Development of a Framework for Assessment of Water-Energy Demand and Supply in Energy Sector

by

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Abstract

Water resource planning and management has become more challenging over the years. To make well-informed long-term system planning decisions, policy makers and resource managers need to fully comprehend the water-energy nexus. There is a scarcity of tools for integrated assessment of greenhouse gases and water footprints for various energy demand and supply scenarios. The overall aim of this research is to develop a framework to address this gap and use this developed framework for the Province of Alberta. The study includes a general overview of Alberta's water resources (surface and ground water), a brief introduction to energy demand and greenhouse gas (GHG) emissions, water allocation patterns for various demand sectors, and framework development of a model for Alberta's major river basins. The Water Evaluation And Planning (WEAP) software is used as a modeling tool in this study, and the timeframe considered is the 42-year period from 2009 to 2050. Based on current water, energy, and economic dynamics, different scenarios were developed for various sectors. The WEAP model evaluates the water demand and supply based on a sector-wise forecast. It analyzes the patterns of water demand and the effects on the health of the water resources for the future economic developments in the regions. Its integration with the Long-range Energy Alternative Planning System (LEAP) model is also assessed. The LEAP-WEAP integrated scenarios for Alberta provide a customized water-energy analysis on the basis of river basins. The output results from the model provide insight into varying patterns of water demands for different sectors under several scenarios, the return flows and consumption, unmet demand, and reliability of the supply source to meet the future needs along with the level of GHG emissions.

The model estimates that the percentage reduction of the total amount of water in the Athabasca River region is 9.27% (both surface and ground water resources inclusive) in 2050 if the oil

sands expansion continues at the current water withdrawal level. The Bow River will undergo a 0.65% flow reduction, and the Peace River Basin will see smaller reductions in overall flow of 0.37%. The water return will drop with the increase in water-demanding activities over the forecast period till 2050. The integrated LEAP-WEAP results indicated that the in-situ is a less water intensive but more emissions intensive method of bitumen recovery than surface mining. In the integrated LEAP-WEAP power generation scenario, GHG emissions and water demand from 2009 to 2050 are reduced by around 50% and 65%, respectively. These different scenario outcomes can help the decision makers in understanding the water-energy nexus in a quantifiable way and to formulate policies or make strategic investment decisions towards sustainable development. The results also highlight the energy demand sectors that need attention because of their high GHG emissions and water demand.

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List of Abbreviations

AESO	Alberta Electricity System Operator
AMEC	AMEC Earth and Environmental Inc.
BCM	billion cubic meters
bpd	barrels per day
CAPP	Canadian Association of Petroleum Producers
CERI	Capital Environmental Resource Inc.
CO_2	carbon dioxide
CSS	cyclic steam stimulation
dam^3	cubic decametre
EG	ethylene glycol
ERCB	Energy Resources Conservation Board
ESRD	Environment and Sustainable Resource Development
EUB	Alberta Energy and Utilities Board
GDP	gross domestic product
GHG	Greenhouse gas
GIS	geographic information system
ha	hectare
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram
KJ	kilojoule
km^2	square kilometer
LEAP	Long-range Energy Alternatives Planning
l/kg	liter per kilogram
lpcd	liter per capita per day

l/KWh	liter per kilowatt hour
l/ton	liter per ton
m^3	cubic meter
m^3/kg	cubic meter per kilogram
m^3/t	cubic meter per ton
MCM	million cubic meter
Mm^3	million cubic meter
MMSCFD	million standard cubic feet per day
mtpd	million tons per day
MW	megawatt
NEB	National Environmental Board
NGCC	natural gas combined cycle
NGL	natural gas liquids
SAGD	Steam Assisted Gravity Drainage
TED	Technology and Environment Database
TPH	tons per hour
t/y	ton per year
WEAP	Water Evaluation And Planning
WSC	Water Survey of Canada

Chapter 1: Introduction

1.1 Background

Water sustains life, so it is more than simply a resource available on earth. Water is said to be the "oil of 21st century" or "liquid gold." United Nations studies show that two-thirds of the world will be water-poor by the end of 2025 [1]. The agriculture sector, worldwide, accounts for 70% of all freshwater consumption, compared to 20% for industry and 10% for domestic use or direct human consumption. However, around or more than 50% of the water available for human consumption is used by industrial demand sector in industrialized nations [2]. Freshwater use have increased threefold over the last 50 years and the demand is rising at a rate of approximately 64 billion cubic meters (BCM) a year. It is expected to increase further due to projected increase in population and growth in energy demand [3].

Water, an important resource, needs adequate attention. Water resource planning and management has become more challenging than in previous years. Concerns around water such as diversions, conservation, quality, and policies for sustainable water use have increased with rising demand for water. Effective alternate plans for water management are required to mitigate the likely future water issues.

1.1.1 Sectorial water distribution in Canada – An overview

Water is an essential resource that drives Canada's economy. Water is required for cooling purposes in many industrial processes. Water is used in irrigation, chemical processes, cleaning, and many other purposes. Water is also used in thermal power generation for cooling and to produce steam to drive the turbines and generate electricity. 85% of Canada's population resides within 300 kilometers of the southern border but around 60% of Canada's freshwater flows to the northern drainage basins [4]. Most of the water used in Canada is for hydroelectric power generation, which is a non-consumptive use of water. Besides hydro-power, the percentages of water used in other sectors are: thermal power generation (64%), manufacturing (14%), municipalities (10%), agriculture (9%), and mining (1%). The amount of water that is returned by these sectors varies significantly. For example, the water return from the agriculture sector is less than 30%. This sector returns the least amount of water and hence is considered to be the largest water consumer in Canada [5]. On provincial basis, the agriculture sector in British Columbia, Alberta, and Saskatchewan are the largest water consumers. The reason is that the amount of water in these regions is naturally low and irrigation systems are implemented widely to improve crop growth with very little water returning to its source after being used [6].

Around 38 BCM of water from surface and ground sources were withdrawn in Canada in year 2009 [6]. The water withdrawn by the thermal power generation sector was the highest among all the industrial sectors that year. The municipal and manufacturing sectors held the second and third positions in overall water withdrawal. Most of the water withdrawn is not consumed and is returned back to the source. About 3.4 BCM of water were used by all the water demand sectors in 2009. The agriculture sector used 2 BCM, or 84%, of the total water withdrawn from water supply sources [6]. The total water diversions from various sectors decreased from 41 BCM in 2005 to 38 BCM in 2009 (Figure 1). Water consumption that year decreased slightly from 3500 MCM in 2005 to 3400 MCM. Figure 1 shows significant reduction in water withdrawal (up to 33%) and consumption (up to 45%) in the manufacturing sector from 2005 to 2009. The major reason for this was the drop in manufacturing production [6].

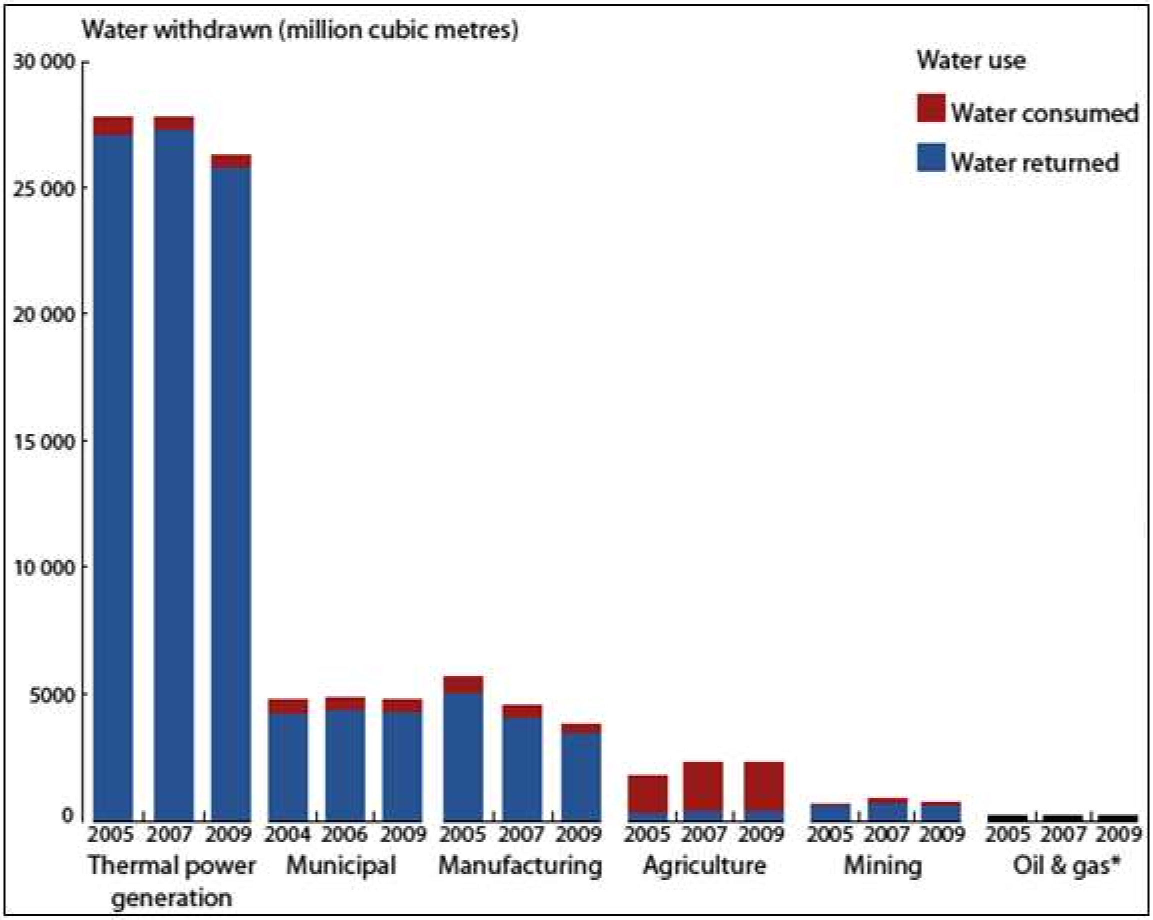


Figure 1: Water withdrawal by different sectors in Canada from 2005 to 2009 [6]

(Courtesy: Environment Canada)

1.1.2 Water network in Alberta – An overview

Alberta is the fourth largest province of Canada. The soaring oil and gas industry has made Alberta's economy one of the most influential in Canada [5]. The economic development share of different provinces in Canada is not uniformly distributed. Ontario, followed by Quebec and Alberta, accounts for more than 50% of the GDP share of Canada, as can be seen in Figure 2 [7].

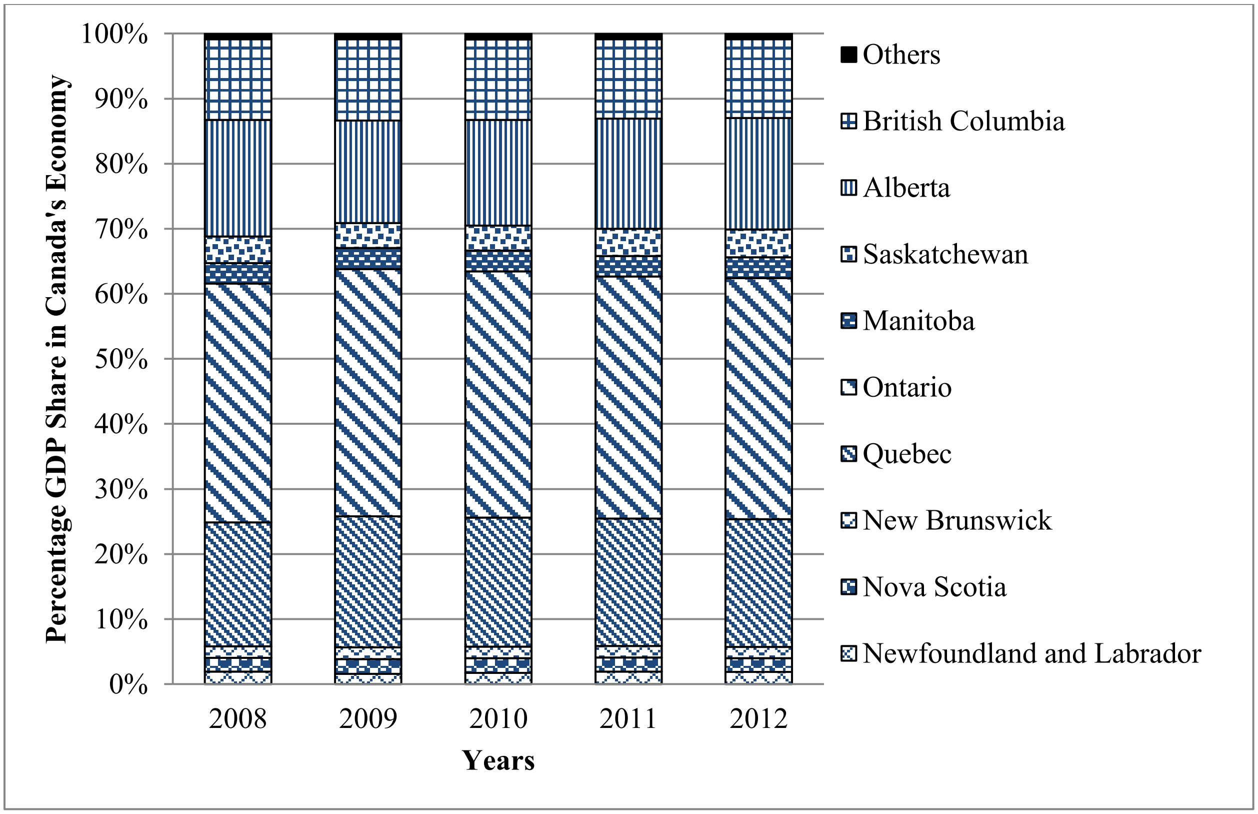


Figure 2: GDP contribution of different provinces in Canada

During the two decades from 1992 to 2012, Alberta showed the highest GDP growth rate in Canada, i.e., 3.6% every year. Alberta's economy grew by 3.8% in 2012. Many private sector forecasters predict that the province will continue to lead the country in economic growth over the long term. The energy sector is the key driver of Alberta's economy; it took about one-fifth of the province's GDP share in 2012 [8].

