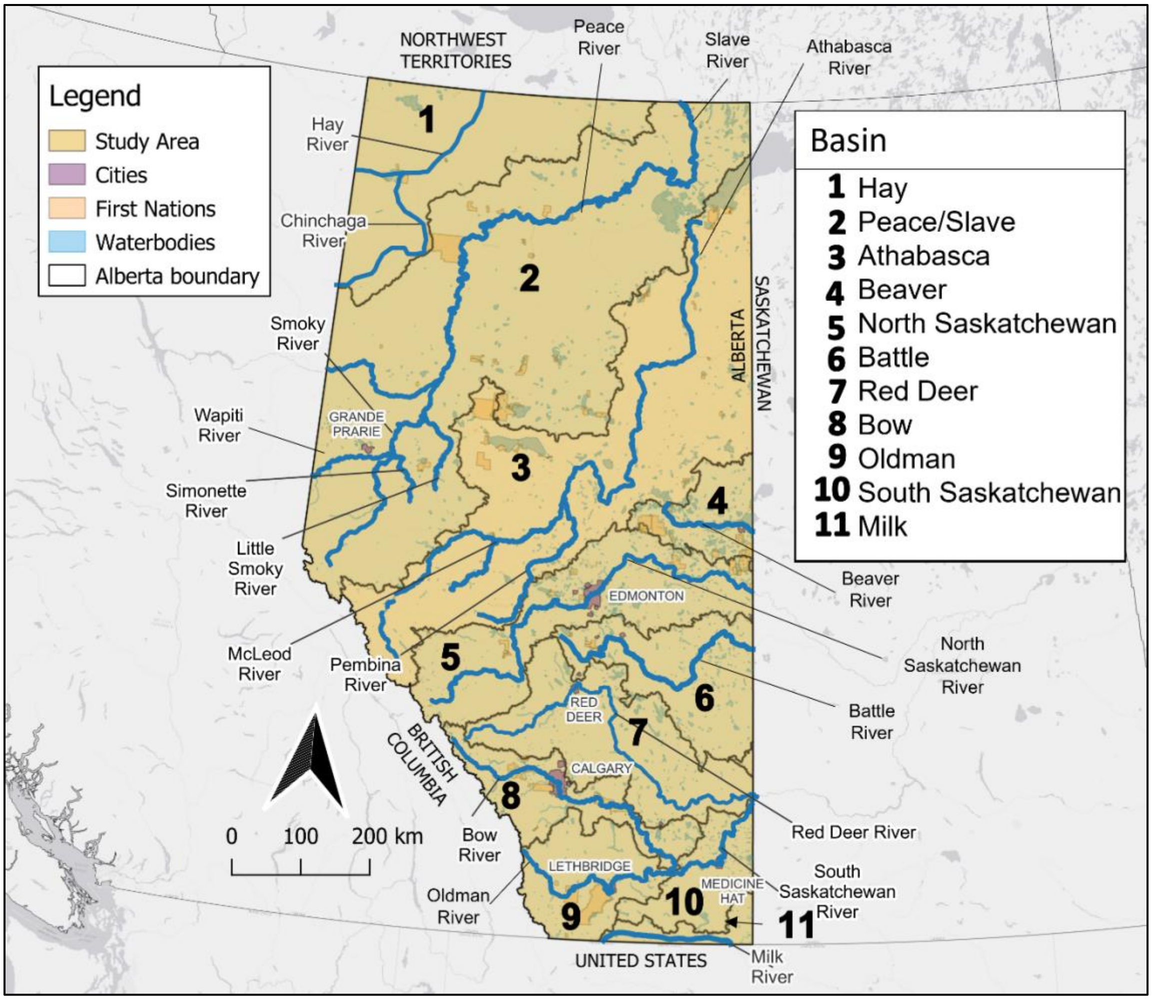

**Figure 3. Map of the specific rivers which were analyzed for water availability in this report. These rivers were selected based on water supply and known and anticipated developments in hydrogen and other sectors.**

## 3.1 Hydrology overview

Alberta's freshwater resources are generally grouped into three categories: groundwater, non-flowing surface water (i.e., lakes and ponds), and flowing surface water (i.e., rivers, streams and creeks). Flowing surface water bodies, most of which have headwaters in the eastern slopes of the Rocky Mountains, are the source of most water used in Alberta. There are very few naturally occurring lakes of significant volume, especially in the southern basins. Notably in the Bow and Oldman river basins, nearly all the large non-flowing water bodies are man-made reservoirs created by damming or diverting water from the major rivers. As noted in Section 1.2, groundwater availability varies widely across Alberta, and it is not used as frequently as surface water. The absence of high quality, consistent, and readily available groundwater data across Alberta can act as a barrier to its use since groundwater exploration can be expensive and with uncertain results.

Alberta's proportionally high reliance on flowing surface water bodies, along with its geographical location immediately east of the Rocky Mountains, makes the province's water supply vulnerable to seasonal variation. River flows across Alberta typically peak between May and July and are lowest between October and February. The May to June peaks are driven by snow and glacier melt from the Rockies, as well as a modest increase in precipitation compared to other months. River flows typically taper off into late summer and early fall and become lowest during the winter months when there is limited contribution from snow and glacier melt. In addition to low flows during the late fall and winter months, prolonged ice cover can create a barrier to access water on some rivers due to physical and regulatory constraints. Figure 4 illustrates the seasonal variability of several rivers in Alberta.

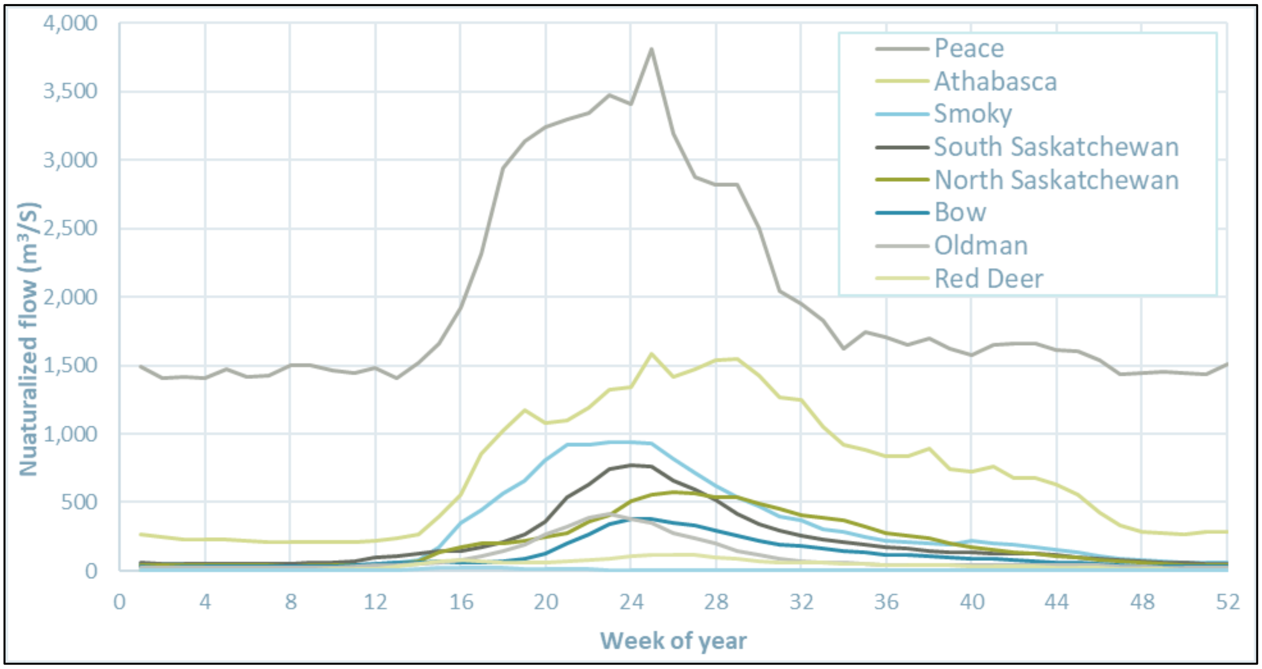

**Figure 4. Illustrative naturalized flow hydrographs for several rivers in Alberta, which demonstrate the potential variability across seasons.**

## 3.2 Water management and regulation

Water resources in Alberta are governed through a suite of regulatory instruments, which vary in type, level of authority, and enforcing body. The *Water Act* is the primary statute for governing water resources in Alberta. It seeks to balance the competing water needs of the environment, people (i.e., high quality drinking water), and industry by providing direction on water management planning, the right to divert water, issuance and administration of diversion licenses, construction of works, and conflict resolution, among other topics. The *Water Act* is enforced by the Alberta Energy Regulator (AER) for energy projects (i.e., oil, oil sands, natural gas, coal, geothermal, and brine-hosted mineral resources) and by Alberta Environment and Protected Areas (EPA) for all other (i.e., non-energy) uses. Hence, petrochemical facilities, such as hydrogen, are regulated by EPA.

