Behind the Scenes: Alberta Water Nexus Project Pilot's Assumptions and Constraints

April 2016

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1. Introduction

1.1. Project background

The purpose of the Nexus project is to produce educational materials that allow Albertans to explore the concept of converging and interacting water demands in the Bow River Basin (BRB). This is accomplished through web-based written and graphical content, along with an interactive simulation that focuses on case studies that show the connections between energy, agricultural and community sectors in the BRB. All of the project materials are available at www.albertawater.com/nexus

1.2. Purpose and overview of this report

This report summarizes the research, base datasets, and technical assumptions that have been used to develop the BRB case study information and interactive simulation presented on the Nexus website. Figure 1 provides an overview of topics explored in this report and highlights the sections in which the related research, datasets, and assumptions are summarized.

The report begins with a discussion of the Nexus Concept, the history of its development and the key research questions guiding the scope of this project (Section 2). Section 3 describes the overall research methodology used to develop the case study content and interactive simulation. Section 4 describes the conceptualization of the BRB and water supplies, as well as ecological and regulatory/operational water conservation objectives. Summaries of the key assumptions and datasets used in each sector's case study are presented in Section 5.

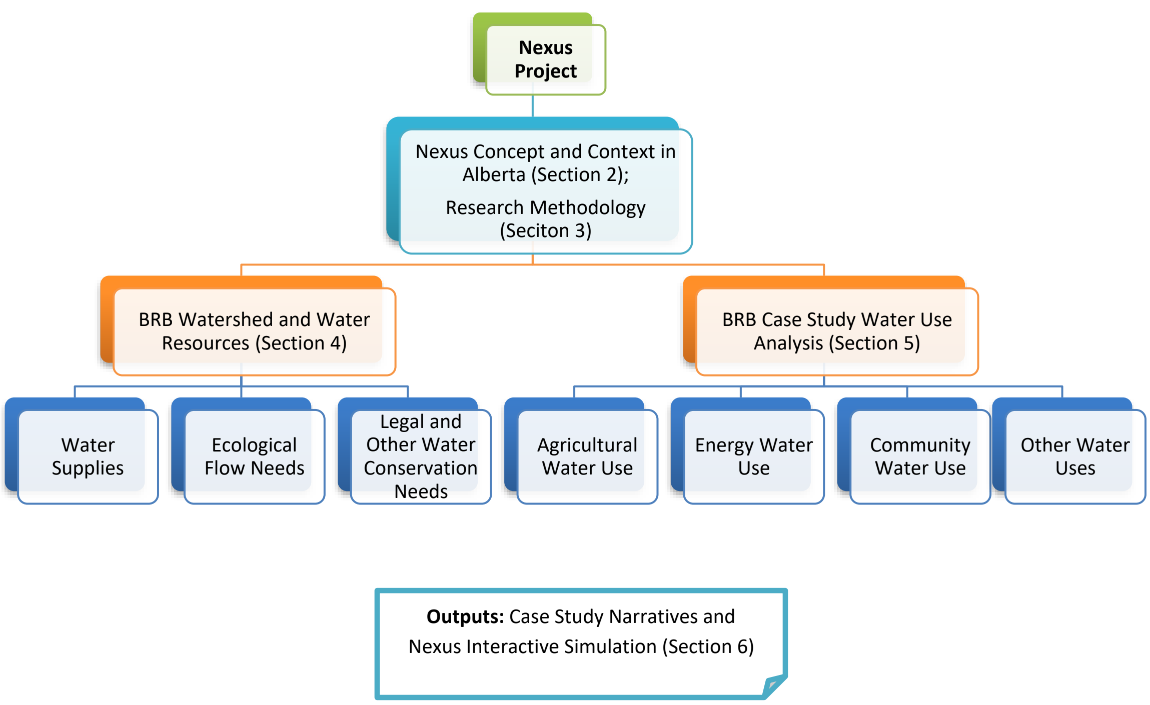

Figure 1. Overview of this technical report and the breakdown of information presented.

2. Overview of the Nexus Concept and applicability to Alberta

The Nexus concept describes the interconnectedness and interdependence of global resources, focusing primarily on water, food, and energy. In recent years, numerous organizations have acknowledged the importance of these specific resources and have explored their interdependence, or Nexus, in the following ways:

- The World Economic Forum identifies the Nexus as the interconnectedness of water, energy, food, and climate[1].
- At the 2011 Nexus Conference held by the German Federal Government, the Nexus was loosely defined as the relationships and interdependencies between the secure supply of water, energy, and food[2].
- The Food and Agriculture Organization of the United Nations (FAO) describes the Nexus as “the complex and inter-related nature of our global resource systems”, wherein “different resource user goals and interests” must be balanced, while also maintaining ecosystem integrity[3].
- A report published by Ceres in 2015 recognizes the Nexus as the connections between water security, agricultural production, and economics[4].

A common understanding of the Nexus concept is critical in the sustainable management of resources as it identifies key interdependencies between multiple sectors[5]. For example, the water, food, and energy sectors each face overlapping challenges that require decision-makers to consider multiple interdependencies and trade-offs. These trade-offs can be challenges such as water use, crop yield, or energy production[6].

Furthermore, the Nexus concept recognizes that interactions between the natural environment and human, social, and economic needs can be managed in relation to one another[7]. This approach can help manage trade-offs between interconnected sectors, while identifying common issues between sectors to limit challenges, such as competition and resource scarcity[8].

Water lies at the heart of Alberta’s social, environmental and economic well-being. An adequate water supply is required to meet demand from our growing population, maintain and improve environmental health, and support the production of food and energy. Meeting all of these needs is already challenging as Alberta experiences increasing pressure on water supplies due to population growth, economic development, and climate change.

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[1] "Water Security - The Water-Food-Energy-Climate Nexus." World Economic Forum. Accessed October 2015. http://www3.weforum.org/docs/WEF_WI_WaterSecurity_WaterFoodEnergyClimateNexus_2011.pdf

[2] “The Water, Energy, and Food Security Nexus – Solutions for the Green Economy.” German Federal Government. Accessed October 2015. http://www.water-energy-food.org/en/conference.html

[3] Food and Agriculture Organization of the United Nations (FAO). 2011.“The Water-Energy-Food Nexus – A New Approach in Support of Food Security and Sustainable Agriculture.”. Available online: http://www.water-energy-food.org/en/conference.html (Accessed October 2015).

[4] “Feeding Ourselves Thirsty: How the Food Sector is Managing Global Water Risks.” CERES. Accessed October 2015. http://www.ceres.org/issues/water/agriculture/water-risks-food-sector

[5] FAO (2011)

[6] “The Water-Food-Energy Nexus: Towards Planning and Decision Support Framework for Landscape Investment and Risk Management.” International Institute for Sustainable Development. Accessed October 2015. http://www.iisd.org/pdf/2013/wef_nexus_2013.pdf

[7] FAO (2011)

[8] Ibid

In Alberta we are further challenged by the fact water is used by numerous sectors across the province. For example, communities require water to meet their daily drinking water, sanitation, and other household needs. Agriculture, Alberta's largest water consumer, uses water for irrigation to help meet food production demands. Alberta's energy industry is also a significant water consumer, with water used intensively in a range of oil and gas production activities such as oil sands mining, in-situ oil sands recovery, and hydraulic fracturing.

Another challenge is that Alberta's water resources and human population are not evenly distributed throughout the province. Approximately 80% of the water resources in Alberta are in the northern half of the province, while 80% of the population resides in the southern half. Alberta's population is expected to reach 6.2 million in 2041, further constraining available water resources in the southern portion of the province[9].

Figure 2 provides an overview of the various components of the Nexus concept as it applies to Alberta.

Figure 2. Conceptualized components of the Nexus within Alberta based on project assumptions.

This figure clearly illustrates the convergence of communities, energy, and agriculture as the main consumptive uses of water. Land use and environmental health provide important watershed context, as these factors are significant determinants of water resource quality and availability. It is recognized that the breakdown presented in Figure 2 is a simplification of a complex system of feedbacks among human society and the environment, in which factors related to the economy, socio-cultural values, and biophysical processes interact. Where possible the project materials attempt to highlight this complexity, however, there are also simplifications and assumptions that have been incorporated and are explained throughout this technical report.

[9] Alberta Finance and Treasury. 2015. "Population Projects: Alberta 2015 – 2041." Available Online: http://www.finance.alberta.ca/aboutalberta/population-projections/2015-2041-alberta-population-projections.pdf (Accessed October 2015).

3. Methodology

This document was created as a reference to provide users of the Nexus tool with information on the research, background data, and assumptions that have been incorporated into the Nexus project.

Although the specific details associated with each component of the Nexus tool is provided in detail throughout Sections 4 and 5, the following summarizes the research methodology and techniques employed to translate technical knowledge into the materials presented on the Nexus web page:

- **Case Study Background Research:** Background research on the BRB's water resources was conducted to determine important components of the watershed that could be used to highlight the convergence of local demand. This involved a literature review of watershed conditions, water supply and demand reports (e.g., Bow River Basin Council's State of the Watershed; South Saskatchewan River Basin water supply and demand estimates), and interviews with local sector representatives and water management experts to identify largest water uses in the basin and narrow the scope of the analysis.
- **Case Study Scoping:** Based on the team's research and analysis of significant water users in the basin, three case studies were selected: one related to agriculture, one related to municipalities, and one related to energy. Case studies from different sectors were selected to highlight the converging and interconnected water usage by multiple sectors in the Bow River Basin (i.e., the Nexus).
- **Sector Case Study Narratives:** Each case study was developed by collecting relevant data and making assumptions and calculations to determine total consumptive water use. Case study data, analysis, and assumptions were summarized into 'fact sheets', which were then reviewed with subject matter experts. Based on feedback from the subject matter experts, assumptions were altered and case studies revised. Once each case study was finalized, matching case study narratives were created. These narratives put the case studies into a concise and easy to interpret format and serve the purpose of providing WaterPortal readers with a story surrounding each case study. Data and figures cited in the narratives are based on the case study research and analysis. Similar to the case study fact sheets, narratives were reviewed by subject matter experts and any feedback was used to revise the narratives.
- **Creation of The Nexus Interactive Simulation (i.e., dynamic bar graph and Sankey diagram):** Once individual sector analysis was completed, it was necessary to bring these together in a way that highlights their convergence in the BRB. This was accomplished using an interactive tool that was piloted with experts and stakeholders and refined according to subsequent feedback. The reference values used in the simulation are based on the volumes of consumptive water researched and calculated during the case study development. In addition to water use by municipalities, agriculture, and industry, the Interactive Simulation also takes into account other water needs in the basin. To account for these volumes, estimates related to the Master Agreement on Apportionment, Protected Flows, and use by other sectors in the basin were developed. Consumptive water use related to agriculture, municipalities, and energy, as well as other volumes related to Master Agreement on Apportionment, Protected Flows, and use by other sectors, form the backbone of the Nexus Interactive Simulation.