Alberta's energy sector includes the oil sands. Of 173 billion barrels of oil reserves in Canada, 170 are found in Alberta and around 168 of these are extracted from bitumen [9]. More water diversions will be required to meet the needs of this growing economy.

Northern Alberta has many rivers and lakes whereas southern Alberta has low-volume rivers and a small number of lakes. Alberta also has a large amount of ground water available either in aquifers or buried channels. Ground water is usually present in cavities or spaces between unconsolidated material (gravel or sand) or consolidated material (conglomerate or sandstone). The water from lakes, rivers, and wetlands falls under the category of surface water [10].

Alberta has seven main river systems: the Peace, Athabasca, Hay, North Saskatchewan, South Saskatchewan, Beaver, and Milk [11]. These river basins make up about 2.95% of Canada's water resources, from which we can infer that Alberta is relatively dry. The water runoff values for the major river basins in Alberta change only a little each year. The annual precipitation values in Alberta vary from 1000 mm to 300-350 mm from the Rocky Mountains to the eastern border of the province [12]. Some of these river basins are further divided into sub-basins; for instance, the South Saskatchewan River Basin comprises the Red Deer, Bow, Oldman, and South Saskatchewan sub-basins. There are seventeen identifiable river basins in Alberta [13]. Water resources are not uniformly distributed throughout the province (see Figure 3). Most water basins are located in the low demand areas of the Peace River Basin in northern Alberta.

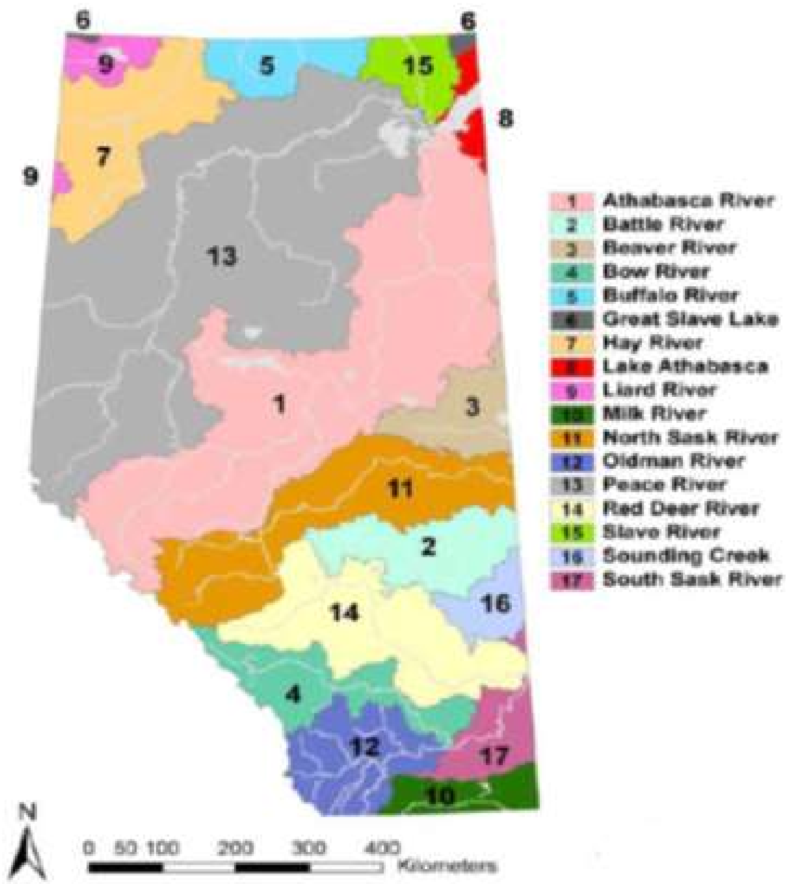


Figure 3: River basins in Alberta, Canada [13]

(Courtesy: Alberta Environment)

Nearly all (87%) of the surface water in Alberta flows north; a small portion (13%) flows east and 0.1% flows south. Interestingly, though the Saskatchewan River has only 13% of the province's water, it fulfils 88% of Alberta's water requirement. As the province's population and economy grow, it becomes increasingly necessary to address and mitigate water management issues that could arise in future [12]. Alberta's six largest rivers are listed in Table 1.

Table 1: Alberta's six largest rivers [5, 13]

Sr. #	Name of the river	Comments	Mean annual natural river discharge in 10^6 m^3	Historical minimum discharge in 10^6 m^3	Historical maximum discharge in 10^6 m^3
1.	Slave	Flows from Alberta to Northwest Territories	107726	83400	155000
2.	Peace	Tributary to Slave	66614	44100	108000
3.	Athabasca	Flows to Lake Athabasca tributary to Slave	22287	15000	34900
4.	Smoky	Tributary to Peace	10958	5910	18500
5.	South Saskatchewan	Flows from Alberta to Saskatchewan	7425	3754	13851
6.	North Saskatchewan	Flows from Alberta to Saskatchewan	7277	4384	12923

Around 97% of water allocations in Alberta are from surface water and the remaining 3% are from the ground water as shown in Figure 4 [5].

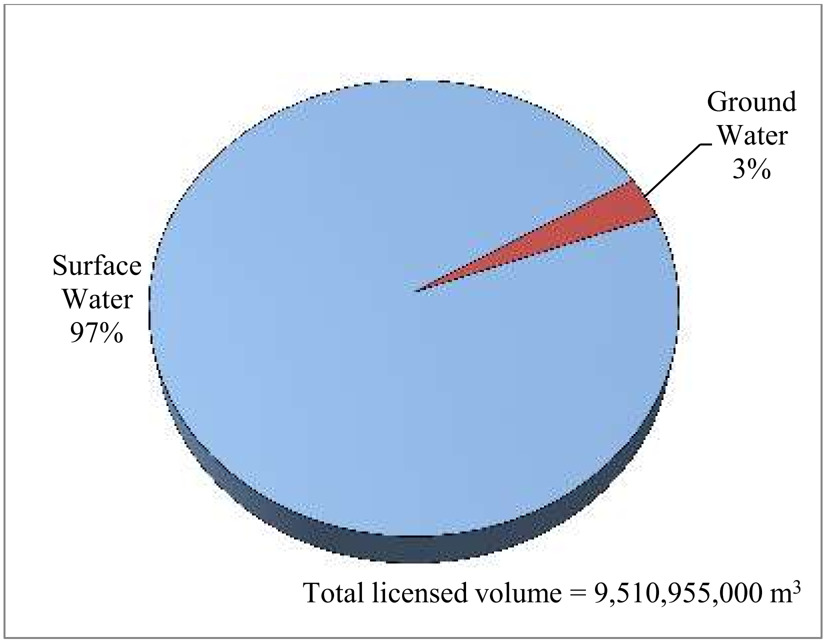


Figure 4: Allocation of water by source in 2005 in Alberta, Canada

Ground water sources, like surface water (e.g., rivers), are not uniformly distributed throughout Alberta. The Paskapoo aquifer is a highly used aquifer in southern Alberta. The Buried Red Deer Valley, a shallow gravel and sand aquifer in central Alberta, yields around 654 m^3/day. The Grimshaw Gravels and Dunvegan Formation aquifers in the Peace River region yield 655 and 165-655 m^3/day [10].

Rain and snow are the factors contributing to Alberta's water supply. The mean annual precipitation received by Alberta is approximately 510 mm; this is equivalent to 336 BCM of water. Of 336 BCM, around 77% is sent back to the atmosphere through transpiration and evaporation, 4.5% recharges the ground water, and the remaining 18% goes to surface run-off [14]. Water from the surface seeping into the ground recharges an aquifer [10].

The Athabasca River had the third lowest surface and ground water allocation of all Alberta river basins in 2005 as shown in Tables 2 and 3 [5].

Table 2: Surface water allocations in Alberta in 2005 [5, 13]

Sr. #	River basin	Allocated volume from surface water sources (Mm^3/year)	Allocated volume as a percent of natural flow (%)	Estimates of consumption contained in licenses (Mm^3/year)	Consumptive allocations as a percent of natural flow (%)
1.	Milk (excluding Pakowk)	39.79	25	38.48	24
2.	South Saskatchewan (including Red Deer)	5424.58	59	4614.15	50
3.	North Saskatchewan (including Battle)	2718.46	36	439.96	5.8
4.	Beaver	49.52	8.1	33.91	5.5
5.	Peace	220.71	0.3	132.83	0.2
6.	Athabasca	716.22	3.2	511.74	2.3
7.	Hay	6.03	0.2	6.03	0.2

Table 3: Ground water allocations in Alberta in 2005 [5]

Sr. #	River basin	Allocated volume from ground water sources (Mm^3/year)	Allocated volume as a percent of natural flow (%)	Estimates of consumption contained in licenses (Mm^3/year)	Consumptive allocations as a percent of natural flow (%)
1.	Milk (excluding Pakowk)	0.94	2.0	0.94	2.0
2.	South Saskatchewan (including Red Deer)	109.79	4.9	76.43	3.4
3.	North Saskatchewan (including Battle)	45.44	3.2	39.02	2.8
4.	Beaver	147.11	8.5	14.53	8.4
5.	Peace	19.32	0.4	16.64	0.3
6.	Athabasca	88.68	2.0	83.00	1.9
7.	Hay	0.89	0.2	0.82	0.2

The high allocation of ground water from the Athabasca River Basin is due to the rapid growth and development of the oil sands sector (including surface mining and in situ). The Peace River Basin is also considered for its in situ activities. Among all the demand sectors of ground water sources, only bitumen extraction (specifically in situ mining) is considered in this study. The Bow River Basin from the sub-basins of the South Saskatchewan River Basin has only around 1.5% of the total water demand met by ground water [15]. The water allocation study on the other sub-basins (Red Deer, Oldman rivers) of the South Saskatchewan River Basin, despite high ground water allocation, is not included in the scope of this work.

The percentage share of surface and ground water allocations for different demand sectors is shown in Figures 5 and 6, respectively. The major surface water consumers are irrigation and commercial cooling. Around 44% and 24% of the surface water was allocated to the irrigation and cooling sectors in 2009 as shown in Figure 5 [10].

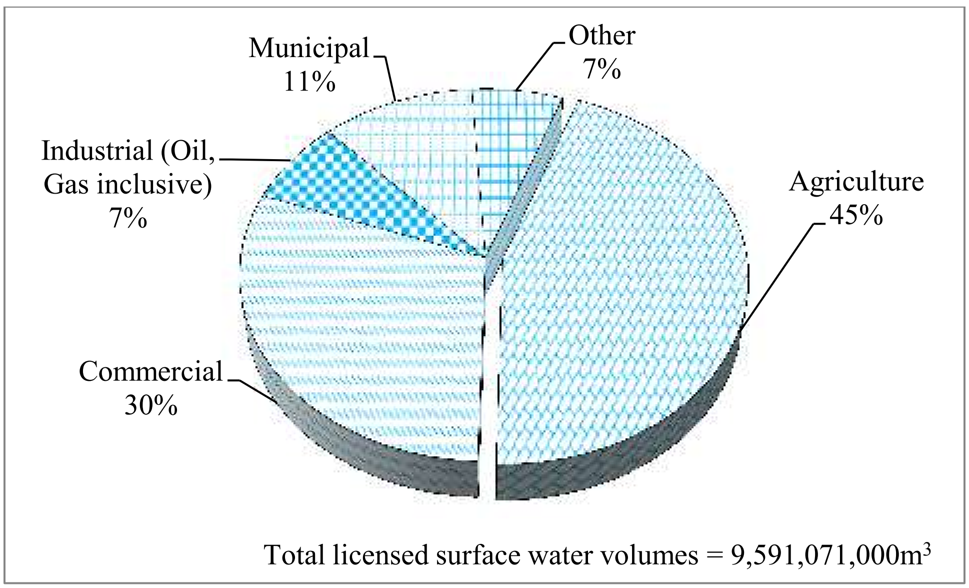


Figure 5: Allocation of surface water in 2009 in Alberta, Canada [10]

The major ground water consumers are the agriculture and oil and gas sectors (as shown in Figure 6). Around 42% of the fresh (non-saline) ground water was allocated to the oil and gas sector (including drilling, injection, and enhanced oil recovery) in 2009 [10]. The use of saline water instead of fresh ground water has increased with the discovery of steam assisted gravity drainage method (SAGD) [16]. Thus, the amount of fresh ground water used in in situ can be reduced. The high concentration of total dissolved solids (TDS) (greater than 4000 milligram/liter [mg/L]) [17] makes saline water unfit for use, therefore, the recycled or saline water in in-situ operations has to be desalinated prior to its use in steam production [18].

The allocation volume of water granted in a license is made up of three parts: consumption, losses, and return flow. Consumption also includes the water lost through evaporation and leakage [5]. So the water allocations, as shown in Figures 5 and 6, do not directly reflect actual use or consumption but rather the maximum amount of water that can be withdrawn from the water body annually.

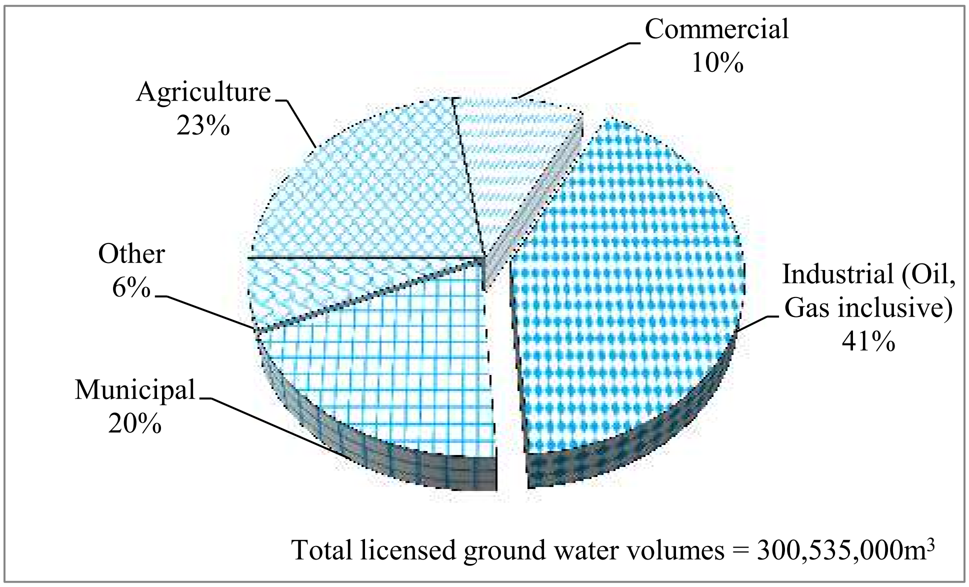


Figure 6: Allocation of ground water in 2009 in Alberta, Canada [10]

1.1.3 River basins

Alberta's water demand is divided into six sectors: municipal, agriculture, industrial, petroleum, commercial, and "other use." The focus of the current study is limited to Alberta's four major river basins: the North Saskatchewan, Bow, Peace, and Athabasca. The Athabasca and Peace rivers are crucial as the oil sand deposits are located in those regions. The North Saskatchewan River is dominated by the industrial sector, so further economic development may lead to some challenges to its water availability. The Bow River Basin has been closed for further water allocations; without additional water licenses, development in that region is a challenge [19] . This study, thus, emphasizes mainly on the above mentioned four river basins.