An important consideration within this regulatory framework is the requirement for Indigenous consultation. The Aboriginal Consultation Office (ACO) provides direction on the regulatory requirements for consultation in Alberta, while some federal departments have additional requirements and processes for projects with elements falling under their jurisdiction. It is important for project proponents to consider whether their projects meet both the provincial and federal requirements for meaningful consultation and the extent to which they may adversely impact First Nations' Treaty rights or traditional uses and Metis settlement members' harvesting or traditional use activities. Beyond regulatory obligations, meaningful engagement around water can also provide important opportunities for both project proponents and Indigenous communities, with links to economic reconciliation.

Several key elements of the *Water Act* which may impact how a project accesses water include:

- **Inter-basin water transfers:** The *Water Act* stipulates that a licence cannot be issued which allows water transfer between major river basins unless it is authorized by a special Act of the Legislature. The major river basins named in the *Water Act* are the Peace/Slave, Athabasca, North Saskatchewan, South Saskatchewan, Milk, Beaver, and Hay River Basins. Hence, water resources are generally considered available for use only within the river basin in which they exist.
- **Environmental protection:** The *Water Act* provides mechanisms for determining the volume of water which should remain in a river for the sake of environmental protection (i.e., the volume which will not be licensed for people to utilize). These mechanisms include cabinet-approved Water Management Plans (WMPs), water conservation objectives (WCOs), and others. The Surface Water Allocation Directive (SWAD), issued under the *Water Act*, provides direction for all rivers and lakes without pre-existing management approaches.
- **Diversion rights:** Water users receive a licence to divert a specified volume of water at a specified rate, commonly referred to as a water allocation. Alberta uses a priority-based allocation system, which means that older (i.e., senior) licenses have higher priority to withdraw water than newer (i.e., junior) licenses. This includes senior licence holders who are downstream of junior licence holders. In situations where water availability is low, the junior licence holders may have their water access restricted, while senior licence holders may continue diverting water.
- **Demonstrated need for water**: Also known as a Development Plan, the *Water Act* requires that applicants for water licenses credibly demonstrate their anticipated water needs over the duration of the project. This requirement prevents speculation on the water resources in Alberta by ensuring only those with legitimate plans to use water can be granted a licence.
- **Construction of works:** The *Water Act* includes requirements and restrictions for the construction of water storage and intake works. Significant restrictions are placed on construction occurring within the river to minimize negative impacts to the aquatic environment.
- **Monitoring and reporting:** Water diversion licenses have requirements on them for monitoring and reporting, and it is expected that licence applicants will have a plan for monitoring quality and quantity criteria and reporting these to the regulator (e.g., annually).
- **Licence transfers:** The *Water Act* includes provisions to permanently transfer all, or a portion of, a water diversion licence from one user to another in basins with a cabinet approved WMP. Such transfers require that the original licence is in good standing, which typically requires that a substantial portion of the licence is currently being used. This restriction can make licence transfers challenging, since current licence holders may be unwilling to permanently transfer away the right to divert water which they currently use. In addition, in basins without an approved WMP, transfers can only be approved by an order of the Lieutenant Governor in Council, which is difficult to secure.
- **Licence assignments:** As an alternative to licence transfers, the *Water Act* also allows for licence

assignments, wherein a senior licence holder temporarily assigns their licence priority number to a junior licence holder, based on a contract negotiated between the parties. Functioning much like an insurance policy, this arrangement allows the junior licence holder to divert water during water-short periods, when they would not have otherwise been able to due to their junior priority. Assignments require that the assigned licence is in good standing.

Other provincial regulatory instruments which may be relevant to a project's water supply include the *Historical Resources Act,* the *Environmental Protection and Enhancement Act,* the *Public Lands Act,* the *Wildlife Act*, the Water (Ministerial) Regulation, the Wastewater and Storm Drainage Regulation, the Pipeline Rules, the Alberta Wetland Policy, and the Environmental Quality Guidelines for Alberta Surface Waters.

In addition, some elements of water access fall under federal jurisdiction, primarily via the *Fisheries Act* and the *Canadian Navigable Waters Act.* The *Fisheries Act* provides a framework for the conservation and protection of fish and fish habitat, with implications for water intake structure design and construction. The *Canadian Navigable Waters Act* provides rules for environmental protection and to promote the continued use of navigable water bodies within Canada by the public, which includes commercial or recreational vessels and Indigenous peoples exercising their Treaty rights. Other potentially relevant federal acts include the *Canadian Environmental Protection Act*, the *Species at Risk Act*, the *Migratory Birds Convention Act*¸ and the *Impacts Assessment Act*

An additional limitation on water use in Alberta is the 1969 Master Agreement on Apportionment, which requires Alberta to allow a volume of water to flow into Saskatchewan equal to half the natural flow in each river [12]. This requirement impacts the volume of water which is available for diversion from the rivers flowing into Saskatchewan. There is also an agreement through the International Joint Commission, which governs how water flows into the United States via the Milk River in Alberta's southeast.

### 3.2.1 Impact of regulations on water availability

Within this suite of regulatory instruments, each water body within Alberta has a unique regulatory context, which directly influences how water is managed and how much water is available for new uses. For example, the *Bow, Oldman and South Saskatchewan River Basin Water Allocation Order* (2007) closes the Bow Basin, the Oldman Basin, and the South Saskatchewan Sub-Basin to new water diversion licence applications [13]. However, the *Oldman River Basin Water Allocation Order* (2003) reserves a small volume of water upstream of the Oldman Dam for specific uses (see Appendix C.7 for more information). In addition, several other basins have prescriptive, cabinet approved WMPs, and still other basins are managed through application of the SWAD. Project proponents must understand the regulatory context and how this impacts water availability in areas they are considering.

Figure 5 illustrates how the regulatory regime impacts water availability from a river, using the Little Smoky River as an example. The SWAD is applied to the Little Smoky River, meaning that water available for allocations is calculated as a variable percentage of total flow. As noted in Section 3.2, water withdrawals are managed to ensure adequate water remains in the river for healthy aquatic species and habitats. Therefore, the SWAD percentage is scaled to be lower when river flow is lower, such that proportionally more water stays in the river during low flow periods (e.g., winter months). For licence holders on the Little Smoky and elsewhere throughout Alberta, this means that, although a water licence is granted as a yearly volume of water, there is no guarantee that a licensee will actually be able to divert that volume, and it is likely that their rate of diversion will need to vary throughout the year (i.e., lower in the winter, higher in the spring). These dynamics of intermittency and variability introduce water supply risks which must be managed (e.g., via water storage). See Section 3.3 for further discussion on water availability throughout the province.