4. BRB watershed and water resource system

Figure 3 provides a conceptual model of the BRB's supplies and allocations, and highlights those estimated in the Nexus project (green boxes and arrows). This model represents a mass balance of the BRB's water, where inflows (supplies) are equivalent to the sum of all outflows (consumption and watershed discharge). Table 1 shows the mathematical basis for the mass-balance presented in Figure 3.

For the purposes of the project, the inflows are estimated on the basis of naturalized flow data provided by Alberta Environment and Parks[10]. Within the conceptual model shown in in Figure 3, water supplies in the BRB have been partitioned into two major main components: (1) water withdrawals (consumed and diverted waters); and (2) protected environmental and apportionment flows. The other natural and human-influenced hydrologic processes, such as groundwater exchanges, return-flow, and evapotranspiration (ET), are not explicitly represented in the Nexus tool, but are incorporated into estimates of the net consumption and protected flows. For example, consumption is calculated as net consumption after return flows, and protected flows are calculated as net outflows (after all natural processes and return-flows have occurred).

On the basis of the mass-balance in the BRB, the protected flows can be understood as representing a fraction of the total water supply within the basin used for ecological protection and other water conservation objectives, such as the Bow River's contribution to the Master Agreement on Apportionment (MAA) with Saskatchewan. It should be noted that a third component in the BRB system is "surplus water" to reflect the fact that, on average, consumption is less than allocated licences and regulatory requirements for the MAA[11]. This is not a physical quantity of water, but is an important indicator of how actual consumption compares to the planned maximum levels of consumption for the basin. Ecological flow requirements, as expressed through Water Conservation Objectives (WCO) assessments, are not always met throughout the basin, even in surplus water[12].

The transit-time in the BRB, from the headwaters to the outflow at the confluence with the Oldman River is, at a minimum approximately 5.5 months[13]. On an annual basis, it is generally assumed that storage facilities have no net effect on outflows from the basin[14]. As such, there is no inter-annual storage assumed in the Bow River system.

It is also crucial to recognize that although protected environmental and apportionment water aims to address two key policy objectives of (1) meeting the MAA and (2) satisfying WCOs, it is actually the same flowing water (plus any surplus water) that contributes to both of these objectives. These flows are managed operationally on an ongoing basis by AEP and the province's Interbasin Water Coordinating Committee of the South Saskatchewan River Basin[15]. Although the decision-making process for operational water management is complex, on an annual basis, the SSRB has never failed to meet

[10] Alberta Environmental Protection (AEP). 1998. South Saskatchewan River Basin Historical Weekly Natural Flows: 1912-1995.
[11] AMEC Earth and Environment. 2009. South Saskatchewan River Basin in Alberta Water Supply Study. Agriculture and Rural Development, Lethbridge, AB.
[12] Alberta Environment. 2005. South Saskatchewan River Basin Water Allocation. Available online: http://aep.alberta.ca/water/programs-and-services/south-saskatchewan-river-basin-water-information/studies/documents/WaterAllocation-SSRB-Jan2005.pdf. (Accessed Feb 23, 2016); Bow River Basin Council. 2010. Environmental Flows in the Bow River Basin. Available Online: http://wsow.brbc.ab.ca/index.php?option=com_content&view=article&id=337&Itemid=83. (Accessed Feb 23, 2016).
[13] AEP (1998)
[14] Interbasin Water Coordinating Committee of the South Saskatchewan River Basin (Alberta). 2009. Apportionment Operations Plan for the South Saskatchewan River Basin (Alberta). ISBN: 978-0-7785-8827-6.
[15] Ibid

apportionment requirements and regularly provides significantly more water[16]. AMEC (2009) estimated that this value could be as high as 40% of the total allocated water withdrawals. It should also be noted that the apportionment requirement is for the entire SSRB and as such the BRB is managed in consideration of potential contributions from other SSRB sub-basins.

This is a highly simplified model of the BRB and could be improved in many ways, including:

- More accurately reflecting the effect of timing (i.e., lag in flows) and potential effect of inter-annual storage in the watershed
- Getting a better understanding of the hydrologic processes currently lumped together (e.g., net groundwater flows, evaporation, etc.)
- Actual consumption is often dependant on the hydrologic conditions (e.g., during wet years, there is less agricultural water demand for irrigation), and
- Allocations and water licenses can be transferred – this is not represented.

[16] Interbasin Water Coordinating Committee of the South Saskatchewan River Basin (Alberta). 2011. Alberta Report (Interim) on South Saskatchewan River Basin Water-sharing with Saskatchewan in 2010 Under the Master Agreement on Apportionment. Available Online: http://aep.alberta.ca/water/programs-and-services/south-saskatchewan-river-basin-water-information/documents/WatersharingSask-InterimReport-2011.pdf. (Accessed Feb 23, 2016); AMEC Earth and Environment (2009)

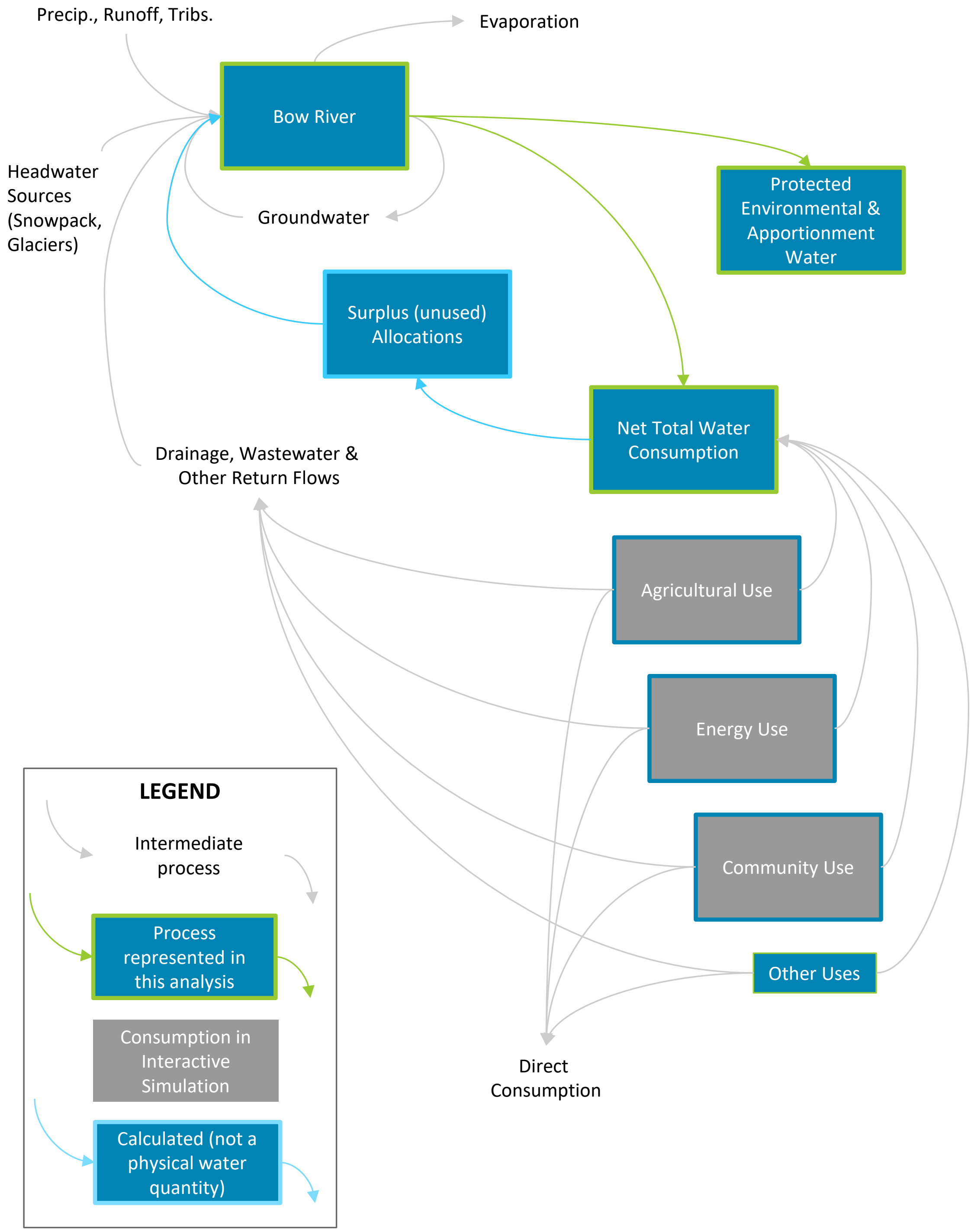

Figure 3. Conceptual model of water supply and demand in the BRB and an illustration of how they are represented in the Nexus simulation (www.albertawater.com/nexus-simulation)