1.1.3.1 North Saskatchewan River Basin

The North Saskatchewan River Basin covers about 80,000 km^2 of the province of Alberta. The Brazeau, Clearwater, and Sturgeon rivers join the North Saskatchewan River in Alberta, and the Battle River flows into the North Saskatchewan River in Saskatchewan. This river has two large dams, the Bighorn and the Brazeau [10].

The percentage distribution of active water allocations in the North Saskatchewan River Basin is given in Figure 7 [13]. The figure shows that the industrial sector dominates the total water allocation (82%), followed by the municipal (8%) and petroleum (5%) sectors.

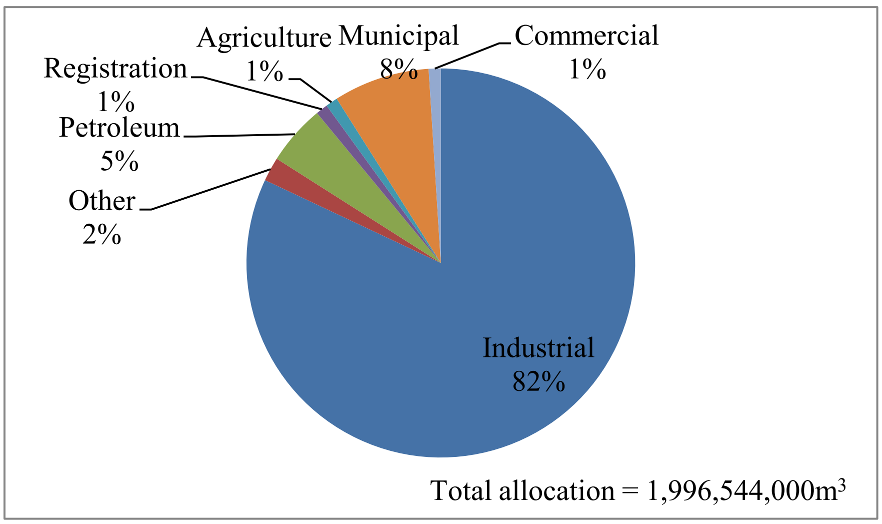


Figure 7: Distribution of water allocation in the North Saskatchewan River Basin [13]

1.1.3.2 Bow River Basin

The combined area of the South Saskatchewan River's sub-basins is 121,095 km^2, 21% of which is from the Bow River [10].

The percentage distribution of active water allocations in the Bow River Basin is given in Figure 8 [13]. The figure shows that the agriculture sector dominates the total water allocation (75%), followed by the municipal (20%) sector.

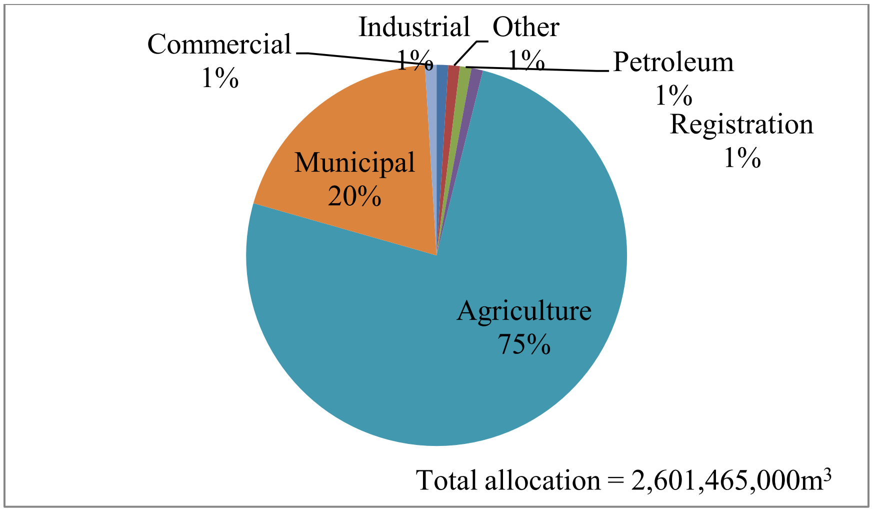


Figure 8: Distribution of water allocation in the Bow River Basin [13]

1.1.3.3 Peace River Basin

The Peace River Basin has a drainage area of 293,000 km^2. Its tributaries include the Wapiti, Smoky, Little Smoky, and Wasbasca rivers [10]. The percentage distribution of active water allocations in the Peace River Basin is given in Figure 9 [13]. The figure shows that the "other" (water management, habitat enhancement) sector dominates the total water allocation (39%), followed by the industrial (37%) and municipal (11%) sectors.

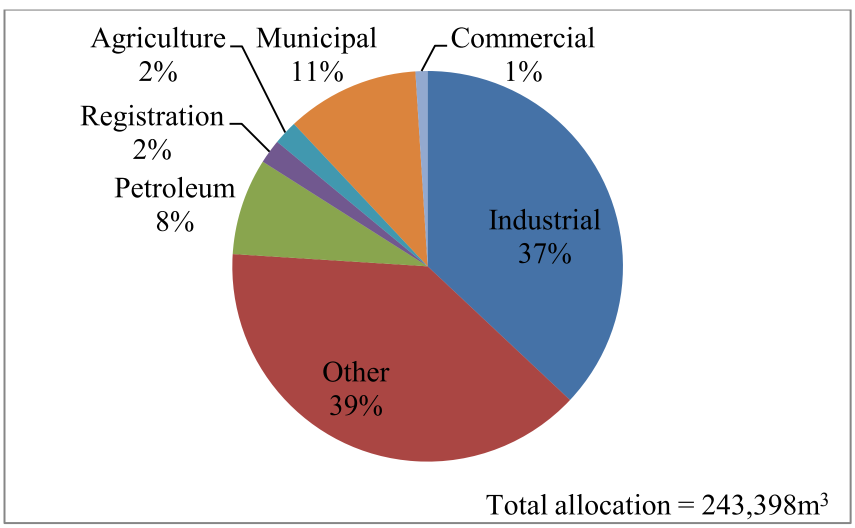


Figure 9: Distribution of water allocation in the Peace River Basin [13]

1.1.3.4 Athabasca River Basin

The Athabasca River Basin covers a drainage area of around 159,000 km^2. The tributaries of Athabasca River include the McLeod, Pembina, Lesser Slave, and Clearwater rivers [10]. There is one dam, the Paddle River Dam on the Paddle River, an indirect tributary of Athabasca River [20]. The percentage distribution of active water allocations in the Athabasca River Basin is given in Figure 10 [13]. The figure shows that the petroleum sector dominates the total water allocation (68%) followed by the industrial (17%) and "other" (7%) sectors.

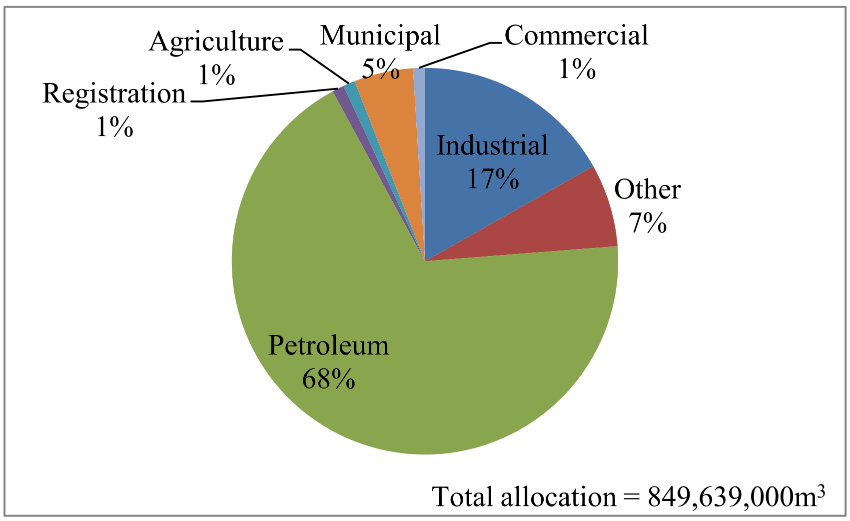


Figure 10: Distribution of water allocation in the Athabasca River Basin [13]

1.1.4 Energy and greenhouse gas (GHG) emissions in Alberta – An overview

The 3rd largest oil reserves of the world are found in Alberta. About 250 million barrels of conventional oil, 5 trillion cubic feet of natural gas, 500 million barrels of bitumen, and 30 million tons of coal are produced in Alberta annually [21]. The province has the capacity to generate more than 12,000 megawatts electricity, and demand is increasing at twice the rate as the rest of Canada [21]. According to Statistics Canada, Alberta is the largest per capita consumer of energy in Canada [21]. Approximately 40% of Canada's emissions are associated with increased economic activity in Alberta; Alberta, therefore, is the highest GHG emitter in the country [21]. Alberta not only emits more GHGs than elsewhere in Canada, it consumes more energy than any other province. There is accordingly considerable pressure for the province to develop energy production pathway that is environment friendly and helps to reduce the carbon footprint [21].

1.2 Research rationale

The water-energy nexus represents the relationship between water required to produce and transfer energy, and energy required to treat water or run various industrial processes [22]. For example, electricity production or industrial methods that highly depend on water (for cooling or making steam) can suffer water constraints that lead to limited energy production. On the other hand, limited energy production may restrict access to the water supplies (i.e., water treatment or transportation) [23]. So the trade-offs between water and energy have significant importance when assessing potential environmental concerns [22].

The ultimate aim of a study based on water-energy nexus is to develop and assist in making the strategies to reduce the vulnerabilities around water and energy, and to mitigate the corresponding GHG emissions. Taking this factor into consideration, a literature review is carried out to reveal that most of the studies neglect to take into account the capability of the water supply/source to satisfy future needs. Moreover, the studies conducted earlier on the water demand-supply issues mostly deal with the water demand by various sectors, water quality or climatic/temperature effects on water. Research on GHG emissions coupled with the water demand and supply is limited as well. The increasing water and energy demands have made it crucial to investigate the water demand-supply balance and water-energy nexus, in depth, to mitigate the future environmental issues and form alternate plans for water management.

A descriptive analysis of sector-wise water withdrawal and use, based on Alberta's river basins, was completed by AMEC Earth and Environmental Inc. in 2007 [13]. This study concentrated mainly on the water withdrawal and consumption from different sectors, and did not emphasize much on the amount of supply resources left after use. The Water Evaluation And Planning (WEAP) model was used in studies by Levite et al. [24] and Mounir et al. [25] on Steelpoort sub-basin in South Africa and Niger River Basin in West Africa, respectively. The studies included evaluation of WEAP as a tool for decision-making in water allocations considering climate variability. The Modular Simulator, MODSIM, was used by Berhe et al. [26] as a water allocation tool for analyzing Awash River Basin in Ethiopia. The study mainly focused on the effects on water balance caused by growth in irrigation sector. Hamlat et al. [27] developed and examined the WEAP model for Western Algerian watersheds. The model was based on different demand side management techniques and policies. WEAP was also used as a forecasting tool by Li et al. [28] and Hollermann et al. [29] to estimate the water resources in Binhai New Area, China and Benin. The work concluded that the rivers will be under more stress in future years because of increasing urbanization, industrialization, and climate change.

Uche et al. [30] investigated the effect of varying demand site priorities on the water demand deficit using AQUATOOL software as a modeling tool. The study estimated the costs associated with water requirement deficits among different demand sectors based on demand site priority. Omar [31] used River Basin Simulation, RIBASIM, to evaluate water challenges faced by Quarun Lake by developing three scenarios (optimistic, moderate and pessimistic). Water demand and supply balance was used to determine the water shortage. According to this study, the water shortage for different scenarios differs because of the varying penetration rates of water efficient technologies and other water management techniques. Eryani et al. [32] analyzed water demand of Bali province by modeling Petanu River in RIBASIM software. The river potential to meet future needs and quality parameters were assessed in the study.

Siddiqi and Anadon [33] reviewed and carried out a quantitative assessment of the water-energy nexus for Middle East and North Africa (MENA region). The production of fuel and electricity along with energy required for water pumping, treatment, distribution and utilization were key focused areas. The study highlighted that the fresh water required specifically for electricity generation is less but the energy demand for water extraction and production is high. Most of the Arabian Gulf countries consume 5 to 12% of the total electricity for water desalination. Hardya et al. [34] estimated the amounts of water use in energy sector (production of biofuels) and energy use in water sector (particularly irrigation) for Spain. The values were calculated based on the water and energy intensities for various processing technologies. Integrated LEAP-WEAP modeling work has also been done in some studies. Such studies have mainly focused on hydro-electricity production [35]. Dubreuil et al. [36] extended the energy optimization TIMES Integrated Assessment Model, TIAM, to form a water-energy nexus. A bottom-up approach was utilized to calculate energy and water demand in Middle East. According to Hamiche et al. [37], the climate change models forecast a decline in rainfall in Algeria by around 20% till 2050.