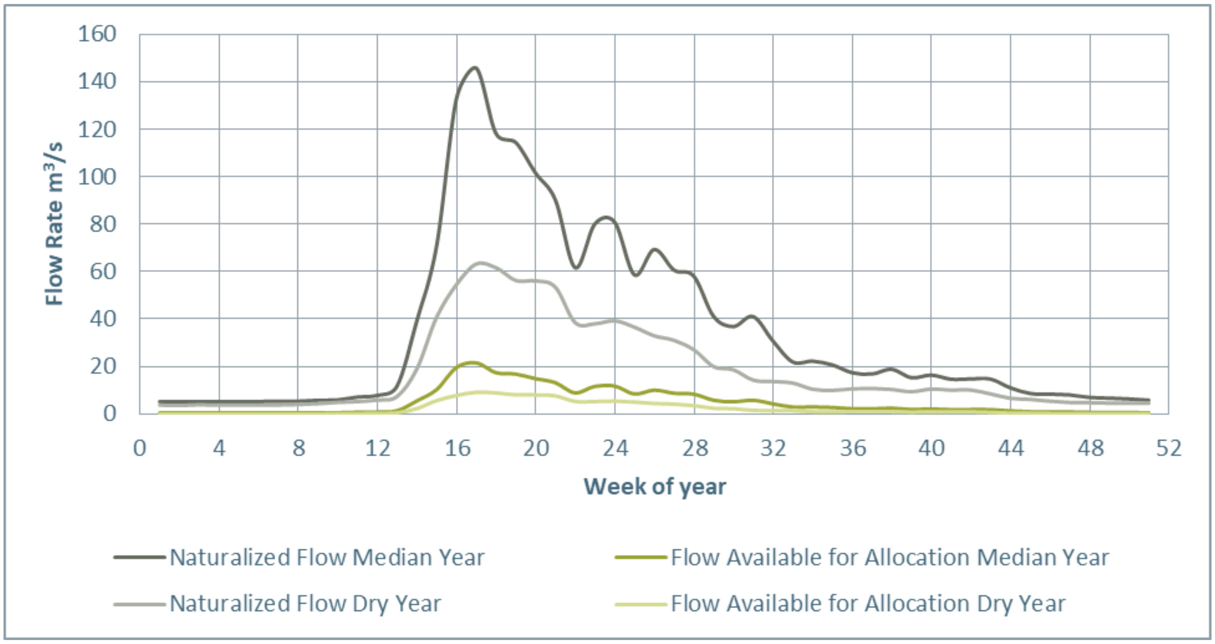

**Figure 5. Hydrograph for the Little Smoky River, showing the seasonal variability of natural flow and how this impacts water available for allocation.**

## 3.3 Water availability

The volume of water available for new consumptive use in Alberta (i.e., water availability) was estimated into the 2050 timeframe. This analysis required assumptions around how much water is currently used and how demand will increase into the future. The results, discussed below, provide a high-level water risk assessment across the province, with a focus on trends and comparisons between river basins, as opposed to the accuracy of specific numbers. Project proponents are encouraged to complete a more detailed, site-specific water risk analysis before investing significant time and money in developing a new project.

Water availability was assessed using publicly available data from several sources. River flow data was sourced from EPA and Water Survey of Canada gauge stations, while data on existing water licenses was pulled from an online database maintained by EPA [14]. For each river basin, the appropriate regulatory framework (e.g., WMPs, SWAD) was applied to calculate the water available for all allocations. From this, anticipated future water use was subtracted to estimate how much water will be available for new allocations, defined as water availability. Two different flow scenarios were utilized to capture the inter-annual variability in flows noted above. Specifically, a median year (also referred to as an average year) and dry year were modelled based on statistical analysis of the hydrometric period of record. See

Appendix D for more details on the water availability methodology.

The heat map in Figure 6 displays the results of the water availability analysis in each basin across the province. The colours indicate how much water is available for new allocations on an annual basis in a median year, and do not directly reflect the inter-annual and seasonal variability which is expected in each basin (per Section 3.1 and Appendix C). Efforts have been made to analyze and differentiate sub-basins on a relevant scale, in recognition that while a large river may have abundant supply, not all its tributaries will (e.g., the Wapiti River in the Peace River Basin). Consistent with the preceding discussion, this heat map provides a high-level comparison between basins, but detailed analysis will be required to confirm the water supply dynamics of a specific project location and develop management approaches.

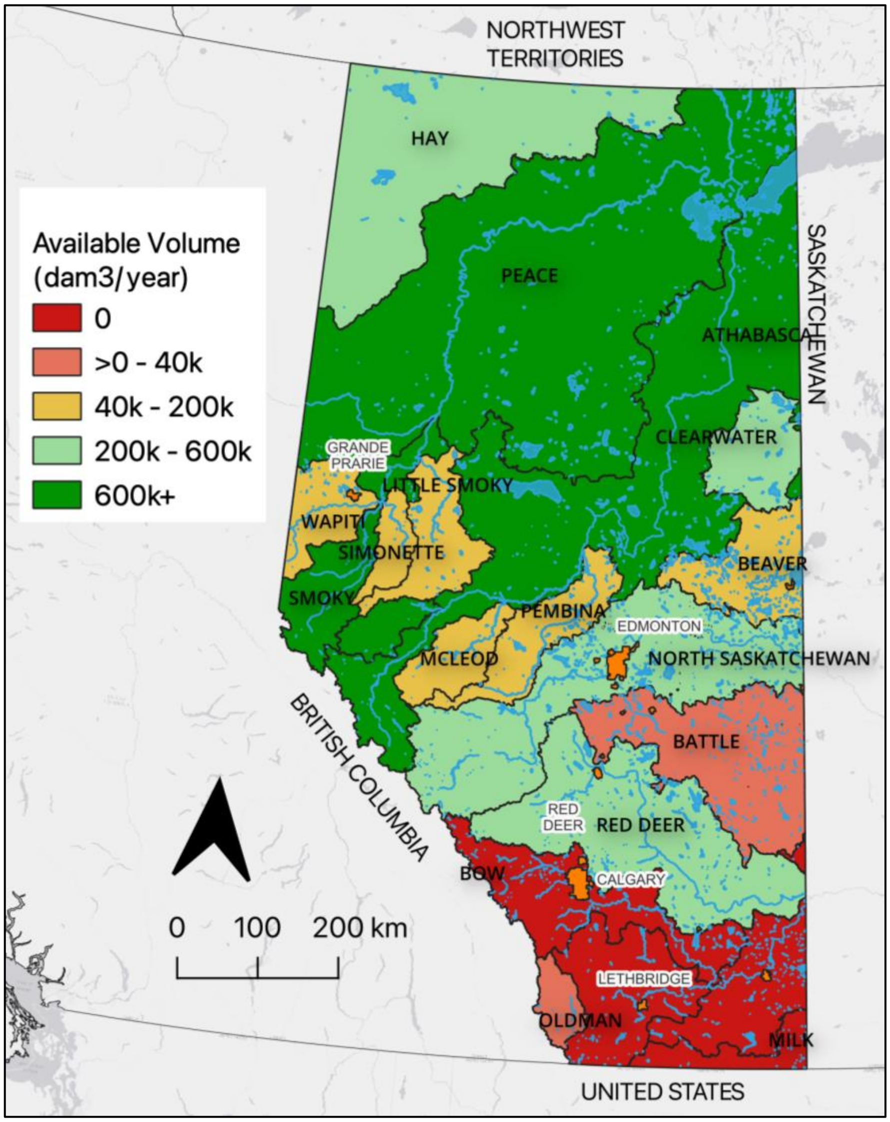

**Figure 6. Heat map of water availability throughout Alberta in an average year. This is a near future estimate of the yearly net volume of water that is available for new uses per basin but may not be reflective of every tributary in that basin. Additionally, see Appendix B for details on seasonal and year over year availability per basin.**

Table 3 was prepared to accompany Figure 6. In both median and dry year scenarios, Table 3 compares the total water flow in each river to the volume which is available for new allocations. The available volume in a median scenario is linked to the colours in Figure 6, and the dry year availability column illustrates how this availability can vary between years. Rivers are listed in descending order based on water availability.