Table 1. Mass Balance Equations for the BRB as Represented in the Nexus

Explanation	Since the apportioned volumes represent flows after WCOs have been met, the flow of water (actual flow) at the Bow confluence represents both the Bow's environmental flows and also its contribution toward apportionment. The outflow of 11.2 cms has historically been AEP's minimum level to assure apportionment. This is significantly lower however, than the WCO definition of "45% of naturalized flow". It should be noted that this outflow is for the entire river, meaning that some reaches may not have met their specific WCOs, even if the total flow at the confluence is greater than the "45% of naturalized flow" requirement.
Assumption 1	Mass balance in the BRB occurs on an annual basis.
Assumption 2	On an annual basis, it is assumed that storage facilities are balanced and have no net effect on outflows from the basin (SSRB MMA Operational Manual).
Assumption 3	The apportionment flows incorporate any protected flows (i.e., by the time the flows have reached the mouth of the Bow River, they have been used to try and protect ecosystems and other water conservation objectives)
Assumption 4	The time-of-travel of flow is not factored-in
Variables	Qin = Total inflows to the Bow River Qout = Total losses and outflow of the Bow River Qsources = Surface water inflows to the Bow mainstem: snow-melt, glacial melt and tributary and precipitation runoff Qnetgw = Net groundwater discharge to the Bow river Qet = Evaporation and evapotranspiration losses from the Bow watershed (assumed negligible from the river but the streamflows routed in the naturalized flow analysis and those observed at the confluence have accounted for watershed ET losses) Qnetconsumption = Net consumption, after return-flows Qnetag = Net consumption for the agricultural sector after return-flows Qnetmunic = Net consumption for communities (e.g., municipalities) after return-flows Qnetenergy = Net consumption for the energy sector after return-flows Qnetother = Net consumption for other sectors after return-flows Qbowatmouth = Flow at the "Bow at Mouth" station, representing the discharge outflow for the Bow River Basin _nat represents naturalized flows produced from AEP (1998) _obs represents actual flows observed at the Water Survey of Canada gauge Qprotected = Water that remains in the river to meet various water conservation and ecosystem objectives and ultimately contributes to SSRB apportionment requirements (i.e., the river's outflow discharge)
Eq.1 (shows how the mass balance in the BRB is represented)	Qin = Qout
Eq.2 (shows how the inflows are represented)	Qin = Qsources + Qnetgw
Eq.3 (shows how the losses are represented – note that the river's discharge is not	Qout = Qet + Qnetconsumption

considered a loss)	
Eq4. (summary of water balance components)	Qsources + Qnetgw = Qet + Qnetconsumption
Eq.5 (elements represented by the naturalized flow data)	Qsources + Qnetgw – Qet = Qbowatmouth_nat (note: Qnetconsumption is not factored-in)
Eq.6 (elements represented in the actual/observed flow data)	Qsources + Qnetgw – Qet – Qnetconsumption = Qbowatmouth_obs
Eq.7 (elements contained within net consumption)	Qnetconsumption = Qnetag + Qnetmunic + Qnetenergy + Qnetother (note: each element is estimated in the case studies and are flexible based in user inputs in the simulation tool)
Eq.8 (assumption for understanding protected flows)	Qprotected ≈ Qbowatmouth_obs

4.1. Determination of available water (inflows)

Understanding the total value of water flowing into the BRB is critical to the Nexus project, because in theory this entire amount could be used by activities within the basin. Therefore, it is necessary to determine this amount as it is an important input for the project.

Total available water in the Bow River was determined on an annual basis using Naturalized Flow Estimates for the Bow At Mouth station, obtained from AEP. Figure 4 presents a chart of total annual volume over time. Base on this record, the mean annual total water availability is 4,042,087 $dam^3\ yr^{-1}$. Median annual flow, which is referenced in WCOs and the MAA is 3,852,364 $dam^3\ yr^{-1}$. Median annual flow is the value represented as the default in the Interactive Simulation. The estimated flow for a wet-year was calculated as the 90th percentile value in the naturalized flow series and is 5,197,400 $dam^3\ yr^{-1}$. Dry-years are represented as the 10th percentile being 2,851,449 $dam^3\ yr^{-1}$.

The naturalized flow estimates do not incorporate the effects of groundwater exchanges, however they do factor in evapotranspiration, evaporation, all tributary and headwater and inflow to the Bow River, and some of total watershed surface runoff (other portions would infiltrate to groundwater)[17]. These estimates are based on naturalized flow from the 1912 through 2001, and while they capture a large range of flow for the BRB, they do not address the potential effects of climate change and hydroclimatic non-stationarity, which will very likely influence the BRB by the 2030s. Additional work is recommended to incorporate the effect of climate change, however preliminary work in the SSRB has demonstrated that on an average annual basis, streamflows are likely to decrease into the future[18].

[17] Alberta Environmental Protection (1998)
[18] Sauchyn, D. J., St-Jacques, J. M., Barrow, E., Nemeth, M. W., MacDonald, R. J., Sheer, A. M. S., & Sheer, D. P. (2016). Adaptive Water Resource Planning in the South Saskatchewan River Basin: Use of Scenarios of Hydroclimatic Variability and Extremes. JAWRA Journal of the American Water Resources Association; Gizaw, M. S., & Gan, T. Y. (2015). Possible impact of climate change on future extreme precipitation of the Oldman, Bow and Red Deer River Basins of Alberta. International Journal of Climatology; Tanzeeba, S., & Gan, T. Y. (2012). Potential impact of climate change on the water availability of South Saskatchewan River Basin. Climatic change,112(2), 355-386.

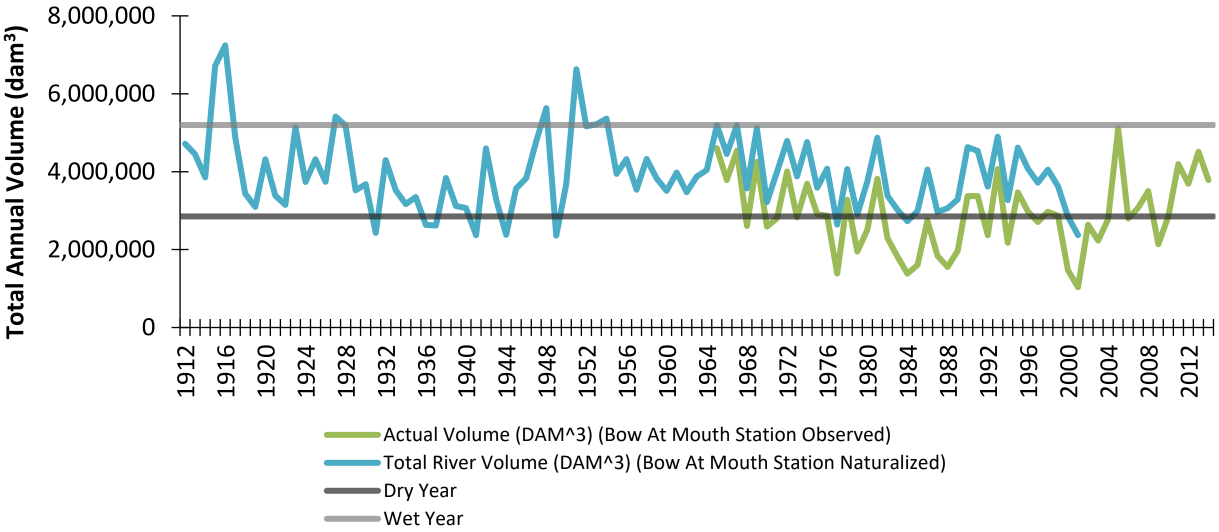

Figure 4. Historical naturalized and actual observed flows at the outflow of the Bow River Basin (Bow at Mouth station)

4.2. Representing apportionment

There is no specific volume of water specified for the Bow River Basin as the MAA only specifies values for the entire SSRB[19]. The specific flows provided to Saskatchewan are determined operationally by AEP with the historical minimum contribution from the Bow River Basin being 11.4 cms at Medicine Hat, although values have been as low as 2.8 cms in dry years[20]. These contributions aim to meet an AEP operational objective of a combined 42.3 cms from the Bow and Old Man rivers in Medicine Hat [21]. Typically, the overall amount of water delivered to Saskatchewan through the SSRB apportionment arrangements is much higher than the requirement in the MAA[22]. The 11.4 cms requirement is equivalent to 359,510 dam^3 yr^{-1}.

4.3. Representing environmental protection

The basis for environmentally-protected flows in Alberta is the concept of Instream Flow Needs (IFN)[23], which Alberta has determined should cover the following ecological functions:

- Fish habitat;
- Riparian Vegetation;
- Maintenance of dissolved oxygen and temperature; and
- Channel maintenance (to flush fine particles from the streambed)[24].

[19] Bow River Basin Council (BRBC). 2010. Environmental Flows in the Bow River Basin. Available Online: http://wsow.brbc.ab.ca/index.php?option=com_content&view=article&id=337&Itemid=83. (Accessed Feb 23, 2016).
[20] Ibid
[21] Ibid
[22] Interbasin Water Coordinating Committee of the South Saskatchewan River Basin (Alberta). 2011. Alberta
[23] Alberta Environment. 2006. Approved Management Plan for the South Saskatchewan River Basin (Alberta). Pub No. I/011. Available online: http://aep.alberta.ca/water/programs-and-services/river-management-frameworks/south-saskatchewan-river-basin-approved-water-management-plan/documents/SSRB-ApprovedWaterManagementPlan-2006.pdf. (Accessed Feb 23, 2016).

The IFN concept suggests that a minimum flow is required to sustain the aforementioned functions, which are essential to overall ecological health of streams[25]. In the SSRB and BRB, the IFNs are operationalized through the implementation of Water Conservation Objectives (WCOs), which are reach-specific and frequently defined in relation to previously determined Instream Objectives (IOs) objectives[26]. Many WCOs are implemented to assure adequate flows for protection of tourism, recreation, transportation and wastewater assimilation[27]. Although WCOs are codified in legislation, permitted withdrawals are given priority[28]. As such, in a dry year the objectives are frequently not met in lower reaches of the Bow River Basin[29]. WCOs in the BRB are summarized in Table 2. In general, 45% of natural flow is the primary objective in high-flow periods, and 110% of IOs are applied during low-flow[30].

Table 2. WCOs for the Bow River Basin[31] (from [2] unless otherwise noted)

Reach	WCO Definition
1. Bow River and Tributaries Above Bearspaw Dam	- Whichever is greater of: (a) current IO OR (b) downstream WCO at any point in time - IOs are defined as 80% of the fish rule curve[32,33]
2. Bow River and Tributaries Below Bearspaw Dam	- Whichever is greater of: (a) 45% of natural flow rate OR (b) 110% of IOs at any point in time - IOs are defined as 80% of the fish rule curve[34]

Unfortunately, no fish rule curves were available for the BRB. However, based on feedback from staff at WaterSMART Solutions Ltd., this is likely due to other operational requirements (e.g., ensuring a minimum adequate flow for the City of Calgary), which greatly exceed fish rule curves downstream of reservoirs.