Consequently, the requirement of the use of water management techniques will grow, raising the energy demand share for water extraction and distribution up to 12% of the total energy consumption. Liu et al. [38] applied the Global Change Assessment Model (GCAM) to form a link between electricity production and water use in the United States of America. The effects of increased electricity demands, different water cooling methods, exploration of water-efficient technologies and climate change were evaluated through this model. The study reported the water demand to decrease by 42 to 91% by 2095 and water consumption to increase by 4.2 to 80%.

The study done by Welsch et al. [39] for the Island of Mauritius emphasized on the addition of value achieved by integrating various modeling approaches. The results obtained from an energy model, Long-range Energy Alternatives Planning (LEAP), and General Circulation (GCM) models were compared with those from an integrated Climate, Energy, Water and Land-use Systems (CLEWS). WEAP water model, the LEAP model and the Agro-Ecological Zones land production planning model (AEZ) were combined to provide integrated results in CLEWS.

Based on the literature review carried out, of which a summary presented above, only a few studies have been conducted on water demand projections, where only a couple of water demand sectors have been considered. Such studies were based on generic assumptions only [10, 13]. Limited water demand-supply forecast modeling studies are available; however, they take into account one or two river sources only. Moreover, those studies have been mainly focused on major water demand sectors of Alberta for water demand projections. Most of the water modeling studies have emphasized on one or two of the dimensions of water demand-supply model (e.g., water withdrawal or consumption or both) [13, 40]. These studies did not consider all the water-related dimensions (e.g. water unmet demand, river flow and demand site coverage). Furthermore, the studies did not provide in-depth scenario development for different sectors. There is also a big gap in studies available on water-energy nexus in terms of GHG emissions. This research addresses the above mentioned gaps.

The present research provides a comprehensive analysis of all the demand sectors as well as the supply resources. This study presents a detailed model for the evaluation of four of Alberta's river basins on the basis of water withdrawal, return flow, water consumption, inflows, and outflows for each sector. The study includes ground water demand and use by in situ operations in the Athabasca and Peace river regions. The research also includes integration of WEAP and LEAP system models for development of energy scenarios. The integrated water-energy model developed for Alberta provides a detailed water-energy analysis based on local rivers and GHG emissions for the expansion of major energy sectors. Such an integrated study can assist industrial sector and policy makers to make responsible long-term decisions related to the interconnections between water-energy use and production for Alberta.

1.3 Objectives of the research

The main objective of this research is to understand water use in Alberta's demand sectors with a focus on the province's four main river basins and to develop different water demand scenarios through WEAP. Specific objectives of this research are:

- To develop a water model using water intensities of various sectors by establishing a water demand tree for Alberta' six sectors (municipal, agriculture, industrial, petroleum, commercial, and "other").
- To develop different scenarios in WEAP for water demand and supply pattern for Alberta's four major river basins for a study period of 42 years (from 2009 to 2050).
- To identify the highest water consuming demand sectors and the effects on the river source for the forecast period if the demand sector's expansion continues.
- To develop an integrated WEAP-LEAP model to estimate the GHG emissions in the petroleum and power sector.

1.4 Overall methodology

The annual activity levels of demand sectors and sub-sectors along with end-use water and energy intensities are input into the modeling softwares WEAP and LEAP. Water consumption, river flows, reservoirs, and return flows are among the other key parameters input into WEAP. Both models work on a demand and supply resource balance. The detailed methodologies are described in Chapters 2 and 4 of the thesis. Figure 11 shows the method used in the study to develop the model for Alberta's four major river basins. The development of the WEAP framework involved the preparation of a reference case scenario for Alberta's demand sectors and supply resources module including the projection of water demand and supply. Then various scenarios were developed in WEAP with low, and high population growths, oil sands expansion, gross domestic product (GDP) growth, power generation development from coal fired power plants to natural gas power plants, and agricultural and livestock population growth as the key variables. These scenarios were compared to the reference case and the water results over the forecast time frame were evaluated. The water-energy nexus diagrams are developed based on the integration of the LEAP and WEAP scenarios results (Chapter 4).

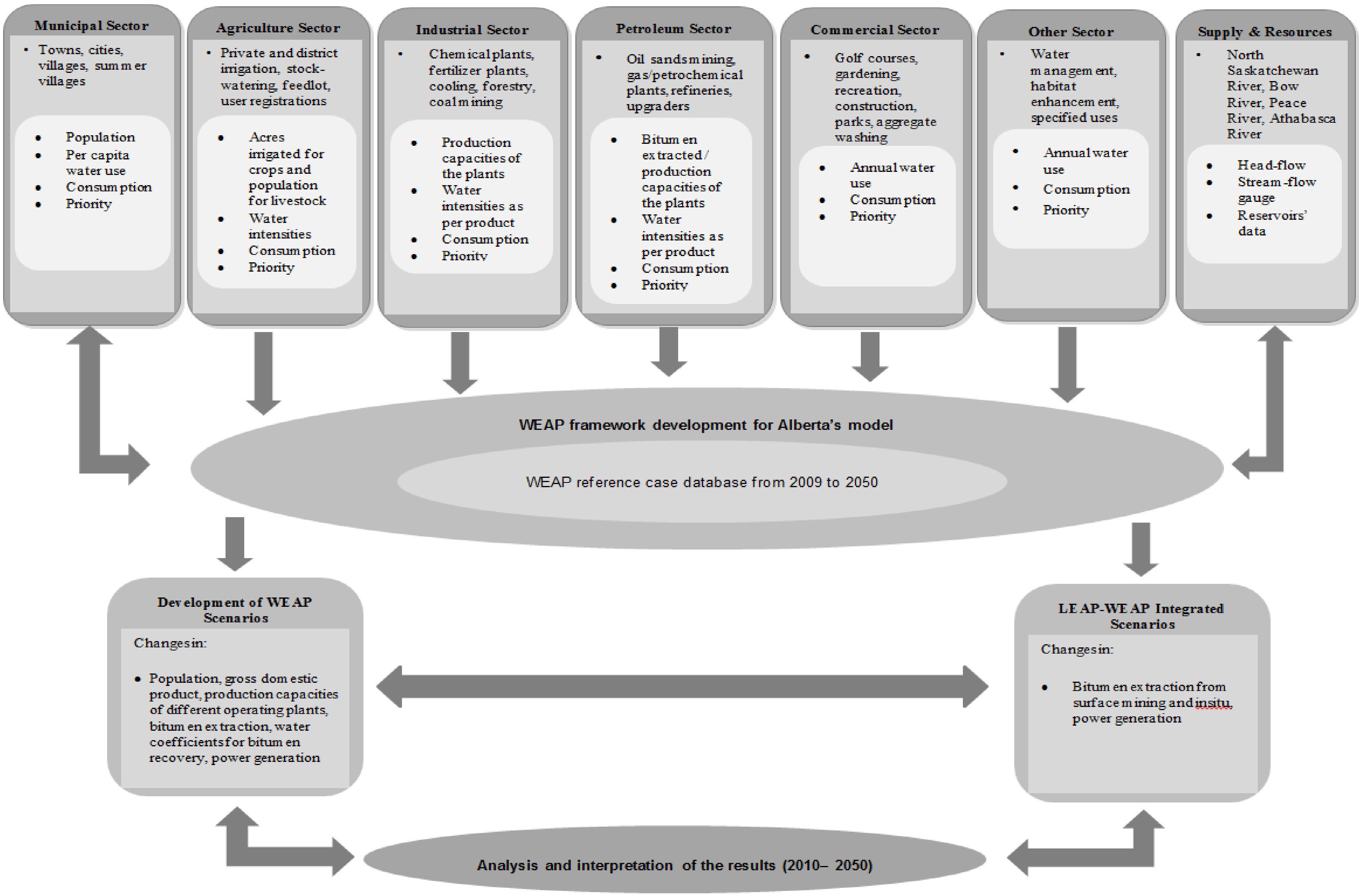


Figure 11: Overall LEAP-WEAP model framework for Alberta

1.5 Limitations of the study

The current study and model are limited to the following factors:

1. Only four rivers, namely, North Saskatchewan, Athabasca, Peace and Bow river basins are considered for the study because of their current critical condition.

2. The forecasting period comprises of 42 years (from 2009 to 2050) with 2009 as base year.

3. The major water demand sectors in the river basins under study have remained the major water customers for the past couple of decades [41]. For example, petroleum (oil and gas) and industrial sectors are the largest water demanding sectors in the Athabasca and North Saskatchewan River Basins for more than a decade [41]. In the light of these facts, the WEAP model is configured to follow the same pattern i.e. main water demand sectors for any river basin stay dominant throughout the forecast period for each river basin under study.

4. Only bitumen extraction (specifically in situ mining) demand sector considers ground water as a supply source to meet its demand. For all other demand sectors, this study considers surface water as the total amount of water in its calculations.

5. Unless specified, the increasing/decreasing trend for annual activities or water coefficients is extrapolated (e.g. Figure A-4 in Appendix A) from the year after which data or forecasts are not available for any demand sector.

6. Data on actual water use by different sectors (e.g. municipal, agriculture, commercial or ‘other’ sectors) is not available due to the lack of reporting of licensees to provincial government through Water Use Reporting System (WURS) [13]. In absence of data, water consumption for a sector is calculated by the available licensed water allocation, water use and return flow. This may overstate the actual water use by the licensees.

7. The only projections available for rivers are based on climate model. In this study, the climatic conditions have not been taken into account for the supply side. Rather, the monthly river flow data (m^3/s) and the reservoir water volume patterns for the last ten years (2001-2011) have been used to develop the supply side. The WEAP option for cyclic repetition of streamflow values has been followed in this research. Thus, the water supply results from the WEAP model are only

true for the above-mentioned particular assumption and may not hold if that assumption is changed (e.g., if climate variability is incorporated).

8. The LEAP-WEAP integration is carried out for two demand sectors only, that are, petroleum and power generation.

9. The parameters of water quality and costs of water saving through demand-side management techniques are not within the scope of this study. Suitable assumptions have been made where data are not available.

1.6 Organization of the thesis

The thesis has five chapters with a table of contents, a list of tables, a list of figures, a list of abbreviations, references, and appendices.

Chapter 1 provides the sectorial water distribution in Canada, water, energy, and GHG emissions' overview for Alberta, objectives, overall methodology and limitations of the scope of this study, and a literature review.

Chapter 2 explains the WEAP-Alberta model structure, input parameters, the key assumptions for each sector on the basis of river basins, and the modeling methodology in detail. This chapter also discusses the validation of the output results of the model for the reference scenario. The results for the reference scenario are given in detail in Chapter 3.

Chapter 3 comprises the various scenarios considered to evaluate changes in water demand patterns for the sectors and the consequent impact on the supply resource based on WEAP-Alberta model. The methodology for developing the scenarios, the input parameters, and the assumptions are described in detail. The approach used to make the scenarios and the results of the scenarios conclude this chapter.

Chapter 4 discusses the development of the LEAP-WEAP scenarios to highlight the integration aspect of these models. This chapter is a continuation of the previous chapter. The water demand results estimated by the WEAP model and coupled with the estimated GHG emissions evaluated by the LEAP model for the power generation and oil sands sectors are presented in this chapter.

Chapter 5 presents the study's conclusions and recommendations for future work with regard to this research.

Appendix A is comprised of WEAP methodology flowcharts and additional tables and figures assisting the scenarios' development in the WEAP model. Appendix B contains the output results of the different modeling scenarios considered.

Chapter 2: Development of Water Demand and Supply Model for Alberta's River Basins

2.1 Introduction

To develop a long-term water planning and forecasting plan, a basic water demand and supply assessment tool is required to predict the demand-source interactions and the effect of different parameter variations over time. The water demand-supply models generally have a demand module that is responsible for keeping all the considered demand sectors and sub-sectors, and a supply module to maintain the supply resources. Some of the water simulation models implemented worldwide include AQUATOOL [42], the Modular Simulator – MODSIM [43], River Basin Simulation – RIBASIM [44], Water Resources Graphical Interface – Simulation – WARGI-SIM [45] , and WEAP [45, 46]. Another emerging water management simulation company is WaterSMART that provides the expertise to integrate various water management strategies [47].

WEAP was selected as the modelling tool to develop the comprehensive Alberta-based water forecasting model in this research, and its rationale is explained in the subsequent sections. On the basis of WEAP, several scenarios were created to compare variation in water demand under different sets of conditions like population, economy growth, and industrial development. This model can be used to study the impacts on water demand by various activity levels carried out in different sectors, to evaluate the water resource potential to satisfy future population and economy expansion, and to set targets to control water consumption by various sectors and enhance water return.

2.2 WEAP software – A modeling tool

The WEAP software – a water-specific planning and modeling tool – was developed by the Stockholm Environment Institute (SEI) [46]. WEAP is an optimization and water allocation tool for integrated water resources planning. Its modeling framework can be used in policy analysis to assess alternative water development and management strategies. In addition, WEAP can be used to balance demand with supply and assists in predicting future water demand and supply in various scenarios of water use. WEAP has been extensively applied in water assessments in many countries, including the United States, Mexico, Brazil, Germany, and Ghana [46].

2.2.1 WEAP modeling methodology

WEAP consists of schematic, data input, results, a scenario explorer, and notes (see Figure 12). Detailed description of each module is given below [46].

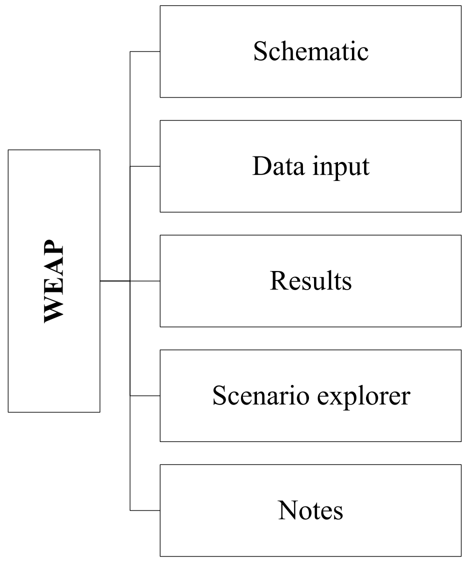


Figure 12: Modeling methodology of WEAP

2.2.1.1 Schematic

A schematic diagram graphically represents the rivers, reservoirs, demand sites, transmission links, return flows and stream-flow gauges. It includes tools to configure the WEAP model easily. Geographic information system (GIS) files can also be imported through WEAP to identify the locations of the river basins, demand sites or reservoirs [48].