**Table 3. Summary of annual flow and water availability for basins and sub-basins in the study area, comparing median and dry year scenarios. The annual, aggregated data presented herein should be considered in combination with the seasonal variability of each river, discussed in Section 3.1 and Appendix C.**

| Basin | Sub-basin | Annual flow (1,000 m³/yr) | | Available water (1,000 m³/yr) | |
|---|---|---|---|---|---|
| | | Median year | Dry year | Median year | Dry year |
| Peace | Peace | 62,263,800 | 47,938,500 | 9,182,000 | 7,033,210 |
| Athabasca | Athabasca | 22,424,790 | 18,274,640 | 2,822,160 | 2,199,640 |
| Peace | Smoky | 9,334,310 | 6,786,440 | 1,377,600 | 995,420 |
| North Saskatchewan | North Saskatchewan | 6,450,570 | 5,086,880 | 431,230 | 272,810 |
| Hay | Hay | 1,968,550 | 1,074,270 | 292,140 | 157,990 |
| South Saskatchewan | Red Deer* | 1,350,860 | 909,010 | 270,000 | 270,000 |
| Peace | Little Smoky | 1,077,400 | 565,150 | 146,840 | 70,010 |
| Peace | Wapiti | 2,585,100 | 1,853,580 | 53,220 | 50,800 |
| Beaver | Beaver | 396,810 | 209,060 | 33,780 | 9,200 |
| Milk | Milk** | 294,860 | 214,450 | 0 | 0 |
| North Saskatchewan | Battle | 168,230 | 93,060 | 8,670 | 1,690 |
| South Saskatchewan | Oldman<br>Upper Oldman*** | 3,044,380 | 2,151,700 | 0<br>1,450 | 0<br>1,450 |
| South Saskatchewan | South Saskatchewan | 6,757,200 | 5,167,210 | 0 | 0 |
| South Saskatchewan | Bow | 3,618,260 | 2,793,690 | 0 | 0 |

*Table Notes:*

**The water available in the Red Deer River reflects the Approved Water Management Plan for the South Saskatchewan River Basin (SSRB) and basin allocation data provided by EPA in 2022. Note that there is currently an irrigation project being scoped in the eastern portion of the basin that could apply for an allocation of a significant portion of the water remaining for allocation.*

***The analysis for the Milk River reflects the rules of the WMP, which are enforced at the Milk River Gauge Station. Water is reserved under the WMP for very specific uses, which do not include hydrogen. See Appendix C.9 for more information.*

****As noted in section 3.2 and Appendix C.7, there is a small volume of water available in the Upper Oldman River Basin. The Order which allocates this water predates the closure of the South Saskatchewan River Basin.*

## 3.4 Climate change impacts

Temperature and precipitation trends demonstrate that measurably climatic changes are already being experienced in Alberta [15]. For example, between 1951 and 2017 data shows that average winter temperatures in the province have already warmed 4 – 5$^{o}$C in southern Alberta and 6 – 7$^{o}$C in northern Alberta [15]. Continuing changes in both temperature and precipitation are driving changes in water availability across the province. These changes, detailed below, are best understood and managed in terms of trends, rather than through specific quantification. Therefore, detailed climate change modelling has not been integrated into the water availability analysis presented in Section 3.3. Instead, the water supply risks associated with climate change are implicitly considered within the different ranges and scenarios presented. Detailed and site-specific climate change modelling will be instructive for planning individual projects.

In 2020, WaterSMART completed an analysis of the projected impacts of climate change for the Prairie region using data from the Coupled Model Intercomparison Project Phase 5 [16]. The Radiative Emissions Pathway (RCP) that was selected for the study was RCP 4.5, which represents a relatively conservative (i.e., low) potential for impacts from climate change [16].

The study analyzed changes in temperature and precipitation, in combination with various other factors including topography and seasonal timing, to develop an understanding of changing conditions and challenges in the region [16]. Overall, the temperature in Alberta is expected to increase from the reference period of 1986-2005 to the projected near future period of 2020-2060. Particularly important from a hydrology perspective is that winter temperatures are projected to increase even more than summer and fall temperatures, especially in the northern part of the province [16]. Increasing winter temperatures may mean more winter precipitation falls as rain, spring snowmelt occurs earlier, and snow will intermittently melt during the winter. These changes are likely to impact water availability patterns. Warmer temperatures are also projected in the summer, which will increase the rate of evaporation and evapotranspiration and may consequently reduce the available surface water and soil moisture [16]. Simultaneously, higher ambient temperatures are likely to increase the demand for water from facilities using evaporative cooling, potentially exacerbating warm-weather water availability challenges.

Overall, the trends in precipitation for Alberta are expected to increase from the reference period of 1986-2005 to the projected near future period of 2020-2060, and particularly in the winter and spring [16]. The precipitation change is also projected to vary by latitude, with the northern half of Alberta projected to see a greater increase than southern areas [16]. Although the average precipitation is projected to increase, models also indicate that the year to year variability of precipitation is expected to increase as well. This means the reliability of river flows and water availability is likely to decrease, even though more water may be expected overall [16].

The anticipated hydrologic changes due to climate change can be generalized into trends for three regions of Alberta:

- The northernmost third of the province will likely experience increasing temperatures, increasing variability in annual precipitation, and on average quite a bit more precipitation relative to the period of 1986 to 2005. This may result in impacts such as higher snowpack, earlier snowmelt, unexpectedly high river flow in the winter, high water levels and flooding in the spring, low late-summer streamflow, and more low-flow years (i.e., droughts).
- The middle third of the province will likely experience increasing temperatures, increasing variability in annual precipitation, and generally somewhat more precipitation on average relative to the period of 1986 to 2005. This may result in impacts such as disappearing glaciers and very low late-summer streamflow, unexpectedly high river flow in the winter, earlier snowmelt, flooding in the spring, and more low-flow years (i.e., droughts).
- The southern third of the province will likely experience increasing temperatures, particularly hot and dry summers, a small overall increase in annual volume of precipitation, and increasing variability in annual precipitation relative to the period of 1986 to 2005. This may result in very low late-summer streamflow, rain and melting events during the winter, lower peak streamflow in the spring, lower snowpack, less reliable and predictable water availability, and more extreme low-flow years (i.e., extreme droughts).

### 3.4.1 Approaches to managing climate change impacts

Climate change is likely to increase the variability of water availability within Alberta, while simultaneously making it more difficult to predict future conditions based on historic data. Greater variability is linked to a higher likelihood of low flow years and droughts when water will not be available for diversion. These changes will make it more difficult for project proponents to assess and manage water risks. However, options exist for managing water risks in a changing climate.

Water storage is one way to increase the reliability of water access in the face of an increasingly variable water supply. In a changing climate, projects may require larger storage volumes than would have been built historically. Another option is to manage water risks by maintaining relationships with other water users in the basin and working together on water management and water efficiency projects. Collaboration with other water users may include establishing legal agreements, such as water assignments under the *Water Act* or water-sharing agreements, in advance of drought situations.

To appropriately deploy risk management approaches, it is critical to understand how water is managed on a local level, including the key decision drivers. Each basin within Alberta is unique, with different drivers, risks, and opportunities. A thorough understanding of local basin context and the existing regulatory system will enable creative solutions to managing future water risks.

# 4.0 Comparing Hydrogen Water Demands to Water Availability

This section presents a comparison of the estimated water demand for hydrogen in Alberta (Section 2.0) with the estimated water available for new allocations (Section 3.0). Figure 7 illustrates how water availability varies in basins across the province in median and dry years, and the extent to which this availability will satisfy the requirements of the Low, Medium, and High water demand scenarios for hydrogen. This is supplemented by Figure 8, in which the anticipated hydrogen projects in Figure 2 are overlaid onto the water availability heat map from Figure 6.

These results indicate that the potential water challenges associated with future hydrogen development vary widely across Alberta. In some basins, ample water is available throughout the year to support both hydrogen and non-hydrogen development, while in others, there are significant annual and/or seasonal water availability limitations. In locations with limited water availability, hydrogen development will directly compete with future municipal growth and industrial development, including sectors which will be critical for the net zero 2050 transition (e.g., CCS, critical minerals mining). As will be discussed in Section 5.0, further analysis will be required to evaluate future water availability accounting for all development, not just hydrogen.