The “45% of natural flow” rule is also difficult to estimate because it is calculated on a reach-by-reach basis, operationally where possible, and through the restriction of new licenses 2005. This value was

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[24] Government of Alberta. 2005. Fact Sheet: Instream flow needs (IFN) for the Aquatic Environment. Available Online: http://aep.alberta.ca/water/programs-and-services/river-management-frameworks/south-saskatchewan-river-basin-approved-water-management-plan/documents/IFNAquaticEnvironment-SSRB-InfoSheet.pdf. (Accessed Feb 23, 2016).
[25] I Clipperton, G.K., Koning, W.C., Locke, A.G.H., Mahoney, J.M. and Quazi, B. 2003. Instream Flow Needs Determinations for the South Saskatchewan River Basin, Alberta, Canada. Alberta Environment. Pub No. T/719; Ibid
[26] Alberta Environment (2006)
[27] Interbasin Water Coordinating Committee of the South Saskatchewan River Basin (Alberta). 2009. Apportionment Operations Plan for the South Saskatchewan River Basin (Alberta). ISBN: 978-0-7785-8827-6.
[28] Alberta Environment. 2007. Establishment of Bow River Sub-Basin Water Conservation Objective. Available Online: http://esrd.alberta.ca/water/legislation-guidelines/documents/WaterConservationObjectivesBowRiver.pdf. (Accessed Feb 23, 2016); BRBC (2010)
[29] Ibid
[30] AMEC Earth and Environment (2009)
[31] From Alberta Environment (2007) unless otherwise specified in the table
[32] Alberta Environment (2006)
[33] Fish rule curves are specified minimum seasonal flows (normally specified for an average year) that should not be exceeded to maintain fish habitat downstream of a reservoir or other hydraulic control structure (Clipperton et al. 2003). Although the specific criteria/calculations for definition fish rule curves have evolved over time with the scientific understanding of aquatic ecosystems, the concept of a temporally variable minimum flow has not (Clipperton et al. 2003). Work in the Highwood River (Clipperton et al., 2002) was used as the basis for IFNs in the broader SSRB as reported in Clipperton et al. (2003), and required assessment on a reach-by-reach basis.
[34] Alberta Environment (2006)

calculated as 1,733,564 $dam^3\ yr^{-1}$ and in an average flow year, the unallocated flow is approximately half of this WCO.

The current WCO for the Bow River indicates that "flows in excess of the current instream objectives are necessary for preferred protection of the aquatic environment"[35]. Based on this statement, it is assumed that the current WCO, which exceeds initial IOs, will remain in-place through the 2030s and potentially be strengthened to address deficiencies in instream flow needs in much of the basin[36]. Within the Nexus project, the initial value for representing WCOs was the difference between total allocations and total available flow. However, in the Interactive Simulation the user has the ability to change this amount.

Due to projected reductions in overall streamflows in the SSRB as a result of climate change[37], the entire observed streamflow record was used to calculate the initial value. The record since 2005 was tested initially, as this represents the period when IFNs were most actively considered in water management decisions (i.e., basin was closed, WCOs established), however, this period was a relatively wetter period in the record (see Figure 4).

5. BRB case study water use analysis

5.1. General assumptions

Several key assumptions that are generally applicable across the case studies were required to develop comparable estimates of water use for the various sector case studies in the BRB. These can be summarized as follows:

- **All case studies are assumed to occur in the Year 2030**: 2030 was selected as the planning horizon because several key regional planning and provincial government policy documents use this year as their implementation deadline. Additionally, the Alberta Government's Climate Leadership Plan established 2030 as a key planning year. Finally, the audience of the Nexus Interactive Simulation would relate to 2030, as it is not too far into the future to be unimaginable, but is distant enough that substantive changes in water management could be imagined.
- **The Bow River Basin is currently closed to new surface water allocations and is expected to remain closed in the year 2030:** There are numerous pressures on water quantity and quality in the Bow River Basin[38]. As was described in Section 4 the basin's water withdrawal allocations are in excess of key water conservation targets (WCOs) and approach the maximum available flow in the river in dry years. Given this, it is foreseeable that the current restrictions on new water withdrawals will remain limited.
- **Although water licence transfers are permitted between sectors, these dynamics are not reflected in the case studies:** Understanding trade-offs between water use among sectors, which can be facilitated through water transfers, is the essence of the Nexus concept. However,

[35] Alberta Environment (2007)
[36] BRBC (2010); Government of Alberta (2005)
[37] Sauchyn et al. (2016); Gizaw and Gan (2012); Tanzeeba and Gan (2012)
[38] BRBC (2010)

there are many complex social, political, economic, and other variables that influence how water transfer decisions are made. Accounting for these dynamics would require additional research beyond the scope of the current project. Additionally, assessing how such trade-offs might occur by the year 2030 is highly uncertain and any figure would remain in the realm of speculation. It was determined that the Nexus message could be best received if users could compare potential water demand to the current state of allocations.

- **Where referenced, water allocations are based on 2010 licences reported in the Web-based State of the Watershed (WSOW):** Where referenced and used in developing basin-scale comparisons of water consumption to allocation, the values reported by the Bow River Basin Council (the Bow River's Watershed Planning and Advisory Council) in its WSOW report were used[39].
- **Sector-based water use was validated against estimates from AMEC (2009):** In order to validate the estimates of water use described in the Nexus narratives and in the default values presented in the Interactive Simulation, it was necessary to compare them against another dataset. This was done using estimates of water consumption in AMEC (2009). It should be recognized that there is no dataset tracking actual water consumption, however, given that the methods used in the current project and AMEC (2009) are independent, a comparison between the two values can yield insight into the potential range of actual sector water use.

5.2. Population by 2030 and its relation to water demand

Within the Nexus project, increasing local and global populations are recognized as key drivers of water demand in the Bow River Basin both directly and indirectly. Community water use and consumption could increase as the population of the basin grows. Other sector water demands, particularly utilities, commerce and industry, are also driven by population. As the overall economy of a region grows with its population, more water is needed to service industry, commerce, and utilities (e.g., electricity) upon which populations rely. It should be noted that agricultural production and its associated water use is not necessarily driven by local population growth in the same way other sectors are. This is because large amounts of Canadian agricultural products (50%)[40], and potentially more in specific basins, are exported internationally. Another significant portion is exported to markets outside of the basin where the agricultural product is produced[41]. That being said, increasing demand for agricultural products in any large-scale production are driven by global demand for such products, and this is also true in Alberta. Global demand is a function of population among many other factors, including affluence, societal values, and technology[42].

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[39] Alberta Environment. 2010. Bow River Basin Allocations. Available Online: http://wsow.brbc.ab.ca/images/wsow/BowAllocations-Feb2010.pdf (Accessed Mar 1, 2016)

[40] Kerr, B. 2016. *Canada's Evolving International Trade Landscape – What Should Canada's Agri-food Sector Expect?* Proceedings of In the Midst of Change: Challenges Ahead for the Canadian Agri-Food Sector. Ottawa, ON. Jan 20-22, 2016. Available online http://ag-innovation.usask.ca/2016policyconference.html (March 16, 2016)

[41] Wheater, H., Bennett, E., de Loe, R., Friesen, R., Hamilton, K. E., Hepworth, L., … Van Acker, R. (2013). *Water and Agriculture in Canada: Towards Sustainable Management of Water Resources*. Council of Canadian Academies. Ottawa, ON. Available online http://www.scienceadvice.ca/uploads/eng/assessments%20and%20publications%20and%20news%20releases/water_agri/wag_fullreporten.pdf (March 16, 2016)

[42] Hoekstra, A. Y., & Chapagain, A. K. (2007). Water footprints of nations: water use by people as a function of their consumption pattern. Water resources management, 21(1), 35-48.

While increases in water demand from a growing population can be offset by conservation behaviours, policies, and technology, these gains in water-use efficiency must be prioritized by water users and decision-makers to have an effect. As such, managing water supply and demand as the population grows is a societal question that the Nexus concept addresses. To allow users to understand the concept of population influences on water and the importance of addressing water use, functionality was implemented in the Interactive Simulation for users to manipulate the population.

Water usage is also reported as a per-capita value for each sector to allow users to understand the water efficiency variable within overall water demand of a population. The suggestion is not that these values represent the actual water consumption an individual person is responsible for, but it provides a universal metric to report water efficiency and relative demand among sectors. This is similar to the concept of Water Footprinting, which assigns a value of liters per unit of production[43].

To make the population-water relationship relevant to the Bow River Basin specifically, several key assumptions were required. First, rather than looking at individual municipalities, it was assumed that each case study is based on municipal growth associated with members of the Calgary Regional Partnership (CRP), which is a voluntary partnership of municipalities. This fits nicely with the regional approach that CRP members are taking towards infrastructure, including regional water, wastewater, and stormwater infrastructure systems[44].

The population of CRP members is expected to grow to three million people, or an additional 1.6 million people, by 2076[45], as is highlighted in Table 3. These population projections were developed by CH2M HILL in collaboration with CRP members in 2012[46]. After a 2014 review of the population projections, it was concluded that the projections are still valid, with the exception of Okotoks, which was updated to reflect the community's revised growth strategy[47].