For the demand and supply model developed for Alberta, the four main river basins along with their tributaries, location of the stream-flow gauges installed on the course of the rivers, and reservoirs were identified through Google Earth. These GIS/vector files were imported in WEAP to represent the course of the rivers. An example of a WEAP model schematic is shown in Figure 13. This schematic shows the four river basins along with their tributaries (blue lines), the transmission links that are the demand site inflows and outflows (green lines), the location of the stream flow gauges (blue dots), the reservoirs (green triangles), and the demand sites (red dots).

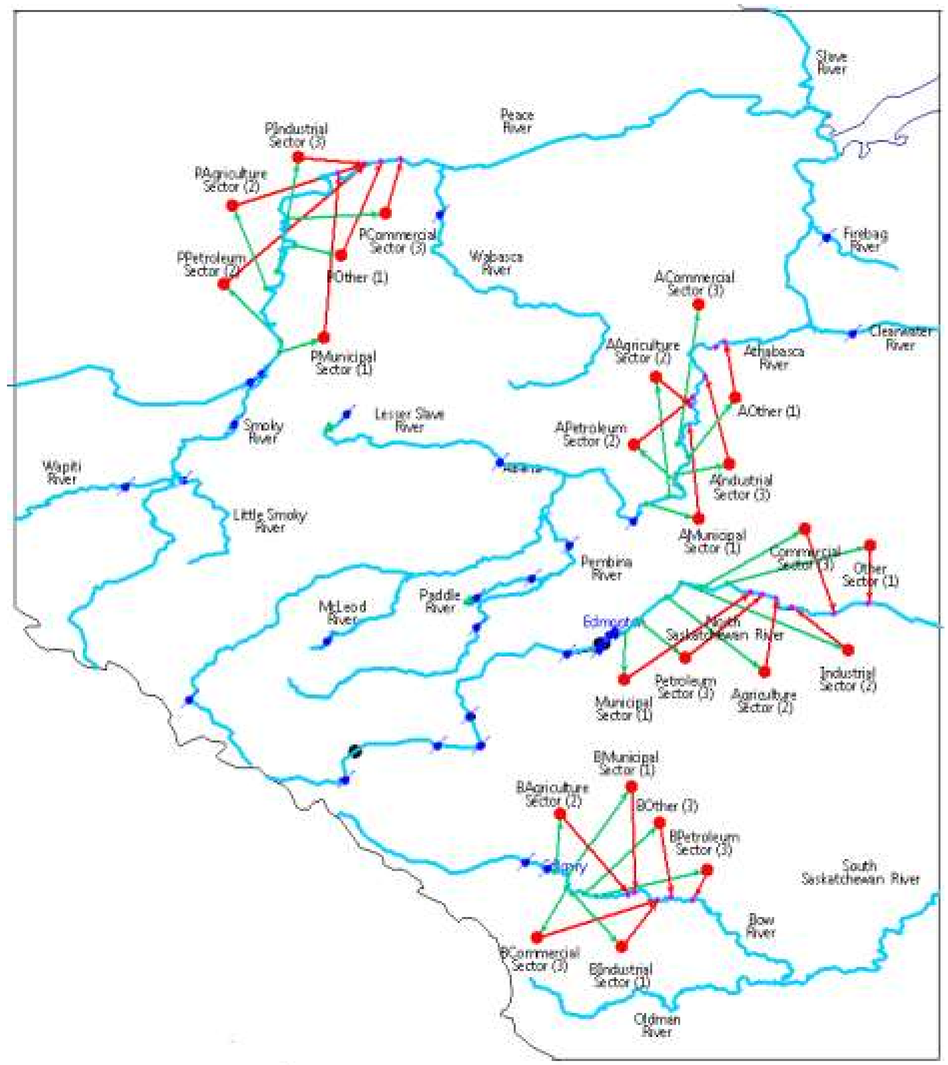


Figure 13: Schematic diagram developed in the WEAP model

2.2.1.2 Data

The data view in WEAP consists of input parameters that are provided to the software. It can build relationships between variables and user-defined assumptions for future projections [48].

Historical data from 2002 to 2009 and in some cases from 2002 to 2012 were used to develop the reference scenario. The base year for this model is 2009 because it is the most recent year for which complete data of annual activities, and water allocation for all the demand sectors under consideration in the WEAP model are available. The details of the data and assumptions made for this model are discussed in detail in the relevant sections of this chapter.

2.2.1.3 Results

WEAP provides a number of results, including water demand, supply requirement, coverage, demand site inflows and outflows, river return flows, unmet demand, reliability of the supply source, demand side management, water cost, water quality, and pollution generation. Coverage indicates the percentage of the water demand met by the supply source. Demand site inflows and outflows represent the total water requirement, use, and consumption of the demand sector under consideration.

2.2.1.4 Scenario explorer

WEAP evaluates scenarios by varying key input parameters to examine the effects on overall water demand results. The details of the scenario explorer and results obtained for various scenarios developed in WEAP for the Alberta model are discussed in detail in Chapters 3 and 4.

2.2.1.5 Notes

The Notes option in WEAP can be used to documents conversions, assumptions, and other miscellaneous information [48].

2.3 Alberta – WEAP framework development

The WEAP model is built considering the demand and supply side of all the water consumers in a river basin. The water consumers were divided into six major sectors for each river basin: the municipal/residential, agriculture, industrial, petroleum, commercial, and “other.” The municipal sector is made up of urban, rural and aboriginal municipalities; the agriculture sector accounts for feed lot, stock-watering, and private and district irrigation; and the industrial sector comprises forestry, chemical plants, fertilizer plants, cooling, and mining. The detailed sub-divisions of each sector are given in Table 4.

Table 4: Demand sectors classification for the WEAP model [13]

Sr. #	Sector	Sub-sectors
1.	Municipal	Urban, rural, aboriginal
2.	Agriculture	Agriculture user registration, feed lot, stock watering, private irrigation, district irrigation
3.	Industrial	Forestry, chemical plants, fertilizer plants, coal mining hydropower/non-thermal, cooling, mining other than coal
4.	Petroleum	Oilfield injection, oil sands mining, gas/petrochemical plants, other uses
5.	Commercial	Gardening, golf courses, parks, aggregate washing, recreation, bottling, water hauling, dust-control, construction
6.	Other	Water management, habitat enhancement, specified use

Figure 14 shows the methodology used in developing the WEAP-Alberta model for water demand and supply sectors of Alberta.

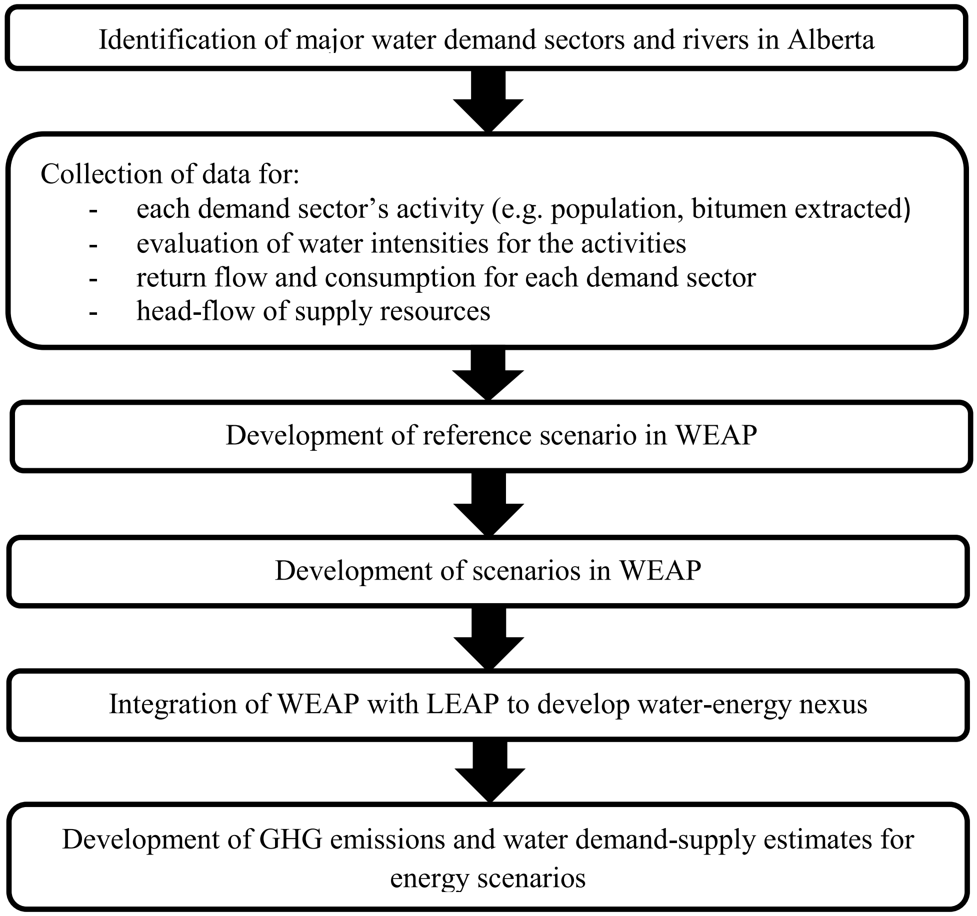


Figure 14: Methodology for development of the LEAP-WEAP model for Alberta

The detailed framework of WEAP specific to this study is given in Figure 15. The framework includes all the major demand sectors and sub-sectors along with the supply resources, that are, river basins.

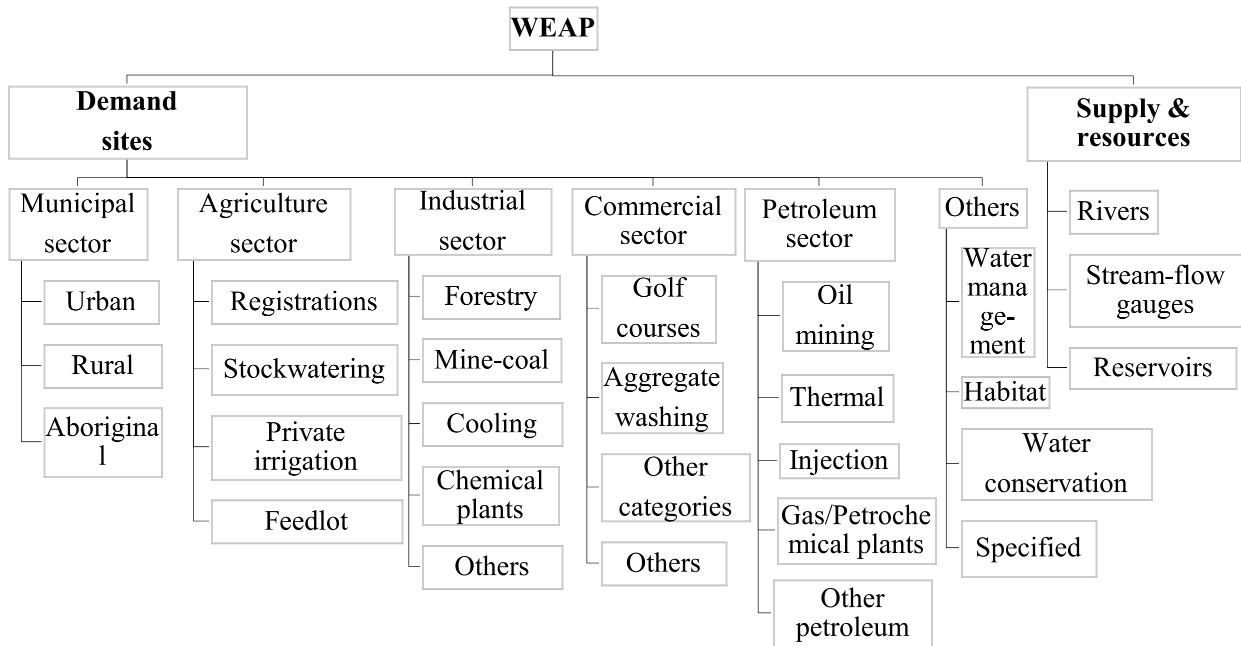


Figure 15: WEAP model framework

The WEAP model framework also includes the major demand sites, their sub-sectors, and the supply side. All the demand sector activity levels were included in the development of a water demand and supply model for Alberta. Data were collected for each sector and sub-sector activity level from federal and provincial agencies like Statistics Canada, the Energy Resources Conservation Board (ERCB), and various branches of the provincial government (Finance and Enterprise, Alberta Environment and Sustainable Resource Development (AESRD), and Alberta Agriculture and Rural Development (AARD), Alberta Municipal Affairs Service Branch of the Government of Alberta. Data were also collected from sustainability reports from companies such as Suncor, Shell, Syncrude, Agrium, Lafarge, and Sulzer. A model was then developed with all the data gathered for activities and water intensities for the base year 2009. After establishing and validating the base year model, projections available from different reports and data sources were made in all the demand sectors for different scenarios up to 2050 to estimate the future water demand.

Activity levels differ among the sectors depending upon the sub-sectors. In the municipal sector for instance, the annual activity level is population-dependent. In surface mining, a sub-sector of the petroleum sector, bitumen extraction in cubic meters is the annual activity level. In the industrial sector, the activity levels vary with the production capacities (e.g., tonnes of urea produced, million standard cubic feet per day [MMSCFD] of hydrogen produced, tonnes of asphalt produced, etc.) of different plants.

An example of the WEAP methodology for Alberta's municipal and agriculture sectors of the Bow River Basin and industrial sector of the North Saskatchewan River Basin is shown in Figure 16. The example shows the sub-sectors along with the data input to the WEAP model against each sub-sector. For example; for the city of Airdrie, the water intensity (per capita water use), and the annual activity level (i.e., population) along with the percentage monthly variation in annual demand, are added into the model. The consumption and priority are then given to the sector as a whole.