As Section 4.1 will detail, the North Saskatchewan River Basin is likely to be home to significant hydrogen production. Based on available data and considered in isolation, there may be enough water on an annual basis to support hydrogen development. However, this ignores the future water demands of all other users in the basin, including the significant number of CCS projects which have been announced and will be necessary to enable SMR- and ATR-based hydrogen production. Also notable are the Bow River Basin and South Saskatchewan River Sub-Basin, which have significant hydrogen demands but no water available for new allocation. The implications of these disparities are discussed in Section 4.2 and 4.3 for Calgary and Medicine Hat, respectively.

This analysis relies on several assumptions, which are described throughout the report. For example, the unknowns of how many hydrogen projects will be built, where they will be built, and how much water they will consume, leads to uncertainty in the water demand estimates. However, considering the drivers documented in Section 1.0, it is clear that future water demands for hydrogen will be significant, regardless of what assumptions are made. While consumptive water use is the focus of this report, it will also be important to understand and evaluate the implications of non-consumptive water use, particularly in locations with low water availability. Non-consumptive water use (e.g., for flow-through cooling), could impact things like aquatic health (e.g., via temperature, quality) and the footprint of water storage.

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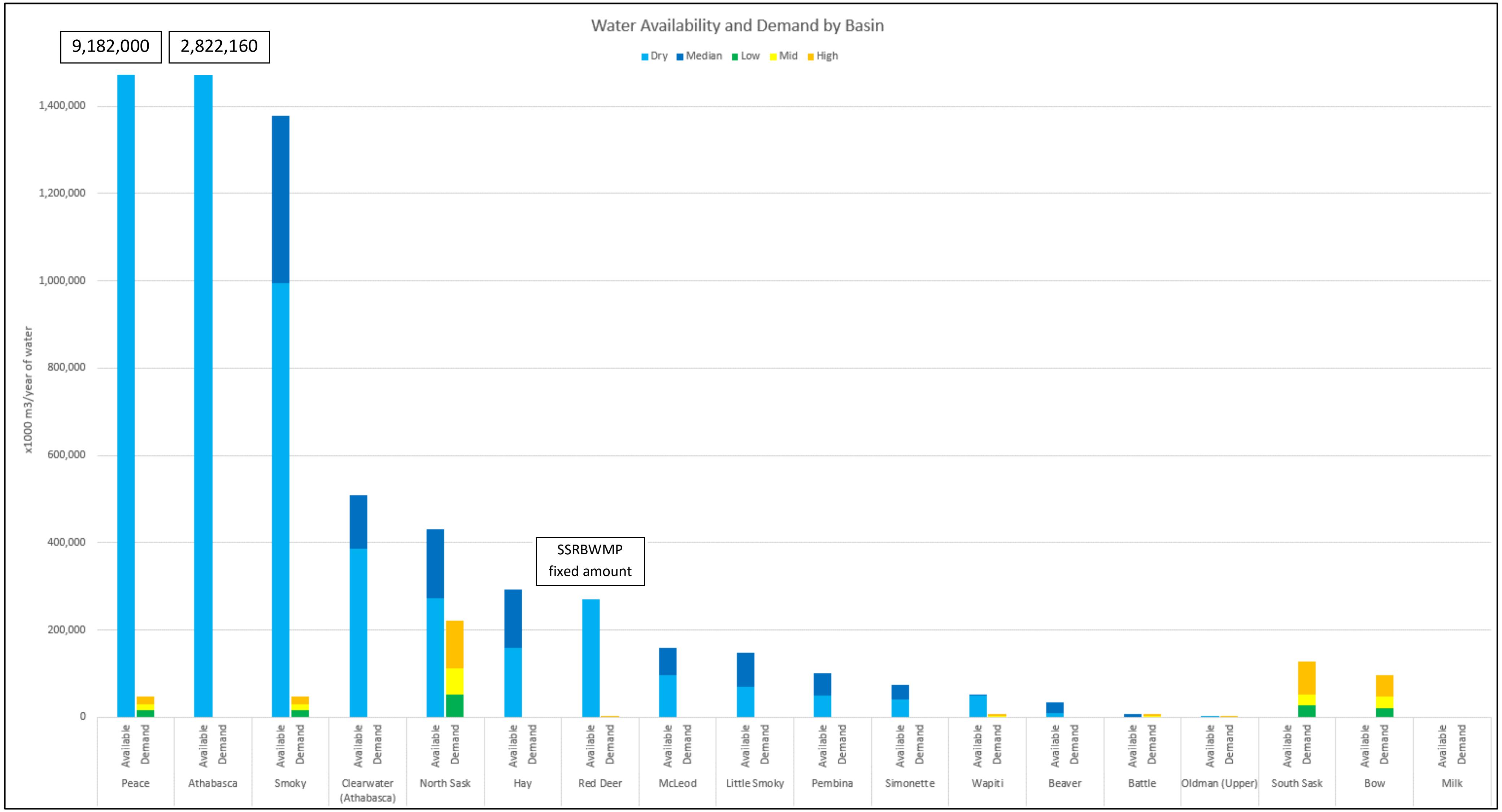

**Figure 7. Available water in both cases (Median, Dry) compared to hydrogen demand in all three cases (Low, Medium, High), for each basin. When the blue bar, representing availability, is shorter than the green/yellow/orange bar, representing demand, there will be water shortages in that basin. This is most apparent on the right, in the South Saskatchewan and Bow basins, where demand is much larger than availability. Note that the Peace contains the Smoky, and the Smoky contains the Wapiti. Hence, the water demands in the Wapiti are copied into the Smoky, and the Smoky demands are copied into the Peace for visualization purposes.**