Table 3. Population of the CRP area, broken down by community and year [48]

Service Area	Population			
	2010	2030 (interpolated)	2041	2076
Airdrie	39,882	55,175	63,526	90,288
Black Diamond Area	2,308	3,643	4,379	6,716
Calgary Area	1,071,515	1,328,433	1,469,738	1,919,344
Calgary East	-	3,000	8,454	17,999
Calgary North West	-	52	148	316

[43] Ibid
[44] "Calgary Metropolitan Plan." Calgary Regional Partnership. Published 2014. Link: http://calgaryregion.ca/dam/Website/reports/General/CRP-current-general-documents/Calgary-Metropolitan-Plan---June-2014/Calgary%20Metropolitan%20Plan%20-%20June%202014.pdf
[45] Ibid.
[46] "Regional Water and Wastewater Servicing Masterplan." CH2M HILL on behalf of the Calgary Regional Partnership. Published 2014. Link: http://calgaryregion.ca/dam/Website/reports/General/Regional-servicing-and-CMP-Implementation/Regional-Water-and-Wastewater-Servicing-Master-Plan/Regional%20Water%20and%20Wastewater%20Servicing%20Master%20Plan.pdf
[47] Ibid.
[48] "Regional Water and Wastewater Servicing Masterplan." CH2M HILL on behalf of the Calgary Regional Partnership. Published 2014. Link: http://calgaryregion.ca/dam/Website/reports/General/Regional-servicing-and-CMP-Implementation/Regional-Water-and-Wastewater-Servicing-Master-Plan/Regional%20Water%20and%20Wastewater%20Servicing%20Master%20Plan.pdf

Calgary South	-	3,071	8,655	18,427
Calgary North (Balzac)	-	23,710	66,819	142,259
Chestermere Area	14,285	26,024	32,481	53,024
Cochrane Area	15,425	31,878	40,928	69,721
Dewinton	-	6,718	18,935	40,314
Dunbow	-	8,666	24,424	52,000
High River Area	11,783	20,810	25,775	41,572
Irricana	1,243	3,533	4,793	8,801
Nanton Area	2,124	3,587	4,392	6,952
Okotoks Area	23,021	47,276	39,705	82,151
Strathmore	12,139	20,047	24,397	38,236
Turner Valley	2,022	3,624	4,505	7,308
Total	**1,195,747**	**1,589,247**	**1,842,054**	**2,595,428**

In preparing the population projections for the 2030s, linear population growth between the years of 2010 and 2030 was assumed[49]. Moving forward with this assumption, population projections for 2030 can be estimated using linear interpolation, as is highlighted in the 2030 column in red font in Table 3.

5.3. Community/municipal water consumption estimates

The municipal case study is based on municipal growth associated with population growth in the Calgary Regional Partnership (CRP) region, which comprises nearly all major population centres in the Bow River Basin. In general, CRP members are taking a regional approach towards infrastructure systems, including water-related infrastructure. CRP members are comprised of those municipalities listed in the CRP Regional Water and Wastewater Servicing Masterplan[50].

The population in the CRP is expected to grow to around 1.6 million people by 2030, based on the assumptions that population growth will be linear and will occur as forecast by the CRP Regional Water and Wastewater Servicing Masterplan[51]. The latter population forecast was developed with by CH2M HILL in collaboration with CRP members in 2012, and were again updated in 2014. Per capita water demand is expected to stabilize around 315 litres per person per day, as per the CRP Regional Water and Wastewater Servicing Masterplan[52]. These values are summarized by community within the CRP in Table 4, and are also compared to other North American communities for illustrative purposes. These per capita demands include residential, as well as small commercial and industrial. As a result, the values are higher than those typically reported for households.

[49] Ibid.
[50] CH2M Hill. 2014. "Regional Water and Wastewater Servicing Masterplan." CH2M HILL on behalf of the Calgary Regional Partnership. Available Online: http://calgaryregion.ca/dam/Website/reports/General/Regional-servicing-and-CMP-Implementation/Regional-Water-and-Wastewater-Servicing-Master-Plan/Regional%20Water%20and%20Wastewater%20Servicing%20Master%20Plan.pdf (Accessed March 1, 2016)
[51] Ibid
[52] Ibid

In its 2014 report to the CRP, CH2M HILL assumes that a value of 315 L/c/d represents minimum water use based on the maximum level of water conservation demonstrated to be achievable using common water conservation techniques in the region. The figure of 315 L/c/d is in-line with other regional estimates, such as estimates by the city of Calgary (350 L/c/d by 2033)[53] and the Alberta Urban Municipalities Association (341 L/c/d by 2020)[54].

For the entire municipal case study, per capita water demands are assumed to include residential water demand, as well as some commercial and light industrial demand. This assumption is justified by the fact that municipal growth will not be limited purely to households.

[53] "Water Efficiency Plan." City of Calgary. Retrieved January 2016. https://www.calgary.ca/UEP/Water/Documents/Water-Documents/water_efficiency_plan.pdf?noredirect=1
[54] "2014 Urban Municipal Water Conservation, Efficiency and Productivity Plan – Targets and Actions for the Urban Municipal Sector." The Alberta Urban Municipalities Association (AUMA). Published 2014. Link: http://www.auma.ca/sites/default/files/Advocacy/Document_library/80674_2014_cep_plan.pdf

Table 4. Per capita water demand is reported for each service area in the CRP and select other municipalities for comparison[55]:

Area	Existing Water Demand (2010) [L/c/d]
CRP Area Communities	
Airdrie	340
Black Diamond	389
Calgary	450
Chestermere	338
Cochrane	402
High River	493
Irricana	279
Nanton	415
Okotoks	301
Strathmore	371
Turner Valley	412
Large Coastal Cities	
Vancouver	489[56]
New York City	476[57]
Other Prairie Cities	
Denver	617[58]
Winnipeg	301[59]

According to CH2M HILL[60], 315 L/c/d is the minimum possible per capita water demand that has been demonstrated to be achievable. Therefore, they advise using a 315 L/c/d as a minimum value, based on common water conservation techniques. Although numerous published benchmarks are below 315, most of the reported figures are purely for residential water use, which does not include the commercial and light industrial water use that should be incorporated into municipal demand. For instance, a 2009 report by the CWWA[61] provides several benchmarks for residential and municipal water use, including one from the South Australia Water Corporation (1998) in which total municipal water consumption per person per

[55] CH2M Hill. 2014.
[56] "Water Consumption Statistics Report." Metro Vancouver – Operations and Maintenance Department. Published 2010. Link: http://www.metrovancouver.org/services/water/WaterPublications/2010WaterConsumptionStatsReport.pdf
[57] "History of Drought and Water Consumption." NYC Environmental Protection. Accessed January 2016. http://www.nyc.gov/html/dep/html/drinking_water/droughthist.shtml
[58] "2010 Comprehensive Annual Financial Report." Denver Water. Accessed January 2016. http://www.winnipeg.ca/waterandwaste/pdfs/water/2010WaterConsumptionSummaryReport.pdf
[59] "2010 Water Consumption Summary Report." The City of Winnipeg Water and Waste Department. Accessed January 2016. http://www.winnipeg.ca/waterandwaste/pdfs/water/2010WaterConsumptionSummaryReport.pdf
[60] CH2M Hill. 2014.
[61] "Water Conservation and Efficiency Performance Measures and Benchmarks within the Municipal Sector." The Canadian Water and Wastewater Association. Published 2009. Link: http://www.cwwa.ca/pdf_files/CWWA%20Water%20Efficiency%20Benchmarking...Final%20Report%20v4.pdf

day is 378 L/c/d. Per capita water demand in several European countries[62] are well below 315 L/c/d; however, reported figures are purely for household use, so one has to be cautious when drawing comparisons. Additionally, the City of Calgary has set a goal, referred to as the 30-in-30 goal, in which it plans to accommodate the 2033 population with the same amount of water used in 2003. This equates to a per capita water municipal water demand of 350 L/c/d. Finally, based on a 2014 report by the AUMA[63], the proposed target for Alberta's urban municipal sector is to achieve a total municipal per capita water use of 341 L/c/d by 2020.

Based on the previous discussion, calculations of community water demand were performed using both the minimum (i.e., 315 L/c/d) and the existing 2010 water demand. This way we can show the possible range of values that can be expected by 2030, depending on how much water use efficiency increases. These results are highlighted in Table 5.

Based on these calculations, to support municipal growth in areas of the CRP, a minimum of approximately 180-million m^3 would be required on an annual basis. According to the 2007 AENV report[64], a total municipal water demand ranging from around 67 to around 93 million m^3 of net water use is forecasted for the Bow River Basin by 2025. These values represent water use, after return-flows have been factored subtracted from total municipal withdrawals. The net use estimates of 67-93 million m^3 represent approximately 27% of municipal withdrawals (based on Table 5-5 in the AENV 2007 report). Assuming that 27% can be applied to the 180-million m^3 gross water use for the 2030s, net municipal water use would be approximately 48.6 million m^3. This is an underestimate of approximately 28-48%, however it is in the right order of magnitude. If however, return-flows decrease, or other factors influencing net consumption change, it is possible that we won't have enough water to satisfy municipal demand if we continue with business as usual in terms of regional water management. This is consistent with the 'Regional Water and Wastewater Servicing Masterplan' report[65], which highlights that several areas of the CRP will likely have insufficient licence volumes and/or infrastructure to meet projected future water demand. More specifically, that report highlights the following vulnerabilities:

- Cochrane, Strathmore, and Turner Valley expected to have insufficient licence volumes as early as 2043, 2023, and 2041, respectively.
- Okotoks is particularly limited by its current licence, and could run out of capacity as early as 2023.
- Water and wastewater infrastructure limitations will likely also be a major issue in several areas.

[62] "Profile of the German Water Sector." German Association for Water, Wastewater and Waste (DWA). Published 2015. Link: https://www.google.ca/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&ved=0ahUKEwjxwIrW6bjKAhUC4mMKHWRTACwQFgg2MAQ&url=https%3A%2F%2Fde.dwa.de%2Fprofile_of_the_german_water_Sector.html%3Ffile%3Dtl_files%2F_media%2Fcontent%2FPDFs%2FStOeP%2FWEB_brachenbild_ENGL_wasserwirtschaft_2015_a4_25062015.pdf&usg=AFQjCNGVUlk_zqfhRnsrps3fShcP_F_sBg&bvm=bv.112064104,d.cGc&cad=rja

[63] "2014 Urban Municipal Water Conservation, Efficiency and Productivity Plan – Targets and Actions for the Urban Municipal Sector." The Alberta Urban Municipalities Association (AUMA). Published 2014. Link: http://www.auma.ca/sites/default/files/Advocacy/Document_library/80674_2014_cep_plan.pdf

[64] "Current and Future Water Use in Alberta." Prepared by AMEC Earth and Environmental on behalf of Alberta Environment. Published 2007. Link: http://wsow.brbc.ab.ca/reports/CurrentFutureWaterUse-Bow.pdf

[65] "Regional Water and Wastewater Servicing Masterplan." CH2M HILL on behalf of the Calgary Regional Partnership. Published 2014. Link: http://calgaryregion.ca/dam/Website/reports/General/Regional-servicing-and-CMP-Implementation/Regional-Water-and-Wastewater-Servicing-Master-Plan/Regional%20Water%20and%20Wastewater%20Servicing%20Master%20Plan.pdf

Licence allocation volumes from both the AENV[66] report and the CH2M Hill[67] report are also presented in the last two columns of Table 5 to further highlight the region's water licence capacity issue.