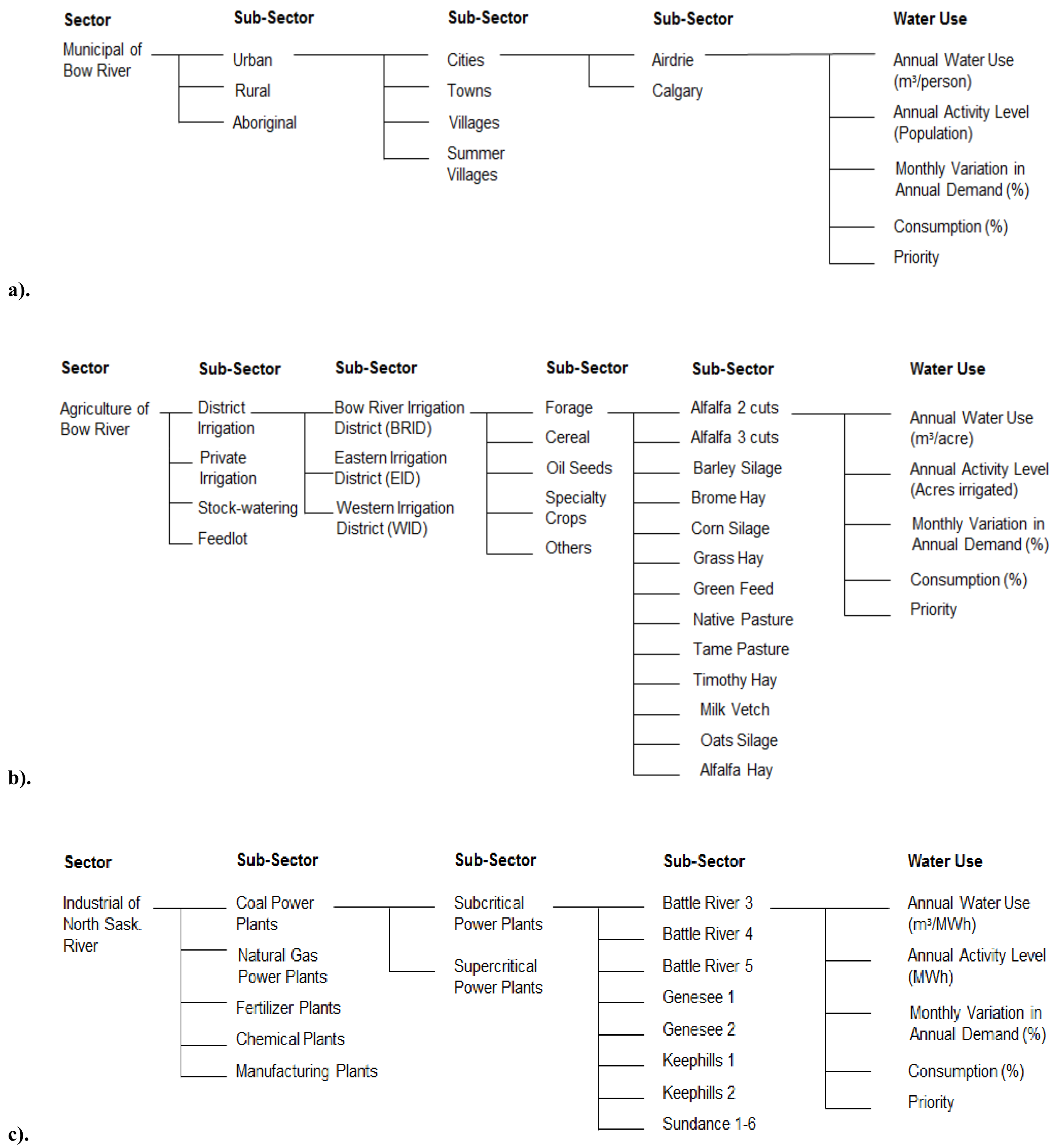


Figure 16: a). The WEAP methodology for the municipal sector of the Bow River Basin, b). The WEAP methodology for the agriculture sector of the Bow River Basin, and c). The WEAP methodology for the industrial sector of the North Saskatchewan River Basin

A descriptive analysis of sector-wise water withdrawal and use on the basis of river basins in Alberta was completed and published by AMEC in 2007 [13]. The Alberta-based WEAP model is much more detailed in terms of supply and resources (rivers), demand sectors and their sub-sectors, water withdrawal coefficients and provides an in-depth analysis of water demand and supply. The specific input data and assumptions made for the four river basins under study and demand sectors of those river basins are discussed in the subsequent sections.

2.4 Supply and resources

The water supply input data for the four river basins considered in the WEAP model are discussed below:

2.4.1 Framework development and input parameters

River flow measurements are taken over time by stream-flow gauges at several sites. The locations selected for this study are shown in Figure 17. These locations were chosen because the annual steam-flow volumes at these points can be considered natural or mostly natural based on the data available for the last ninety years [49]. Naturalized flow is the adjusted flow obtained by correcting flow volumes for the effects of human intervention on reservoirs, for instance. Natural flow can only be calculated based on an analysis of the historical data [50]. The gage flow, on the other hand, measures the amount of water passing (with or without human intervention) through that location per unit time (usually measured in m^3/s). The data for each river basin's stream-flow gages for the previous years (2001-2011) were obtained from the Water Survey of Canada (WSC) [11, 51].

For the North Saskatchewan River, WSC gauge 05DF001 near the city of Edmonton is considered. The mean annual discharge at this location is 212 m^3/s [49]. WSC gauge 05BH004 near the city of Calgary is considered for the Bow River. The mean annual discharge at this location is 91.1 m^3/s [49]. The Athabasca River at Athabasca with the WSC stream-flow gauge 07DA001 is considered and the mean annual discharge at this location is 423 m^3/s [49]. The Peace River at the town of Peace River with WSC gauge 07HA001 is selected. The mean annual discharge at this location is 1830 m^3/s [49].

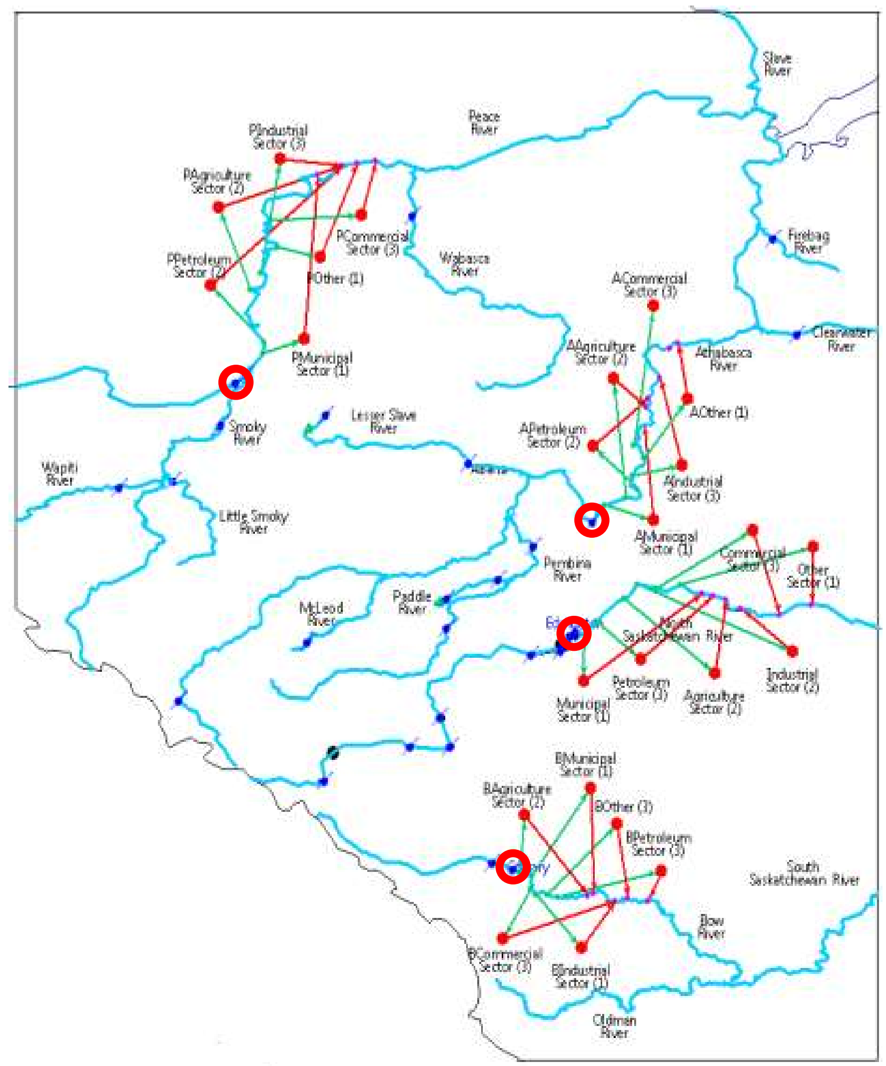


Figure 17: Alberta's river basins study locations

The Lesser Slave, Pembina, Paddle, and McLeod rivers are among the tributaries considered for the Athabasca River Basin. The tributaries considered for the four river basins are in Table 5:

Table 5: Tributaries of the four river basins considered for the WEAP model [10]

Sr. #	Rivers	Tributaries
1.	North Saskatchewan	------
2.	Athabasca	Lesser Slave, Pembina, Paddle, McLeod, Firebag, Clearwater rivers
3.	Peace	Wapiti, Little Smoky, Smoky, Wabasca rivers
4.	Bow	------

Data for the South Heart Reservoir and the Paddle River Dam were entered into the model. The initial storage, storage capacity, top of conservation, volume-elevation curve, and top of inactive zones were taken from AESRD [52]. The reservoir volume figures were taken from 2001 to 2011.

The flowchart showing the framework development and input parameters entered in the WEAP model for the supply side is given in Figure 18. The head flow and stream-flow gauge data for each river has been added into the model. For reservoirs, the initial storage and the storage capacity are among the model inputs.

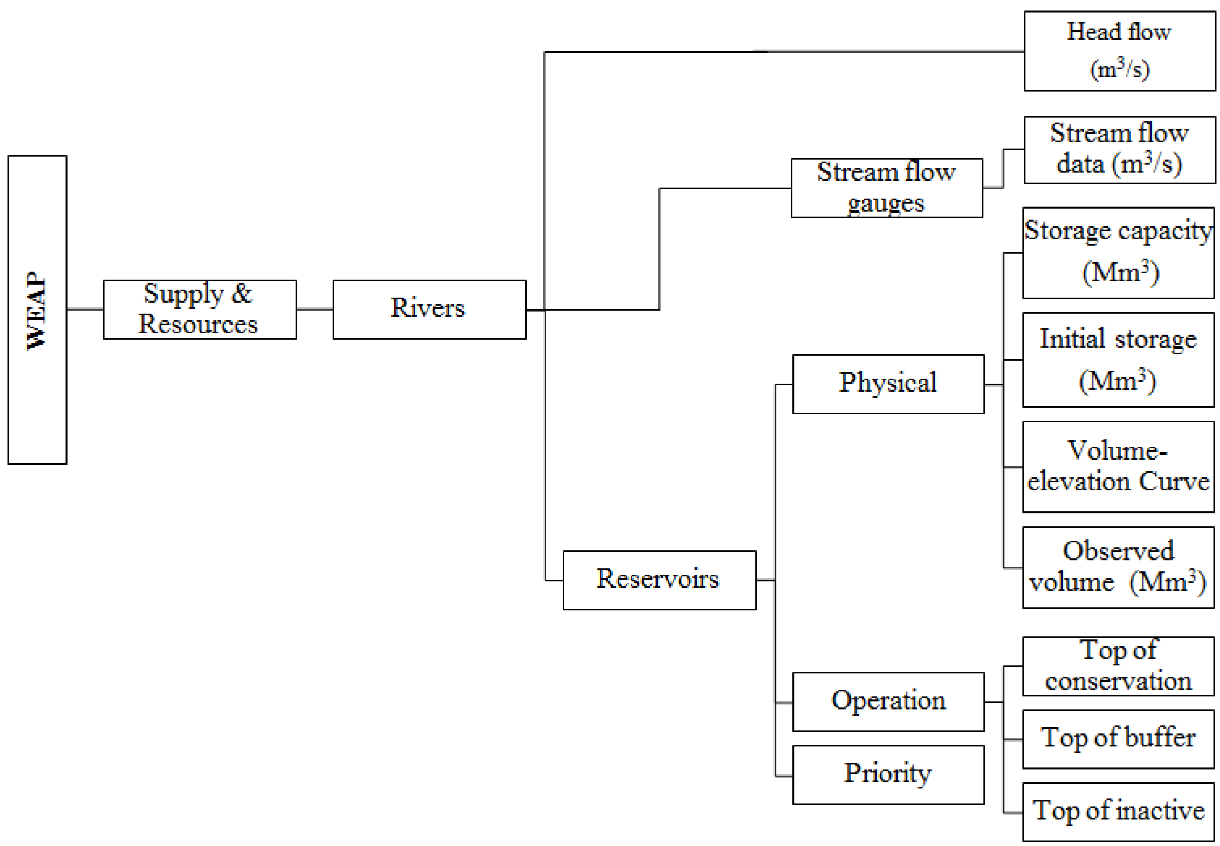


Figure 18: Framework development and input parameters for supply and resources in the WEAP model

2.4.2 Assumptions

1. It is assumed that the river water flow and the reservoir water volume patterns observed between 2001 and 2011 will repeat until 2050. The only projections available for rivers

are based on climate model. In this study, the climatic conditions have not been taken into account as also described in detail in 'Limitations of the study' in Section 1.5.

2. The observed volume of water in the reservoirs for the last ten years from 2001 to 2011 is assumed to repeat the same pattern over the study period as also described in 'Limitations of the study' in Section 1.5. Since the reservoirs considered in this study are water storage bodies so they act as water demand sites in the WEAP model.

2.5 Demand sectors

The specific input data and assumptions made for each demand sector in the four river basins are discussed in the sections below.