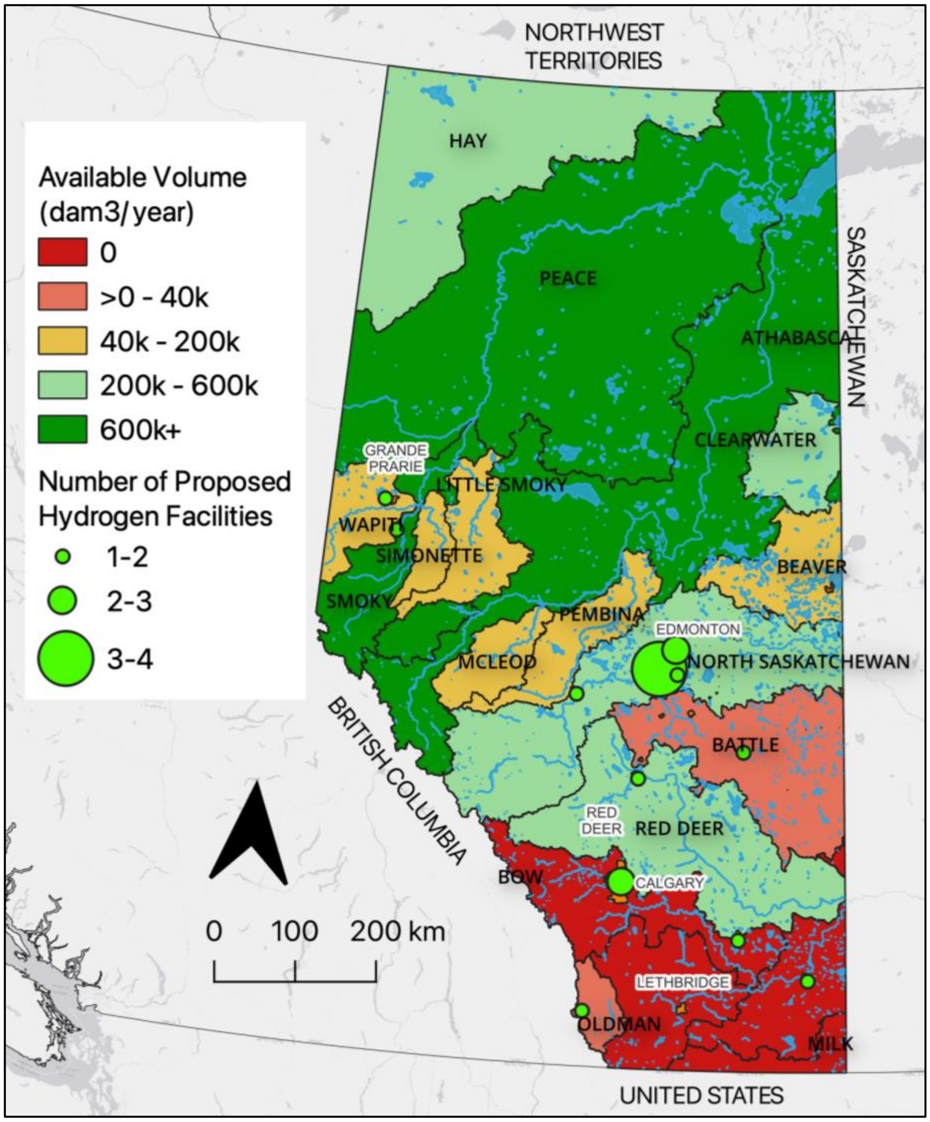

**Figure 8. Announced hydrogen projects on top of an average year heat map, to provide visual context of demand per basin and water available in that basin.**

Given the significant water demands associated with hydrogen development, future hydrogen projects in some basins may constrain other developments by limiting their water access. In addition, the hydrogen projects themselves will be forced to contend with water supply challenges across seasons and years. As part of strategically managing the transition to net zero 2050, project proponents, funders, and regulators must carefully evaluate the potential trade-offs associated with hydrogen development. This is illustrated in Figure 9, which presents a modified water availability heat map for a future scenario where the identified hydrogen projects have been built. Specifically, Figure 9 shows future water availability for other uses in a dry year, after water has been diverted for a High hydrogen demand scenario. See Table 4 for accompanying data.

Due to the sheer size of the Peace River and Athabasca River Basins, they remain relatively unimpacted. However, the significant hydrogen development planned in the North Saskatchewan River Basin will have a material impact on future water availability. Additionally, as noted in Section 3.0, most of Alberta's population lives in the southern part of the province, which is the region most vulnerable to both dry years and future hydrogen demands.

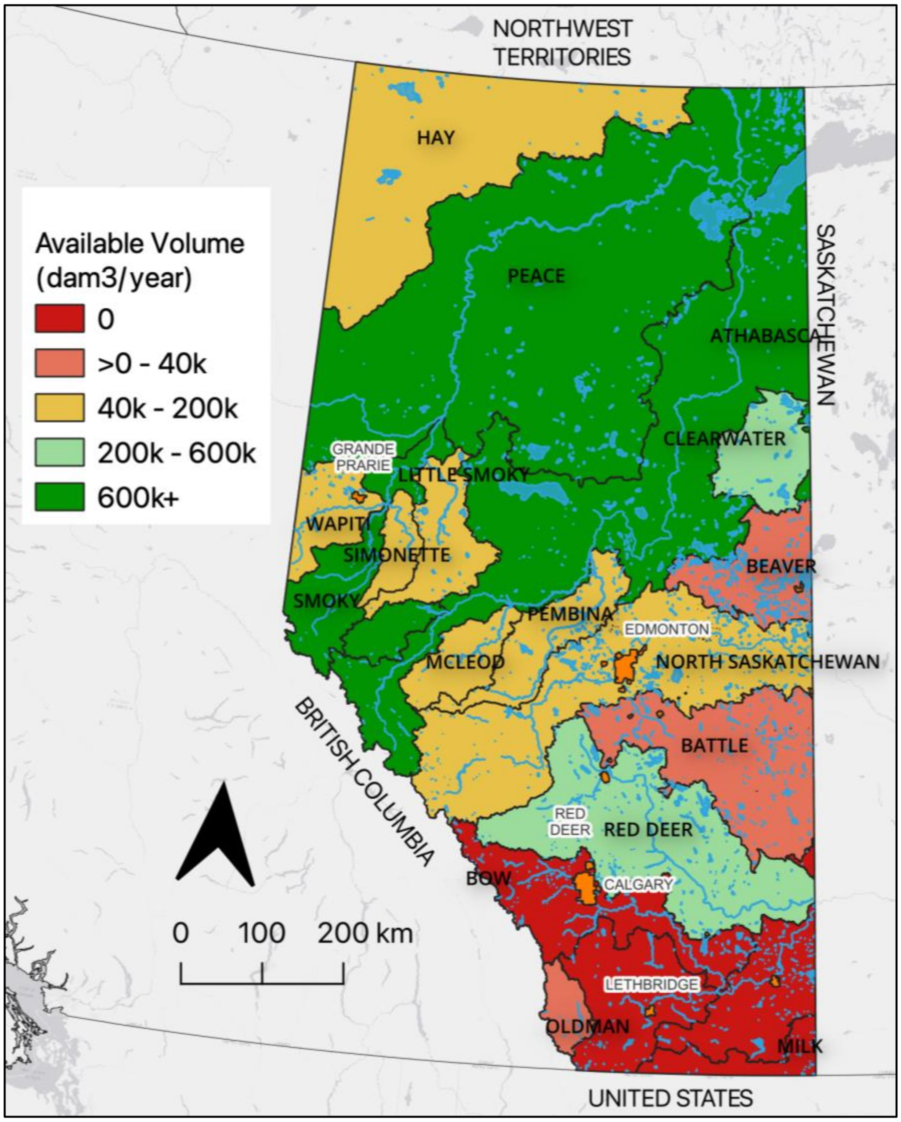

**Figure 9. Annual Available Volume per basin in the case of High hydrogen demand in a dry year.**

**Table 4. Available water in the case of a dry year after High hydrogen demand.**

| ***Basin*** | ***Sub-basin*** | ***High Hydrogen Demand (1,000 m$^3$/yr)*** | ***Water Available in Dry Year After Hydrogen (1,000 m$^3$/yr)*** |
|---|---|---:|---:|
| Peace | Peace | 47,110 | 6,986,100 |
| Athabasca | Athabasca | *0* | 2,199,640 |
| Peace | Smoky | 47,110 | 948,310 |
| North Saskatchewan | North Saskatchewan | 220,740 | 52,070 |
| South Saskatchewan | Red Deer | 90 | 269,910 |
| Hay | Hay | *0* | 157,990 |
| Smoky | Little Smoky | *0* | 70,010 |
| Smoky | Wapiti | 7,520 | 43,280 |
| Beaver | Beaver | *0* | 9,200 |
| North Saskatchewan | Battle | 6,520 | -4,830 |
| South Saskatchewan | South Saskatchewan | 128,650 | -128,650 |
| South Saskatchewan | Bow | 96,620 | -96,620 |
| South Saskatchewan | Oldman | 0 | 0 |
| | Upper Oldman | 630 | 820 |
| Milk | Milk | 0 | 0 |

## 4.1 Edmonton region

The Edmonton region within the North Saskatchewan River Basin includes the City of Edmonton, the Alberta Industrial Heartland, and the surrounding municipalities (e.g., Strathcona County) [17]. Within this region, significant effort and attention has been directed at the potential to develop world-scale hydrogen projects [18]. Detailing these efforts is outside the scope of this report, and readers are referred to agencies such as Edmonton Global and the Transition Accelerator to learn more.

As noted in Section 2.4, there are many projects anticipated within the Edmonton region for the production of hydrogen and related products for regional and international use. Per Figure 7 and Table 4, the consumptive water demand for hydrogen is expected to require a significant proportion of the water available in the North Saskatchewan River Basin, as much as 80% in dry years. Over the lifetime of the proposed projects, it can be reasonably expected that the region will be subject to even drier conditions than those modelled, possibly including multi-year drought. In such cases, water demand for hydrogen could exceed the annually available water volume, introducing water supply risks for both hydrogen projects and other water users. Furthermore, this analysis compared availability to demand on an annual basis, but water supply can vary significantly on a seasonal basis (Section 3.1 and Figure 10). This introduces an additional dimension of water supply risk for future hydrogen projects which must be considered.