[66] "Current and Future Water Use in Alberta." Prepared by AMEC Earth and Environmental on behalf of Alberta Environment. Published 2007. Link: http://wsow.brbc.ab.ca/reports/CurrentFutureWaterUse-Bow.pdf

[67] "Regional Water and Wastewater Servicing Masterplan." CH2M HILL on behalf of the Calgary Regional Partnership. Published 2014. Link: http://calgaryregion.ca/dam/Website/reports/General/Regional-servicing-and-CMP-Implementation/Regional-Water-and-Wastewater-Servicing-Master-Plan/Regional%20Water%20and%20Wastewater%20Servicing%20Master%20Plan.pdf

Table 5. Summary of calculated community water demands

Service Area	2030 Population (Interpolated)	Existing (2010) Water Demand [L/c/d]	Water Demand based on Existing per capita Demand [L/d]	Existing Annual Demand [m3]	Water Demand based on minimum (i.e., 315 L/c/d) per capita Demand [L/d]	Minimum Annual Demand [m3]	2005 Licence Allocation [m3]	Existing Licence Capacity as per CH2M report [m3]
Airdrie	55,175	340	18,759,354	6,847,164	17,379,990	6,343,696	588,000	3,818,717
Black Diamond Area	3,643	389	1,417,294	517,312	1,147,680	418,903	955,000	954,721
Calgary Area	1,328,433	450	597,794,721	218,195,073	418,456,305	152,736,551	460,184,000	460,550,000
Calgary East	3,000	NA	NA	NA	944,910	344,892	NA	NA
Calgary North West	52	NA	NA	NA	16,380	5,979	NA	NA
Calgary South	3,071	NA	NA	NA	967,365	353,088	NA	NA
Calgary North (Balzac)	23,710	NA	NA	NA	7,468,785	2,726,107	NA	NA
Chestermere Area	26,024	338	8,796,064	3,210,563	8,197,515	2,992,093	NA	2,550,000
Cochrane Area	31,878	402	12,815,013	4,677,480	10,041,615	3,665,67	4,940,000	4,933,960
Dewinton	6,718	NA	NA	NA	2,116,305	772,451	NA	NA
Dunbow	8,666	NA	NA	NA	2,729,880	996,406	NA	NA
High River Area	20,810	493	10,259,260	3,744,630	6,555,105	2,392,613	4,622,000	4,621,887
Irricana	3,533	279	985,787	359,812	1,112,985	406,240	NA	NA
Nanton Area	3,587	415	1,488,546	543,319	1,129,860	412,399	NA	1,232,000
Okotoks Area	47,276	301	14,230,033	5,193,962	14,891,895	5,435,542	2,766,000	3,010,816
Strathmore	20,047	371	7,437,437	2,714,665	6,314,805	2,304,904	2,659,000	1,850,001
Turner Valley	3,624	412	1,492,970	544,934	1,141,470	416,637	516,000	515,719
Total	**1,589,247**	**381 (avg.)**	**675,476,479**	**246,548,915**	**500,612,850**	**182,723,690**	**477,230,000**	**484,037,821**

5.4. Agricultural water consumption estimates

The premise of the agriculture case study is to determine the amount of water used to produce cereal crops on irrigated land in the Bow River Basin. It is assumed that wheat, oats, and barley are the primary cereal crops produced in the BRB and can therefore be used to represent cereal crops as a whole. Production of wheat, oats, and barley on irrigated land is assumed to remain relatively constant over time, since generally higher valued crops are grown on irrigated land, and since cereal crops are often grown for crop rotation purposes. Additionally, historical production data of cereal crops do not show any significant increasing/decreasing trends with time[68].

It should be noted that field crops, such as grains and oilseeds, only constitute approximately 14% of overall irrigated land in southern Alberta (based on the 2011 Canadian Census of Agriculture)[69], however, as a narrative, a focus on these crops provides a helpful insight into one potential future agricultural scenario in the Bow River Basin.

According to the Alberta Irrigation Information Booklet[70], total irrigation area in the Bow River Irrigation District (BRID), Eastern Irrigation District (EID), and Western Irrigation District (WID) producing cereal crops is 214,125 acres. Based on visual inspection of a map of the Bow River Basin, it is assumed that roughly 50% of the BRID, EID, and WID are located in the Bow River Basin. Therefore, the total amount of irrigated land that is used to produce cereal crops in the Bow River Basin is 107,063 acres, which is about 7% of the total area of all the irrigation districts in the basin 1,412,331 acres[71].

It is assumed that all irrigation water comes from the Bow River Basin (i.e., no water from the Red Deer River Basin). Based on a paper published in the Canadian Water Resources Journal[72], the average net irrigation water requirement for cereal crops is assumed to be 244 mm. Therefore, the total average net irrigation required to irrigate 107,063 acres of cereal crop land (assumption 4) is around 106 million m^3. The total irrigated land in the Bow River Basin is assumed to be approximately 324,000 acres[73] (i.e., half the total area of the three Bow River Basin districts). If all of the irrigated land in the Bow River Basin were used to grow cereal crops, the total average net irrigation water required would be around 320 million m^3.

This agricultural case study is structured into two parts. Part 1 estimates the future demand for irrigation water to produce cereal crops if current practices continue. By current practices, we are referring to the observation that a relatively small fraction of cereal crops are grown on irrigated land, and that cereal crops are mostly grown for crop rotation purposes. Additionally, since typically higher value crops are grown, it is not expected that there will be a major increase in the growth of cereal crops on irrigated land.

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[68] "Agriculture Statistics Yearbook – 2014." Alberta Government. Accessed February 2016. http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/sdd15546/$FILE/2014%20Yearbook%20in%20PDF%20for%20web.pdf

[69] Based on calculations from the Census of agriculture, where southern Alberta was defined as Agricultural Districts 1, 2 and 3 in Alberta. Source data is from: Statistics Canada. Table 004-0210 - Census of Agriculture, irrigation in the year prior to the census, every 5 years and Table 004-0203 - Census of Agriculture, land use, every 5 years (accessed: March 29, 2016). Total farmland was calculated as the sum of "Area in Christmas trees, woodlands and wetlands", "Land in crops (excluding Christmas tree area)" and "Tame or seeded pasture" from Cansim Table 004-0203.

[70] "Alberta Irrigation Information 2014." Alberta Agriculture and Forestry. Accessed February 2014. http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr7401/$FILE/altairriginfo2014.pdf

[71] Ibid

[72] Bennett, D. R., Harms, T. E., & Entz, T. (2014). Net irrigation water requirements for major irrigated crops with variation in evaporative demand and precipitation in southern Alberta. Canadian Water Resources Journal/Revue canadienne des ressources hydriques, 39(1), 63-72.

[73] Personal correspondence with Richard Phillips from the Bow River Irrigation District. February 29, 2016.

Part 2 expands on Part 1, and assumes that all irrigated land in the basin will be used to grow cereal crops in the future. This is an extreme scenario; however, for the Nexus project it is important to examine the effects that growing demand for food may have on water and land use in the basin.

5.4.1. Part 1: Estimates of future demand for irrigation

Based on data from the Agriculture Statistics Yearbook,[74] Figure 5 shows that average production of wheat, oats, and barley during the last 10 years has been 8,418,820 tonnes, 606,210 tonnes, and 4,737,570 tonnes, respectively.

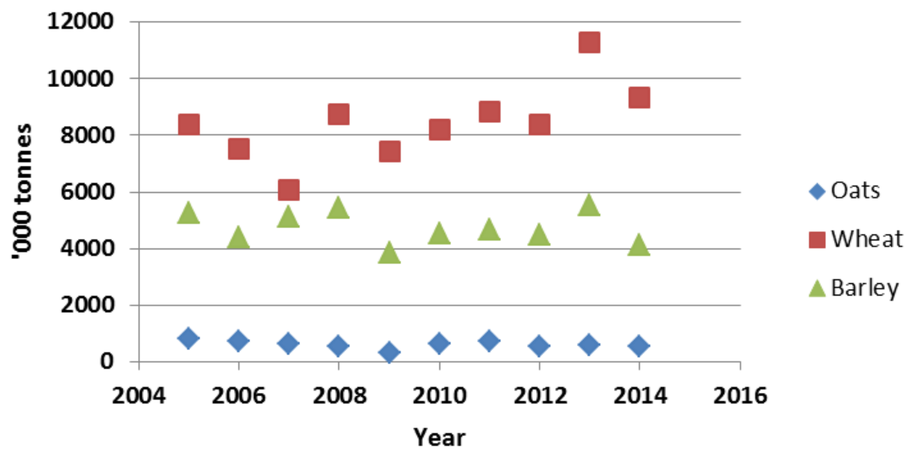

Figure 5. Quantity of cereal production in Alberta over time[75]

Production of wheat, oats, and barley is assumed to remain relatively constant on irrigated land, since cereal crops are generally not the most profitable crops, and are often grown for crop rotation purposes. Additionally, historical production data of cereal crops is variable and does not show any significant increasing/decreasing trends with time. According to the Alberta Irrigation Information Booklet[76], Table 6 summarizes the portion of irrigation land in the BRID, EID, and WID were used to produce cereal crops.