2.5.1 Municipal sector

2.5.1.1 Framework development and input parameters

The following are the input parameters entered in the WEAP model for the municipal sector for all four river basins:

1. For the municipal sector, municipalities for all four river basins were divided into urban (towns, villages, and summer villages) and rural (rural, regional, and aboriginal). The further sub-division of the urban and rural municipalities of the North Saskatchewan River Basin is given in Table 6. Tables 7, 8, and 9 show the urban and rural municipalities for the Bow, Peace, and Athabasca river basins, respectively. Only those communities whose water licenses are around 100 cubic decameter (dam^3) or more were listed [13]. Population values for the years 2005 to 2009 were taken for each community from yearly population lists published by Alberta Municipal Affairs, Municipal Services [53-57]. Populations in the base year (2009) are 1,319,441, 1,326,422, 255,263, and 281,024 for North Saskatchewan, Bow, Peace, and Athabasca river basins, respectively [57]. The population projections from 2010 to 2050 were taken from the Government of Alberta, Finance and Enterprise, for three scenarios (reference, and low and high population growth) [58].
2. The residential sector is the major water customer in the municipal sector followed by the commercial sector [59]. The amount of water use among different customers depends on

their pattern of water use. So one major consumer from commercial or residential group can change the water demand trend for the whole group. For all customers (including commercial, industrial, residential), the average water demand, on daily basis, for the past decade in Edmonton has stayed stable to 350 million liters per day (ML/day) [59]. The total water usage for residential sector in Edmonton from 1991 to 2008 has varied ±7% from the average 241.3 liters/capita/day (lpcd) [59]. The trend has a slight abrupt fluctuation with no prominent increase or decrease in the per capita water use for the time period specified. From 1998 onwards, the water use for commercial or industrial sector has also shown a steady behavior. It means that people have opted for water efficient ways which has helped to keep the water demand stable despite the increase in population. Since there has not been much of a well-defined increasing or decreasing change in the per capita of residential sector which is also a major water consumer among municipal sector, so the five-year average water use of 370 lpcd [59] is assumed for Edmonton for the reference scenario.

3. The ten-year (1996-2006) average per capita water demand considered for Calgary is 517 lpcd [60]. According to the 30-in-30 conservation goal of introducing universal metering and leak detection systems for Calgary, the per capita water use is expected to reduce from 517 to 453 lpcd by 2015 and then decreases to 350 lpcd by 2033 [60].
4. Alberta's average water use in 2009 was 395 lpcd, which is less than the Canadian average of 510 lpcd [61]. Alberta is also among the three provinces (the other two are Manitoba and Ontario) that have the lowest total per capita water use as the 2009 "Municipal Water and Wastewater Survey" done by Environment Canada in 2009 [62]. The total water use per capita of Alberta is to be reduced to 341 lpcd by 2020 according to the "New Water Conservation, Efficiency and Productivity Targets" set by Alberta Urban Municipalities Association (AUMA) [62]. AUMA will renew these goals in 2020 [62].

Table 6: Urban and rural municipalities within the North Saskatchewan River Basin [13]

North Saskatchewan					
Urban Municipality				**Rural Municipality**	
Cities	**Towns**	**Villages**	**Summer Villages**	**Rural or Regional**	**Aboriginal**
Edmonton	Stony Plain	Thorsby	Sandy Beach	Strathcona County	Saddle Lake First Nation
St. Albert	Beaumont	Alberta Beach	Horseshoe Bay	Parkland County	Frog Lake First Nation
Spruce Grove	Morinville	Mannville	Sunset Point	Sturgeon County	Enoch Cree Nation
Leduc	Rocky Mountain House	Kitscoty	Val Quentin	Leduc County	Paul Band
Fort Saskatchewan	Drayton Valley	Wabamun	Silver Sands	Clearwater County	Alexander First Nation
Lloydminister	Vegreville	Breton	Ross Haven	County of Vermilion River	Alexis Band
	St. Paul	Warburg	Seba Beach	County of St. Paul No. 19	O'Chiese Band
	Devon	Marwayne	West Cove	Brazeau County	Sunchild First Nation
	Vermilion	Clyde	Yellowstone	Lamont County	Fishing Lake Metis Settlement
	Gibbons	Andrew	Sunrise Beach	Smoky Lake County	Stony Band
	Redwater	Thorhild	South View	Beaver County	Elizabeth Metis Settlement
	Calmar	Spring Lake	Kapasiwin	County of Wetaskiwin No. 10	Makaoo
	Tofield	Ryley	Lake View	County of Minburn No. 27	
	Lamont	New Sarepta	Betula Beach	Lac Ste. Anne County	
	Bon Accord	Holden	Point Alison	County of Thorhild No. 7	
	Elk Point	Myrnam		County of Two Hills No. 21	
	Bruderheim	Willingdon		Westlock County	
	Two Hills	Vilna		Yellowhead County	
	Legal	Waskatenau		Camrose County	
	Smoky Lake	Chipman		Improvement District No. 9	
	Onoway	Innisfree		MD of Bonnyville No. 87	
	Mundare	Dewberry		County of Barrhead No. 11	
		Derwent		Improvement District No. 13	
		Minburn		Flagstaff County	
		Hairy Hill		County of Athabasca No. 19	

Table 7: Urban and rural municipalities within the Bow River Basin [13]

Bow River					
Urban Municipality				**Rural Municipality**	
Cities	**Towns**	**Villages**	**Summer Villages**	**Rural or Regional**	**Aboriginal**
Airdrie	Banff	Arrowwood	Ghost Lake	Newell No. 4	Siksika Nation
Calgary	Black Diamond	Hussar	Waiparous	Cypress	Stoney Band
	Canmore	Longview		ID No. 9 (Banff)	Tsuu T'ina Nation
	Chestermere	Milo		Kananaskis ID	
	Cochrane	Standard		Mountain View	
	Crossfield	Tilley		Bighorn No. 8	
	High River			Foothills No. 31	
	Okotoks			Ranchland No. 66	
	Strathmore			Rocky View No. 44	
	Turner Valley			Taber	
	Vulcan			Willow Creek No. 26	
				Vulcan	
				Wheatland	

Table 8: Urban and rural municipalities within the Peace River Basin [13]

Peace River					
Urban Municipality				Rural Municipality	
Cities	**Towns**	**Villages**	**Summer Villages**	**Rural or Regional**	**Aboriginal**
Grande Prairie	Peace River	Rycroft		City of Grande Prairie No. 1	Little Red River Cree Nation
	Grande Cache	Hythe		M.D. of Greenview No. 16	Bigstone Cree Nation
	High Level	Berwyn		M.D. of Mackenzie No. 23	Sturgeon Lake Band
	Fairview	Hines Creek		M.D. of Northern Lights No. 22	Whitefish Lake First Nation
	Grimshaw	Donnelly		Clear Hills County	Gift Lake Metis Settlement
	Fox Creek	Nampa		M.D. of Opportunity No. 17	Woodland Cree Band
	Beaverlodge	Girouxville		Saddle Hills County	Paddle Prairie Metis Settlement
	Valleyview			M.D. of Smoky River No. 130	Tallcree Band
	Sexsmith			Northern Sunrise County	Beaver First Nation
	Wembley			Reg. Mun. of Wood Buffalo	Dene Tha' First Nation
	Manning			M.D. of Fairview No. 136	Horse Lake Band
	Falher			Birch Hills County	Mikisew Cree First Nation
	Spirit River			M.D. of Peace No. 135	Duncan's Band
	McLennan			M.D. of Spirit River No. 133	Peavine Metis Settlement
				M.D. of Big Lakes	Lubicon Lake Band
				Improvement District No. 24	

Table 9: Urban and rural municipalities within the Athabasca River Basin [13]

Athabasca River					
Urban Municipality				Rural Municipality	
Cities	**Towns**	**Villages**	**Summer Villages**	**Rural or Regional**	**Aboriginal**
	Hinton	Boyle	Whispering Hills	Regional Municipality of Wood Buffalo	Driftpile River Band
	Whitecourt	Sangudo	Island Lake South	Yellowhead County	Peavine Metis Settlement
	Edson	Kinuso	Island Lake	County of Athabasca No. 12	Sucker Creek Band
	Slave lake		Birch Cove	Lac Ste. Anne County	East Prairie Metis Settlement
	Westlock		Sunset Beach	County of Barrhead No. 11	Swan River First Nation
	Barrhead		West Baptiste	M.D. of Big Lakes	Chipewyan Prairie First Nation
	Lac La Biche		South Baptiste	Westlock County	Fort McKay First Nation
	High Prairie		Nakamun Park	Municipality of Jasper	Heart Lake First Nation
	Athabasca		Larkspur	Woodlands County	Bigstone Cree Nation
	Swan Hills			Lakeland County	Kapawe No First Nation
	Mayerthorpe			M.D. of Lesser Slave River No. 124	Gift Lake Metis Settlement
				Brazeau County	Sawridge Band
				Parkland County	Alexis Band
				M.D. of Opportunity No. 17	
				M.D. of Greenview No. 16	
				County of Thorhild No. 7	
				Northern Sunrise County	
				M.D. of Smoky River No. 130	
				Improvement District No. 12	
				Improvement District No. 24	
				Improvement District No. 9	
				Improvement District No. 25	

2.5.1.2 Assumptions

The following are the assumptions for the municipal sector for all four river basins:

1. It is assumed that the North Saskatchewan River Basin and the Bow River Basin have the same per capita water use as that of Edmonton and Calgary respectively because these cities comprise most of the population of these river basins.
2. The per capita water use for the Athabasca and Peace river basins is not available so Alberta's average per capita water use for 2009 is assumed for these basins as Athabasca--Grande Prairie--Peace river regions comprised of only around 10% of the Alberta's population in 2011 [63, 64].

2.5.1.3 WEAP demand tree

The demand tree includes all the sub-sectors of the demand sector. It also represents the input parameters for the model for each demand sector or sub-sector. The demand tree for the municipal sector is shown in Figure 19. The water intensity method is applied for WEAP's framework development. The water intensity is the water required per unit of the activity. The water intensity method includes the water demand calculation based on the annual activity level (i.e., municipal sector population) and the per capita water use. The value of consumption added for this sector assists in calculating the return flow.

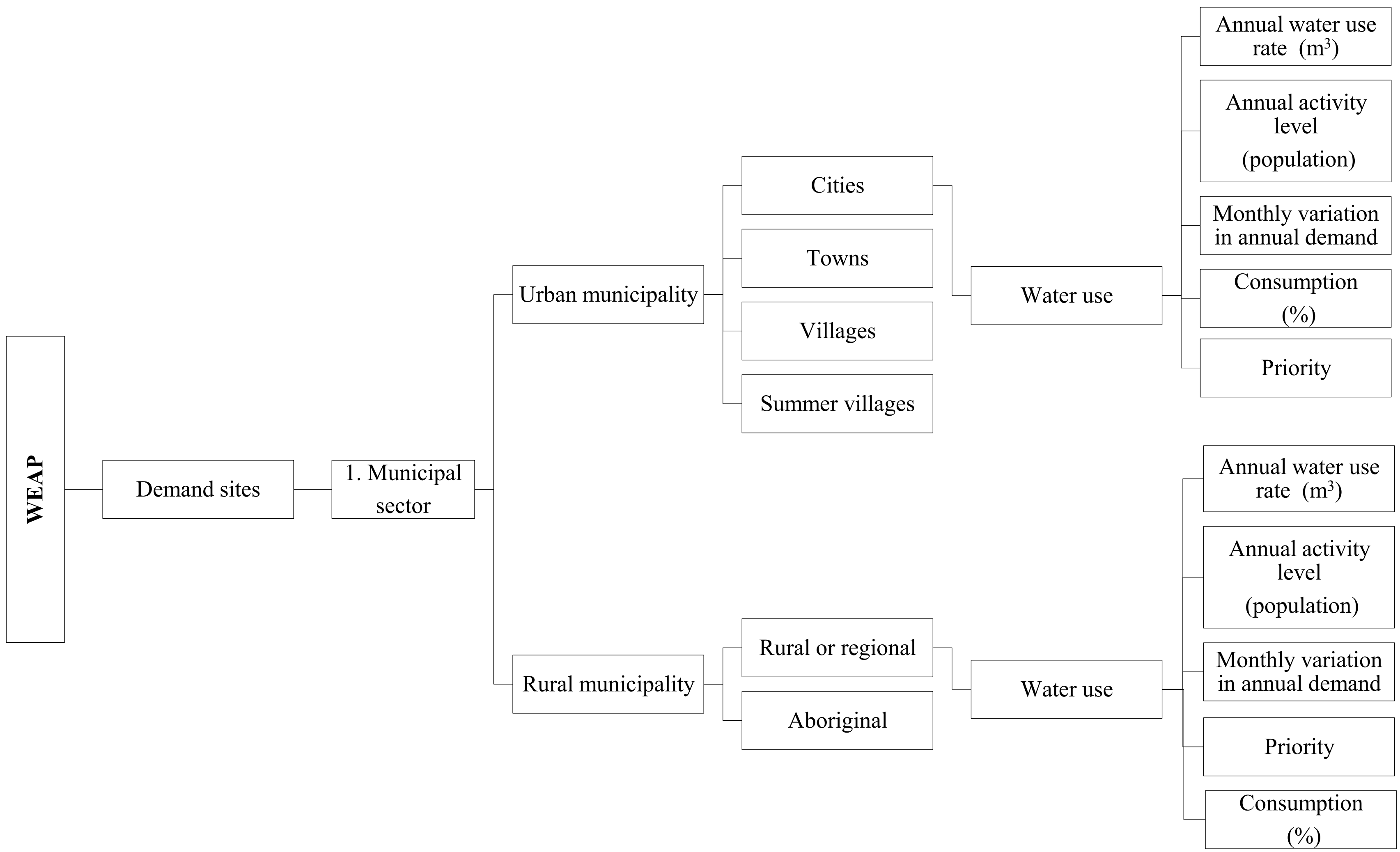


Figure 19: Demand tree and input parameters for the municipal sector in WEAP

2.5.2 Agriculture sector

2.5.2.1 Framework development and input parameters

For the agricultural sector for all four river basins, the following data are used:

1. For all river basins, the agriculture sector annual water allocation values for each sub-sector – registrations, private irrigation, and feed lot – for the year 2005 were input into WEAP. The water allocation is the maximum amount of water that can be diverted from the source as set out in water licenses under Alberta's Water Act [13].
2. The agriculture sector in the Bow River region has been allocated 77% of the total water of the region. Out of this 77%, 85% is for district irrigation. The Bow River Basin has three irrigation districts: the Bow River Irrigation District (BRID), the Eastern Irrigation District (EID), and the Western Irrigation District (WID) [13]. Each district grows five types of crops: forage, cereal, oil seeds, specialty crops, and others [65-72]. The forage is further divided into 2nd and 3rd cut alfalfa, barley silage, corn silage, grass hay, green feed, native pasture, tame pasture, Timothy hay, milk vetch and oats silage. The further sub-divisions of the crops are given in Table 10. The high water-use crop, third-cut alfalfa, is used to calculate the Bow's crop water requirement because the crop's annual growing season nearly coincides with the annual irrigation season [65-72]. The net irrigation requirement for water was used to calculate the total water withdrawal.
3. In 2009 the net irrigation requirement for water from the Bow River Basin was 384 mm [68]. This figure is used for the base year as the crops' water intensity to calculate the total water withdrawal.