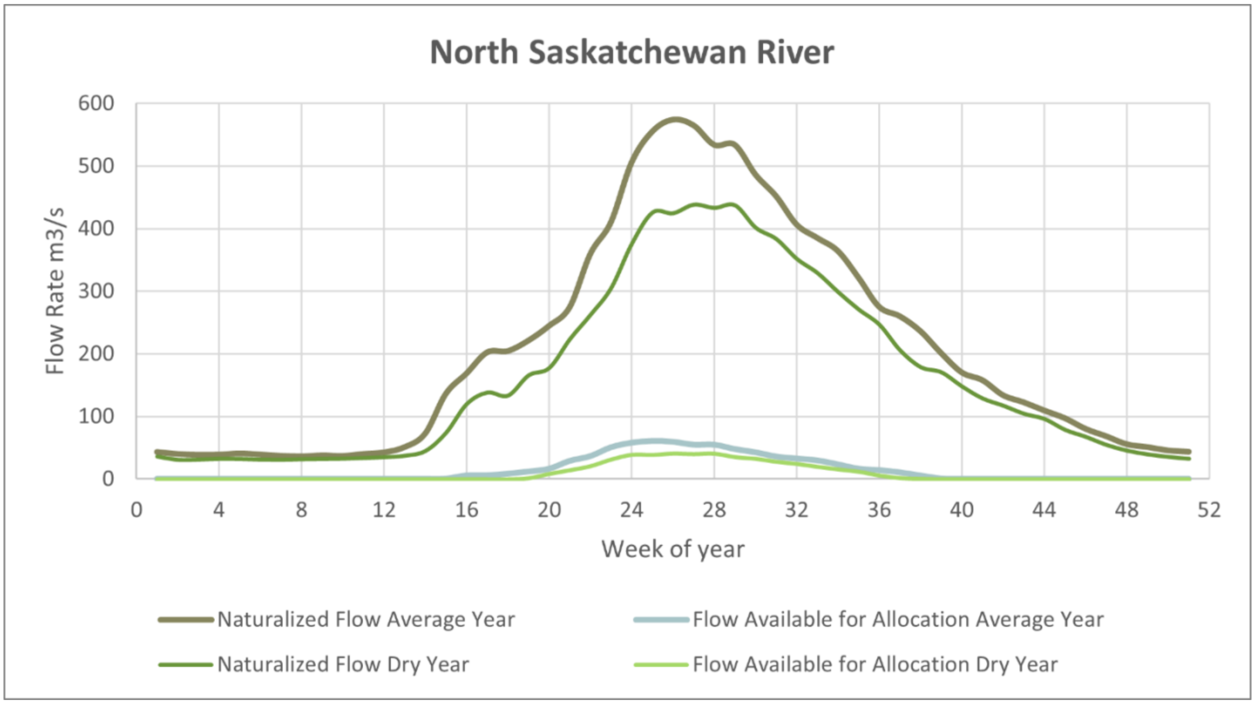

**Figure 10. Comparison of water flow to water available in the North Saskatchewan River, in dry and average years. Under the SWAD, water availability drops significantly during the winter months (October – April).**

Others have also studied the North Saskatchewan River's capacity to support future industrial development, including, but not exclusive to, hydrogen. In 2022, the regional water system within the Industrial Heartland was analyzed to assess its capacity to meet current and future water requirements for industrial development [19]. The study authors projected future industrial water use within the region by estimating the current water use, on a per-area basis, and multiplying this rate by the total area of industrial land (including future industrially zoned land). The 50-year water demand estimated in this study is an order of magnitude higher than the demand presented in Section 2.4 because the study considered all industrial uses, not just those associated with the hydrogen economy (e.g., it included gas-to-liquids facilities, electricity generation, fractionation plants, etc.). Although both the scopes and findings vary between the 2022 study and this hydrogen-focused report, consistent conclusions can be drawn from both efforts. Indeed, the 2022 study emphasizes the potential water access risks to future project development of all types, when considered together. This reinforces the importance of conducting site-specific water risk assessments as part of project development, and links to opportunities for regional water management.

Both this report and the 2022 study identify seasonal variability as an important contributor to water supply risk. Constructing water storage is an obvious, though expensive, approach to address seasonal water supply challenges. The 2022 study also recommended a regulatory change to address this issue. Currently, water licenses are issued on the North Saskatchewan River using the SWAD, which calculates available water as a percentage of naturalized flow. By definition, naturalized flow does not account for the positive impacts of the Brazeau and Bighorn dams on winter stream flows. Therefore, it has been argued that the SWAD effectively under-predicts the volume of water, which is present in the river during the winter, and hence how much can be withdrawn [19]. The 2022 study recommended that a new Directive be issued which allows licenses to be granted while accounting for the increased winter flows caused by upstream dams, which would thereby increase the volume of water available both annually and during low flow periods. This approach is likely to involve significant engagement of stakeholders and Indigenous communities who may be affected by the change, and it is unknown if the necessary political will is currently in place to support this process.

In recognition of the importance of systems-based approaches to water management, an alternative way to address water supply challenges in the North Saskatchewan River Basin should be considered. A basin-scale, collaborative, and data driven process could be effectively deployed to confirm and quantify water risks relevant for hydrogen production as well as other water users and the environment. This would inform water management approaches which satisfy the needs of as many water users as possible, including for hydrogen, while balancing water-energy-food nexus tradeoffs and environmental considerations.

## 4.2 Calgary region

As Figure 7 indicates, there is significant hydrogen development planned within the Bow River Basin, even though no new water licenses can be applied for. Based on the research documented in Section 2.0, it is understood that the majority of this new hydrogen development will occur within the City of Calgary and surrounding area [20]. Already, there are many industrial activities in Calgary which utilize water under the City's existing water licenses, and it is therefore assumed that future hydrogen development would also primarily draw on water which is already allocated to the City.

The City of Calgary holds numerous water licenses for a variety of purposes, with a total annual allowable diversion of 461,645,481 $m^3$/yr. Based on the details of the City's licenses, 99% of this diverted volume is designated for urban use, which includes domestic, commercial, and industrial use. Of the 461,645,481 $m^3$/yr that the City is allowed to divert, approximately 80% must be returned to the environment. This means that the City currently has a maximum annual consumptive allocation of 90,669,335 $m^3$/yr, some of which is already being used. As discussed in Section 2.0, it is this consumptive volume, which is particularly important when considering new hydrogen production, which will consume water. Table 5 compares the City's consumptive allocation to the consumptive volume associated with the anticipated hydrogen demand in both the Bow River Basin and in the Calgary Hydrogen Production

Hub [20]. The existing consumption within the City is not included in this comparison.

**Table 5. Water demands for hydrogen within the Bow River Basin and the Calgary Hydrogen Production Hub as percentage of the Calgary's existing consumptive water licence (90,669,335 m$^3$/yr).**

| H2 demand scenarios | Bow River Basin | | Calgary Hydrogen Production Hub | |
|---|---|---|---|---|
| | Annual consumptive water demand (1,000 m$^3$/yr) | % of total City consumptive volume licensed | Annual consumptive water demand (1,000 m$^3$/yr) | % of total City consumptive volume licensed |
| Low | 21,290 | 23% | 10,120 | 11% |
| Medium | 47,780 | 53% | 23,930 | 26% |
| High | 96,620 | 107% | 46,020 | 51% |

As Table 5 reveals, future hydrogen development could require up to 50% of the City of Calgary's total consumptive allocation, even if the Calgary Hydrogen Production Hub is the only project to proceed. This ratio increases to more than Calgary's entire consumptive allocation if all potential hydrogen projects are built in the Bow River Basin and draw water from the City. These consumptive water demands for hydrogen could have a material impact on the City's water supply and will directly compete with current and future water use for all other domestic, commercial, and industrial purposes within the City.