Table 6. Summary of total irrigated cereal crops for each irrigation district in the Bow River Basin

Irrigation District	Irrigation Area Producing Cereals[acres]
BRID	98,396
EID	88,776
WID	26,953
Total	**214,125**

[74] "Agriculture Statistics Yearbook – 2014." Alberta Government. Accessed February 2016. http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/sdd15546/$FILE/2014%20Yearbook%20in%20PDF%20for%20web.pdf
[75] Ibid
[76] "Alberta Irrigation Information 2014." Alberta Agriculture and Forestry. Accessed February 2014. http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr7401/$FILE/altairriginfo2014.pdf

The total area of all 13 irrigation districts is 1,412,331 acres[77]. The total area of the BRID, EID, and WID is 647,371 acres[78]. The total irrigation area in the BRID, EID, and WID producing cereal crops is 214,125 acres. Assuming that roughly 50% of the BRID, EID, and WID are in the Bow River Basin (visual estimation from the map), the total amount of irrigated land that is used to produce cereal crops in the Bow River Basin is 107,063 acres, or about 7% of the total area of all the irrigation districts. The results of this assumption and calculations are provided in Table 7. These calculations assume that the distribution of cereal production (versus other irrigated agriculture) is evenly distributed across each irrigation district. All irrigation water comes from the Bow River Basin, none from the Red Deer River Basin.

Table 7. Calculation of total irrigated cereal crops in the Bow River Basin

Irrigation District	Total Cereal Irrigation Area [acres]	Fraction in BRB	Total Irrigated Land Growing Cereals in the BRB [acres]
BRID	98,396	0.5	49,198
EID	88,776	0.5	44,388
WID	26,953	0.5	13,477
Total	**214,125**	**Total**	**107,063**

Based on a paper published in the Canadian Water Resources Journal, the average net irrigation water requirement for cereal crops can be calculated using the values summarized in Table 8.

[77] Ibid.
[78] Ibid.

Table 8. Summary of crop water requirements for various cereal crops in southern Alberta[79]

Cereal Crop	Average Net Irrigation Requirements [mm]
Barley	200
Hard Wheat	261
Soft Wheat	270
Average	**244**

Therefore, the total average net irrigation required to irrigate 107,063 acres of cereal crop land is:

$$107{,}063\ acres \times \frac{4{,}046\ m^2}{1\ acre} \times 244\ mm \times \frac{1\ m}{1{,}000\ mm} = \mathbf{105,694,670\ m^3\ or\ 85,688\ acre-feet}$$

5.4.2. Part 2: Basin-wide irrigation demands

The FAO estimates global food production is expected to increase by 70 to 100% by 2050[80]. According to a recent report[81], "Canada is one of five countries that can meaningfully increase its food exports to help feed the world's growing hunger." An extreme scenario could involve the Bow River Basin using the majority of its irrigated land to produce cereal crops as food for the growing population. The total irrigation district land in the Bow River Basin is approximately 324,000 acres[82] (half the total area of the three Bow River Basin districts). If all of the irrigated land in the Bow River Basin were needed to grow cereal crops, this would require the following net amount of irrigation water:

$$Total\ Irrigation\ Land\ in\ BRB \times Average\ Cereal\ Net\ Irrigation =$$

$$324{,}000\ acres \times \frac{4{,}046\ m^2}{1\ acre} \times 244\ mm \times \frac{1\ m}{1{,}000\ mm} = \mathbf{319,860,576\ m^3\ or\ 259,316\ acre-feet}$$

Therefore, if all of the irrigated land in the Bow River Basin were used to grow cereal crops, the total average net irrigation water required would be around 260,000 acre-feet.

5.4.3. Combining Part 1 and Part 2

The area of irrigated land can be converted into the amount of cereal crops produced by using the following yield data published by Alberta Agriculture[83] (Table 9).

[79] Bennett, D. R., Harms, T. E., & Entz, T. (2014). Net irrigation water requirements for major irrigated crops with variation in evaporative demand and precipitation in southern Alberta. Canadian Water Resources Journal/Revue canadienne des ressources hydriques, 39(1), 63-72.
[80] Molden, D. (ed). (2009). Water for Food Water for Life. A Comprehensive Assessment of Water Management in Agriculture. IWMI and Earthscan, London. 2007. Also UNESCO. Water in a Changing World: The United Nations Water Development Report 3. Earthscan, London.
[81] Schreier, H. & Wood, C. (2013). Better by the drop: Revealing the value of water in Canadian Agriculture. Prepared for the Blue Economy Initiative. Link: http://www.cwn-rce.ca/assets/resources/pdf/Blue-Economy-Initiative/BEI-Better-by-the-Drop-report-EN-web.pdf
[82] Personal correspondence with Richard Phillips from the Bow River Irrigation District. February 29, 2016.
[83] " Yield Alberta 2015." Alberta Agriculture. Accessed February 2016. https://www.afsc.ca/doc.aspx?id=7883

Table 9. Summary of crop productivity of irrigated cereal crops[84]

Crop	Productivity per acre irrigated land [bushel/acre]	Productivity per acre irrigated land [tonne/hectare]	Weighting Factor
Wheat irrigated	71	4.77	0.74
Barley irrigated	82	4.41	0.23
Oats irrigated	80	3.05	0.02
Weighted Average	**-**	**4.65**	

*****Weighting factor calculated based on irrigated land use reported in Alberta Irrigation Information Booklet**[85]

Other ratios/figures required for the previous calculation are as follows:

- The average caloric value of cereal crops based on data from the FAO online database is 1,644 kcal/kg [86].
- According to the World Food Programme[87], the average daily caloric intake needed to lead a healthy life is 2,100 kcal/cap/day.
    - Example: Calculate how many people could have their daily caloric intakes satisfied with 609,325 tonnes of cereal crops.

$$\frac{609{,}325{,}000\ kg \times 1{,}644\,\frac{kcal}{kg}}{2{,}100\,\frac{kcal}{cap.day} \times 365\ days} = 1{,}306{,}888\ people$$

Note: The productivity (tonne per acre) numbers for irrigated land are extremely low. Preferred units would be Mg or tonnes per hectare. Maximum potential yield for wheat is 7.8 Mg ha^{-1} and for barley is 7.3 Mg ha^{-1} in southern Alberta (Bennett and Harms, 2011)

[84] Ibid
[85] "Alberta Irrigation Information 2014." Alberta Agriculture and Forestry. Accessed February 2014. http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr7401/$FILE/altairriginfo2014.pdf
86 "The Green, Blue and Grey Water Footprint of Crops and Derived Crop Products." Hoekstra, A.Y. & Mekonnen, M. M. (UNESCO Institute for Water Education). Published 2010. Link: http://waterfootprint.org/media/downloads/Report47-WaterFootprintCrops-Vol1.pdf
[87] "What is Hunger?" World Food Programme. Accessed February 2016. https://www.wfp.org/hunger/what-is

5.5. Energy water demand estimations

The energy case study is based on meeting the electricity demand of the growing population in the Calgary Regional Partnership (CRP), which comprises nearly all major population centres in the Bow River Basin. The population in the CRP is expected to grow to around 1.6 million people by 2030. This is based on the assumptions that population growth will be linear and will occur as forecasted by the CRP Regional Water and Wastewater Servicing Masterplan[88]. The latter population forecast was developed by CH2M HILL in collaboration with CRP members in 2012 and were again updated in 2014. It should be noted that these population estimates are the same as those used in the calculation of municipal water demand and throughout the Nexus project (Sections 5.2 and 5.3).

For this case study, it is assumed that there is no coal production in the Bow River Basin, which is supported by the fact that there are no active coal mines in the Bow River Basin[89]. Therefore, water consumption due to coal extraction is assumed to be insignificant in the basin. It is assumed that natural gas extracted for electricity production is produced from shale gas using hydraulic fracturing. However, since the amount of hydraulic fracturing activity in the basin is minimal, this natural gas is assumed to come from outside of the basin, from resource plays such as the Montney and Duvernay. Therefore, water consumption due to natural gas extraction is assumed to be insignificant in the basin.

In November of 2015 the Alberta government announced their Climate Leadership Plan, which focuses primarily on phasing out coal completely by the year 2030 through a transition to more renewable energy and natural gas generation. When coal-fired generation is phased out, the Bow River Basin could expand natural gas generation to compensate for the loss. Alternatively, coal facilities outside of the basin may be replaced with natural gas facilities, in which case electricity would continue to be imported into the BRB.

Based on data from AESO[90], the 2013 average electricity load was 2,224 MW, serving a population of 1,691,000 people. This data is for the Southern Alberta region, of which the main population centre is Calgary. Using these values, the per capita load is 1.32 kW per person, which is assumed to stay constant in the future. Assuming a 2030 population of around 1.6 million people in the CRP region (assumption 1), combined with the per capita load of 1.32 kW per person (assumption 6), it is assumed that in 2030 a total generation capacity of 2,090 MW will be needed.

ENMAX has two major facilities in the Bow River basin: Shepard Energy Centre[91] and Calgary Energy Centre[92]. Based on information provided by ENMAX, both facilities are combined cycle facilities, which require significant amounts of water for cooling. Taken together, these facilities can produce 1,120 MW. It is assumed that these two facilities represent the majority of natural gas generation capacity in the basin and will be capable of meeting 54% of the 2030 demand (see above for details). It is assumed that the remaining 2030 generation capacity not met by Shepard Energy Centre and Calgary Energy Centre will be met by renewables, such as hydroelectric and other electricity generation methods including new or

[88] "Regional Water and Wastewater Servicing Masterplan." CH2M HILL on behalf of the Calgary Regional Partnership. Published 2014. Link: http://calgaryregion.ca/dam/Website/reports/General/Regional-servicing-and-CMP-Implementation/Regional-Water-and-Wastewater-Servicing-Master-Plan/Regional%20Water%20and%20Wastewater%20Servicing%20Master%20Plan.pdf

[89] "Coal and Mineral Development in Alberta – 2014 Year in Review." Alberta Energy. Accessed February 2016. http://www.energy.alberta.ca/minerals/pdfs/Coal_and_Mineral_Development_in_Alberta_Year_in_Review_-_2014_(CMD_YR-04).pdf

[90] "Alberta Electric System Operator 2014 Long Term Outlook." AESO. Accessed December 2015. http://www.aeso.ca/downloads/AESO_2014_Long-term_Outlook.pdf

[91] "Shepard Energy Centre." ENMAX. Accessed February 2016. https://www.enmax.com/generation-wires/generation/natural-gas-powered/shepard-energy-centre

[92] "Calgary Energy Centre." ENMAX. Accessed February 2016. https://www.enmax.com/generation-wires/generation/natural-gas-powered/calgary-energy-centre

expanded natural gas facilities. This is estimated to be approximately 485 MW annually. In addition, it is assumed that by 2030 two thirds of current coal-fired generation will be converted to renewables or other lower-emission forms of natural gas generation. The 2030 electricity generation capacity not already met by Shepard Energy Centre and Calgary Energy Centre, or renewables/hydro/other, is approximately 485 MW (i.e., 23% of total 2030 load), and is assumed to be met by expanding combined cycle natural gas generation..