The planned hydrogen development in Calgary illustrates the potential tension between water for people and water for energy within the context of the water-energy-food nexus. Table 5 highlights the importance of informed and strategic decision making around how to best use our shared water resources. The City of Calgary and surrounding region will need to evaluate priorities for water use relative to future population growth, industrial development, environmental protection, and risk management, and integrate these priorities into decision making around hydrogen projects. For developers, this analysis indicates that careful planning will be required to identify a viable water source and manage its risks, whether water is sourced from the City or via a water licence transfer under the *Water Act*.

## 4.3 Medicine Hat region

Southeastern Alberta, particularly the Medicine Hat region, has been identified as a location suitable for future hydrogen development, called the Southeast Alberta Hydrogen HUB (SAHH) [20] [21]. With the region already producing about 10% of Alberta's hydrogen annually, it is estimated that as much as 8,850 t/day of new hydrogen production could come online by 2050, to bring the total to 10,000 t/day in the region [20]. This new hydrogen production would meet a combination of demands within the region (e.g., transportation, agri-food processing, power generation), and would service significant export markets, both domestically and internationally [20].

While the region is well positioned for hydrogen production from the perspectives of natural gas feedstock availability, access to renewable energy, and proximity to transportation corridors, future hydrogen development in Southeastern Alberta will be challenged by access to water. As noted in Section 3.2, the South Saskatchewan River Basin, where Medicine Hat is located, is closed to new water licence applications. Therefore, new hydrogen production will need to identify alternative sources of water. Two such alternatives which have been proposed are water licence transfers from irrigation licence holders (authorized under the cabinet approved WMP for the South Saskatchewan River Basin) and sourcing brackish water from locally producing natural gas wells (i.e., produced water reuse) [20].

It is possible that irrigation water licence transfers and produced water reuse will be suitable options for individual projects, following detailed and specific analysis (e.g., technical and logistical feasibility, economics, and environmental net effects). However, it will be challenging for these sources to provide sufficient water supply for the entire development ambition of the SAHH to 2050, as currently envisioned.

Table 6 compares the anticipated consumptive volume of water required for full build out of the SAHH to the volumes available from produced water and irrigation sources in the region. For this comparison, it is assumed that half of the hydrogen production in the SAHH will come from electrolysis and half from SMR, based on information from the Transition Accelerator [20]. For context, Table 6 also compares all the licenses currently issued in the South Saskatchewan River Sub-Basin in the bottom row. Table 6 is specific to the SAHH and does not include any additional hydrogen demands which may occur in the region, which were discussed in the context of projects without known locations in Section 2.3.

**Table 6. Comparison of consumptive water demands for the Southeast Alberta Hydrogen Hub to potentially available produced water and irrigation licenses, as well as to existing licenses for all purposes.**

| | Hydrogen production scenario | | |
|---|---|---|---|
| | Low | Medium | High |
| Annual water demand for hydrogen (1,000 $m^3$/yr) | 25,034,438 | 45,223,500 | 113,058,750 |
| % of produced water supply | 28% | 51% | 127% |
| % of existing irrigation licenses | 47% | 85% | 212% |
| % of all existing consumptive licenses in the basin | 14% | 25% | 62% |

The Transition Accelerator estimates that 7,400,000 $m^3$ of produced water is generated in the region each month (i.e., 88,800,000 $m^3$/yr) [20]. The extent to which a significant portion of this produced water can be used for hydrogen production will require further, detailed study to address logistical and treatment considerations while confirming economics. As Table 6 indicates, even if all produced water in the region is utilized for hydrogen development, the full consumptive demands of the SAHH would not be supported under a high hydrogen water demand scenario.

Critically, hydrogen production requires clean water, especially for electrolysis. Even with a high-quality source of raw water, as much as 40% of an available volume can be disposed of as part of the treatment process to meet process water specifications [5]. With a lower quality produced water, the proportion which is disposed of is expected to be higher. Hence, Table 6 is likely an ambitious estimate for how much hydrogen production can be supported by the available produced water in the region. In addition to the available volume, the capacity to dispose of water treatment waste products must be considered for the SAHH. The implementation of centralized water treatment hubs may improve the economics of produced water treatment and disposal of residual waste; however, supply-side limitations on water are expected to persist regardless of how it is gathered and treated.

For irrigation licence transfers, only 52,257,599 $m^3$/yr of consumptive use is currently allocated for a combination of private irrigation and irrigation districts. As Table 6 indicates, even if all current allocations were transferred for hydrogen production, the consumptive demands of the SAHH would not be met. The likelihood of even one project being supported by an irrigation water licence transfer must be evaluated against the current global context. Exacerbated by a changing climate and Russia's invasion of Ukraine, the global food crisis is becoming more acute. Both irrigators and the provincial government in Alberta have expressed a clear commitment to increase food production in the face of these challenges, which is expected to require a greater proportion of existing irrigation licenses are used, meaning less water will be available for licence transfers [22].

For additional context, Table 6 compares the consumptive use associated with the SAHH to the existing licenses in the South Saskatchewan River Sub-Basin. With the SAHH being equivalent to 14 – 48% of all licenses currently issued for all other purposes, this reinforces the significance of hydrogen's demands for water and the associated water-energy-food nexus considerations which must be made by water managers and policymakers. For project proponents in the region, the above analysis indicates the extent to which a secure water supply is likely to be a material risk. Robust analysis will need to be completed early in project development to assess and manage water supply risks and costs.

# 5.0 Recommendations & Next Steps

This report demonstrates that full development of the hydrogen sector within Alberta is likely to both cause water supply challenges and be limited by water availability. The extent of water risks varies across the province on a water basin and sub-basin level, and understanding local water context is critical to identifying and managing water risks and water-energy-food nexus trade-offs. When considered in the context of the net zero 2050 transition, which will involve other water-dependent technologies, and future development of all other types, it becomes even more critical to strategically manage our shared, and limited, water resources.

In response to these challenges, the following recommendations are provided for project proponents and investors:

1. Conduct detailed, site-specific analysis of the local water context to better understand how water availability will be impacted by the regulatory framework, stakeholder and indigenous community concerns, other water users, and seasonal and inter-annual hydrologic dynamics.
    a. This analysis will materially impact project risks and costs and should be completed early in project development before significant investments are made.
2. Carefully consider climate change risks, informed by location-specific analysis.
3. Develop approaches to manage water supply risks in an increasingly variable and unpredictable climate. These may include:
    a. Constructing water storage with sufficient capacity to supply operations during low flow periods.
    b. Working with other water users in the basin to develop water-sharing agreements, and/or collaboratively manage water on a basin level.
    c. Seeking opportunities to reduce overall consumptive water requirements, for example by using air cooling instead of evaporative cooling.
    d. Seeking alternatives to freshwater use, including saline groundwater and water reuse.

To develop better knowledge and tools for identifying and managing water-related challenges, the following next steps should be undertaken:

1. Utilize collaborative, data-driven processes to identify, understand, and manage water challenges on a river basin scale, while balancing water-energy-food nexus tradeoffs and environmental considerations.
    a. The North Saskatchewan River Basin should be a top priority for this work, given the absence of existing models and tools for this purpose and the abundance of hydrogen development planned for the region.
    b. This work should consider the implications of both consumptive and non-consumptive water use associated with future development.
2. Repeat this study to examine other technologies and sectors which will be involved in the net zero 2050 transition (e.g., CCS, small modular nuclear reactors, critical minerals, etc.).
3. Recognizing that net zero 2050 commitments are being made across Canada, repeat this study in the other provinces and territories, which are currently grappling with many of the same

challenges documented for Alberta.

4. Develop a better understanding of Alberta's groundwater resources and make this data available publicly in a consistent and usable format.

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# Appendix A Hydrogen Water Demands Details

*This appendix will be publicly released in December, 2023.*

# Appendix B Hydrogen Project Details

*This appendix will be publicly released in December, 2023.*

# Appendix C Watershed Details

*This appendix will be publicly released in December, 2023.*

# *Appendix D* Water Availability Analysis Methodology Details

*This appendix will be publicly released in December, 2023.*