Assuming a 2030 population of around 1.6 million people in the CRP region (assumption 1), combined with a per capita consumption of 32,543 kWh (assumption 13), it is assumed that in 2030, total consumption in the CRP will be 51,719 GWh, 23% of which will be met by natural gas expansion (assumption 11). In other words, 12,003 GWh, will need to be met using combined cycle natural gas expansion.

Based on industry data[93], the consumptive water use for combined cycle generation is assumed to be 0.43 m^3 per MWh. Therefore, to produce 12,004 GWh of electricity with combined cycle generation (assumption 13) would require around 5.2 million m^3. In other words, meeting increased electricity demand due to population growth in the CRP region by expanding natural gas facilities in the BRB could require 5.2 million m^3 of water.

The premise of this case study is to quantify the consumptive water use that would be associated with expanding natural gas electricity generation in the Bow River Basin. Natural gas expansion is anticipated, in order to replace coal-fired capacity, and to satisfy the electricity demand of the growing population.

Based on data from AESO[94], the 2013 average load was 2,224 MW, serving a population of 1,691,000 people. This data is for the Southern Alberta region, of which the main population centre is the City of Calgary. The per capita load can be calculated as follows:

$$Per\ Capita\ Load = \frac{2{,}224{,}000\ kW}{1{,}691{,}000\ ppl} = \mathbf{1.32\ \frac{kW}{cap}}$$

It is assumed that this ratio of 1.32 kW/cap stays constant in the future.

From the municipal case study, the 2030 population is expected to be 1,589,247. Therefore, the 2030 Average Load can be calculated as follows:

$$2030\ Average\ Load = 1{,}589{,}247 \times 1.32 \frac{kW}{cap} = \mathbf{2,090\ MW}$$

Based on data from AUC[95], per capita demand of electricity in Alberta is 32,543 kWh/cap which includes residential, commercial, and industrial consumption. From the municipal case study, the 2030 population is expected to be 1,589,247. Therefore, the 2030 demand for electricity can be calculated to be 51,719 GWh. Of this demand, 23% (12,003 GWh) will need to be met using natural gas expansion. Assuming a consumptive water use of 0.43 m^3/MWh [96], the total volume of water needed for cooling a new/expanded natural gas facility will be 5,161,249 m^3. In other words, to meet increased electricity demand due to

[93] "Water Conservation, Efficiency, and Productivity Plan – Electric Power Generation." Atco Power, Capital Power, and TransAlta, compiled by Golder Associates, information from AESO, ERCB, and AESRD. Published August 2012. Link: http://environment.gov.ab.ca/info/library/8682.pdf
[94] "Alberta Electric System Operator 2014 Long Term Outlook." AESO. Accessed December 2015. http://www.aeso.ca/downloads/AESO_2014_Long-term_Outlook.pdf
[95] "Customer Usage Estimates." Alberta Utilities Commission. Accessed February 2016. http://www.energy.alberta.ca/electricity/682.asp
[96] "Water Conservation, Efficiency, and Productivity Plan – Electric Power Generation." Atco Power, Capital Power, and TransAlta, compiled by Golder Associates, information from AESO, ERCB, and AESRD. Published August 2012. Link: http://environment.gov.ab.ca/info/library/8682.pdf

population growth in the CRP by expanding natural gas facilities in the BRB will require 5,161,249 m^3 of water. The results of the previous analysis are summarized in Table 10.

Table 10. Summary of variables and values used for the electricity demand estimations

Calculation Variable	**Value**
2013 Average Load (MW)	2,224
2013 Population	1,691,000
Per Capita Load (kW/capita)	1.32
2030 Population in CRP	1,589,247
2030 Average Load (MW)	2,090
Shepherd Energy Centre + Calgary Energy Centre (MW)	1,120
Deficit (MW)	970
Deficit (%)	46%
Renewables/Hydro/Other + 2/3 Coal (%)	50%
Deficit for Natural Gas (MW)	485
Average Per Capita Demand (kWh)	32,543
Total Demand (GWh)	51,719
Deficit of Total Demand (GWh)	24,006
Deficit for Natural Gas (GWh)	12,003
Cooling Water Demand (m3/MWh)	0.43
Total Water Demand (m3)	**5,161,249**

5.6. Other consumption estimates

There are a range of other consumptive water uses in the BRB, as described in AMEC (2009) and other reports. An estimate of the contribution to total consumption has been calculated as the difference between total actual consumption for 2030 estimated for BRB in AMEC (2009) and the sum of the initial-estimated municipal, electrical, and agricultural net consumption. As such, the estimated value is 235,871,153 dam^3 yr^{-1}. It should be noted that an upper and lower limit for total BRB actual 2030 consumption was provided in AMEC (2009) and the higher of these two values was used in the above calculation.

5.7. Comparison of basin-scale estimates and refinement for the simulation

As was mentioned in Section 5.1, it was necessary to validate the sector-based calculations for communities, energy, and agriculture against other calculations at the scale of the Bow River Basin. Each of the case study subsections above presented comparisons for individual-scale estimates, however, it was necessary to determine how these numbers scaled-up to the BRB. Table 11 provides a summary of the basin-scale estimates (per-capita water consumption x 2030 population) as calculated in the Nexus project compared to AMEC (2009) for 2030.

Table 11. Comparison of Nexus and AMEC (2009) water demand estimates for the analysed Sectors in the BRB

Sector	Per-Capita Estimated Demand	AMEC (2009) 2030 (m^3)	Case Study based Consumptive Water Demand in 2030 (m^3)
Municipal	63	68,901,000	36,544,735
Electricity	38	20,137,000	22,239,112
Agriculture	Initially 228 but refined to 1,875 when AMEC was rendered as a per-capita value	1,087,530,000 (All agricultural water consumption)	132,257,135 (irrigated field crops only)

Evident from Table 11, the estimates for the municipal and electricity demands were comparable and within the same order of magnitude. Agricultural consumption was however significantly lower owing to the different assumptions and components of agricultural production considered within each study. Given the large discrepancy in the agricultural estimates, ultimately the AMEC (2009) value was used in the Nexus Interactive Simulation, as it captured a fuller range of the sector's consumption. The differences in the other sectors are also a reflection of varying assumptions within each study's calculation.

6. Showing convergence of consumption

Figure 6 presents a summary of the use estimates, in addition to protected and allocated water in the Bow River Basin based on the calculations highlighted throughout this report. Thresholds for water conservation and total allocations are also shown. Based on this figure it is evident that only in wet years do water conservation objectives approach being met. It is also evident that in dry years, total allocations approach the total water available in the river. This is particularly concerning, as drier years are likely to become more frequent due to climate change. It is evident in Figure 6 that the difference in consumption between wet and dry years was not factored in to the Nexus analysis. Water demand is typically higher in drier years, as precipitation does not provide the water needed in in many sectors. As such, water resources could be under even greater stress in these periods if demand is not managed proactively.

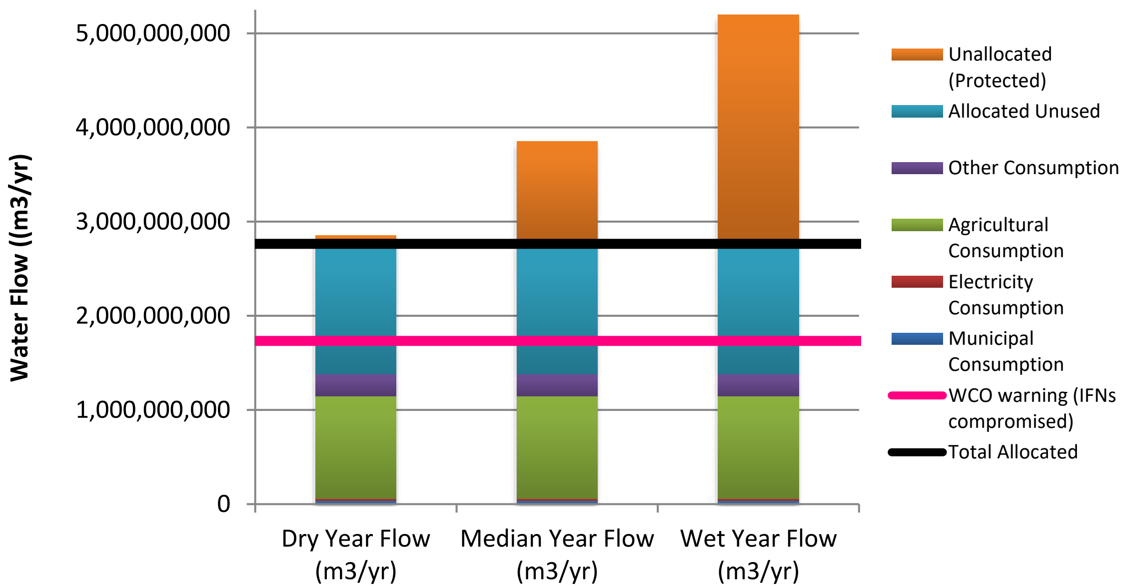

Figure 6. Comparison of initial starting values for different conditions in the Bow River Basin as represented in the Interactive Simulation

7. Future research

Moving forward, there are exciting opportunities and pathways for the Nexus Concept to continue in Alberta. These opportunities include:

- Continuing to develop data in the Bow River Basin to create a more accurate future picture of the convergence of demands.
- Continuing to update water supply forecasts considering the impacts of future climate change.
- Applying the Nexus Concept to other basins in the Province.
- Applying the Nexus Concept to other sectors in the Province.
- Developing more simulations for the public to use.
- Create an educational module for decision-making that introduces the Nexus and trade-off decision-making.
- Ground the research in economic data and analysis of on-the-ground impacts to job growth, GDP, and trade can also show the far-reaching role of Alberta's water resources.

In pursuing these opportunities and pathways, the Nexus Concept can be applied to more geographic locations and circumstances to show how interconnected our water resources and sector developments are both within Alberta and throughout the world.

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