Table 10: Types of crops in the Bow River Basin's three irrigations districts [65-72]

	Crop Type
Forage	Second-cut alfalfa, third-cut alfalfa, alfalfa hay, barley silage, brome hay, corn silage, grass hay, green feed, native pasture, tame pasture, Timothy hay, milk vetch, oats silage.
Cereal	Barley, CPS wheat, durum wheat, grain corn, hard spring wheat, oats, rye, soft wheat, triticale, winter wheat, malt barley.
Oil Seeds	Canola, flax, mustard.
Specialty Crops	Alfalfa seed, canola seed, dry beans, dry peas, faba beans, fresh corn sweet, fresh peas, grass seed, hemp, market gardens, mint, nursery, potatoes, soya beans, sugar beets, sunflower, carrots, lawn turf, lentils, safflower, seed potatoes, small fruit.
Other	Miscellaneous, summer fallow.

2.5.2.2 Assumptions

The following are the assumptions for the agriculture sector for all four river basins:

1. As per the historic trend, irrigated acres decreased in the North Saskatchewan River and Athabasca River basins. It is assumed that forage available in these two regions will be able to support a modest increase in the livestock population [13].
2. For the Bow River Basin, expansion in irrigated acres will be limited as that basin's allocations have been capped (i.e. issuance of new water licenses stopped) [13].
3. In the Peace region, expansion of crop areas to support expansion in livestock is possible. It is assumed that water requirements will increase by a certain percentage every year to support some increase in livestock population.
4. Except for the district irrigation sub-sector in the Bow River Basin, the agriculture sub-sectors are a small percentage of the total water allocation in the North Saskatchewan, Bow, Athabasca, and Peace River regions. The water withdrawal values of the sub-sectors (e.g., registrations, private irrigation, and feed lot) are assumed to remain the same in 2009 as in 2005 and to stay constant throughout the forecast period.

2.5.2.3 WEAP demand tree

The demand tree for the agriculture sector for all river basins is shown in Figure 20. The agriculture sector consists of the following sub-sectors: registration, stock watering, private irrigation, and feedlot. All of the sub-sectors are incorporated in WEAP. The district irrigation demand tree data input for the Bow River Basin is shown separately in Figure 21. Crop-wise water intensity data were used for WEAP modeling. The activity level in the district irrigation for the Bow River Basin is acres. The number of acres irrigated for each crop along with the water intensity (m^3/acre) was entered in the model for the years 2005 to 2009.

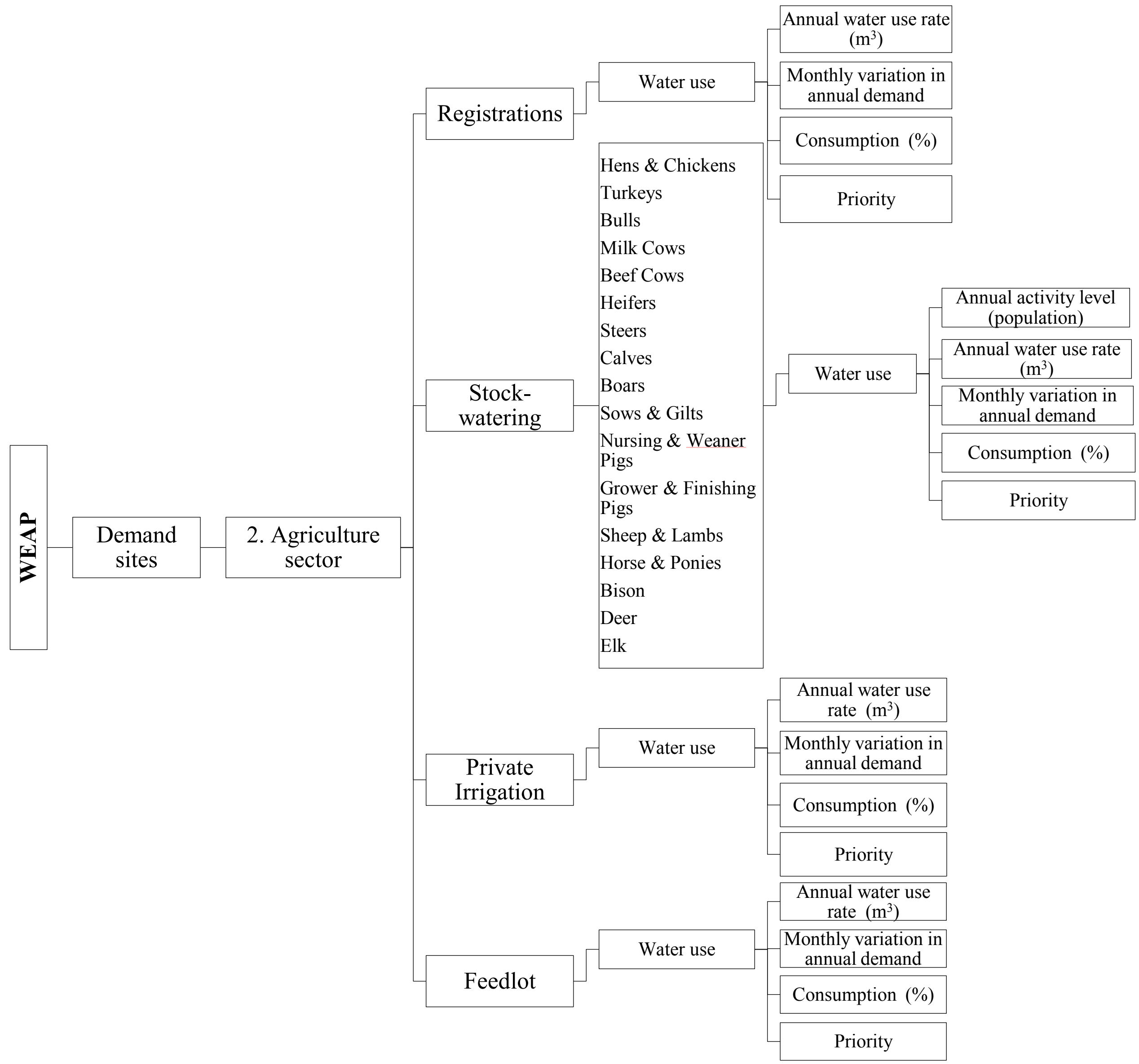


Figure 20: Demand tree and input parameters for the agriculture sector in WEAP

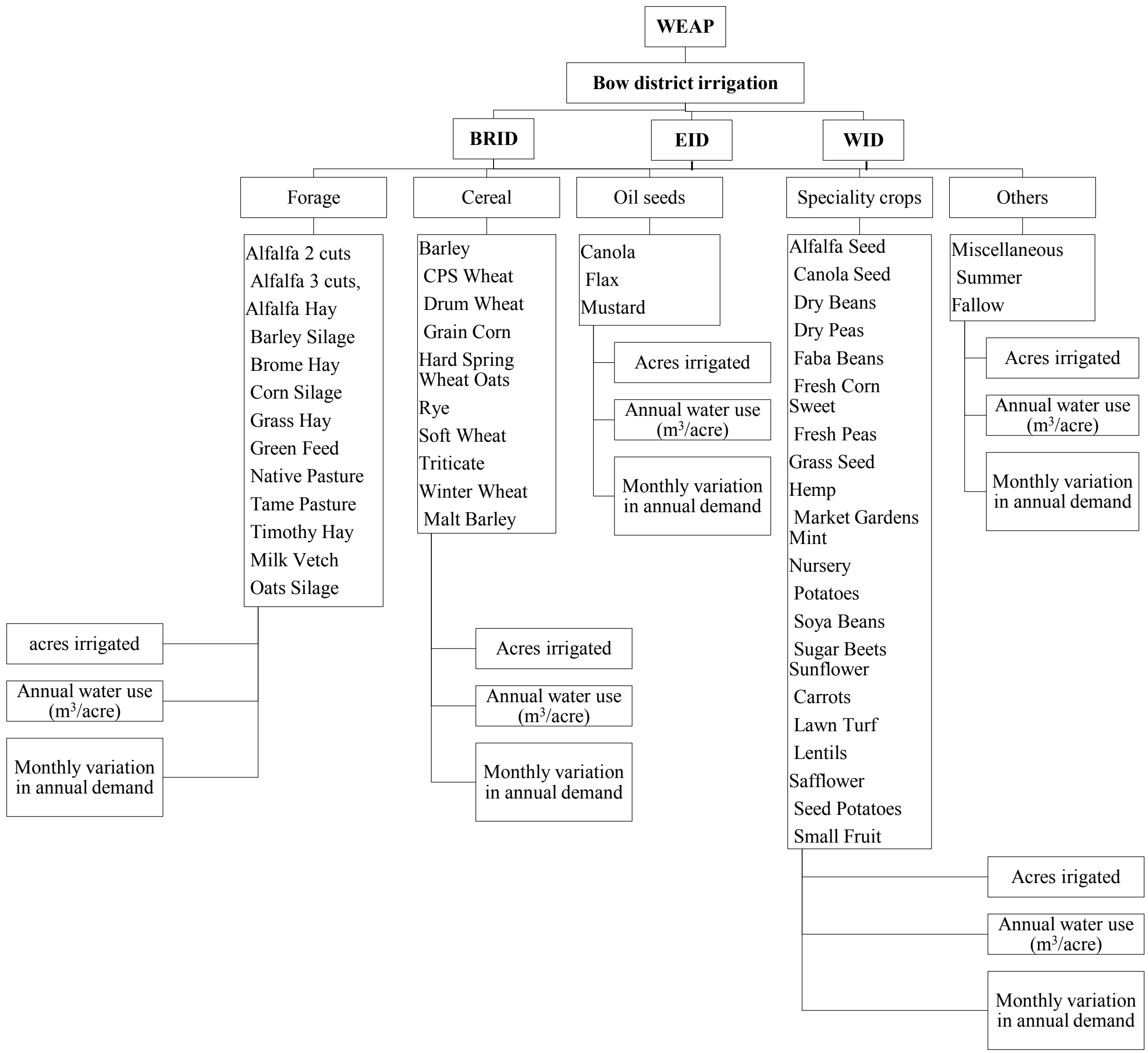


Figure 21: Demand tree and input parameters for the Bow Irrigation District in WEAP

2.5.3 Industrial sector

2.5.3.1 Framework development and input parameters

For the industrial sector of all river basins, the following input parameters were used:

1. For the industrial sector, Alberta's Industrial Heartland portion of the North Saskatchewan River Basin is considered. Alberta's Industrial Heartland comprises Strathcona County, the City of Fort Saskatchewan, Lamont County, the City of Edmonton, and Sturgeon County [73]. The sub-sector of the industrial sector was made up from the list of chemical plants, manufacturing plants, fertilizer plants, and power plants operating in Alberta's Industrial Heartland and in the North Saskatchewan River Basin. The details of annual activity levels, i.e., the production capacities of all the industries along with the water intensities, were collected and analyzed and are presented in Table 11. Appropriate assumptions were made where required and are described in Table 11. For the sub-sectors (coal mining, hydro, mining other than coal, and other industrial uses), the annual water allocation values were the input to the WEAP model.
2. The annual activity levels of four natural gas power plants located in the Bow River region – the Carseland Cogeneration Natural Gas Power Plant and Crossfield Energy Centers 1, 2, and 3 – are also included in the WEAP model. The annual water allocations from AMEC for the sub-sectors of the industrial sector in the Bow River Region were entered in the WEAP model.
3. The industrial sub-sectors in the Peace River region are forestry, cooling, chemical plants, and coal mining. Water withdrawal licenses have been issued to forestry sub-sector for two pulp mills in this river basin, Diashowa-Marubeni and Weyerhaeuser. There is only one surface water license for cooling, and that was issued to the H.R. Milner Power Station, a 144 MW coal-fired power station close to the town of Grande Cache. There has been only one surface water license issued to a chemical plant in the Peace region [13].
4. The sub-sectors of the Athabasca River region industrial sector are forestry, cooling, chemical plants, coal mining, and other industrial uses. For forestry, the six major surface water licenses were issued to the five pulp mills located in the basin: Alberta Newsprint

Company, Alberta Pacific Forest Industries Inc., Millar Western Forest, Slave Lake Pulp, and West Fraser [13]. The annual water allocations for the industrial sub-sectors (pulp mills, chemical plants, coal mining, and other industrial uses) of the Bow, Peace, and Athabasca river regions are entered as input data in the WEAP model.

Table 11: Production capacities and water coefficients for several industries in Alberta's Industrial Heartland

Sr. #	Companies	Production capacities	Water withdrawal coefficients and assumptions	Ref. #
Strathcona County				
1.	Imperial Oil Refinery	185,000 barrels of crude oil daily	The water withdrawal coefficient used is 1.75 m^3/m^3.	[73-79]
2.	AltaSteel Ltd.	350,000 tons of steel billets annually	The daily industrial water-input per ton of crude steel produced in such plants is calculated to be between 7.3 and 14.6 m^3/ton crude steel, and from this the average water withdrawal coefficient of 10.95 m^3/t is taken.	[73, 80]
3.	Keyera Alberta Envirofuels Facility	Rated capacity to produce iso-octane approximately 520,000 tons/year	Since iso-octane is a refined petroleum product, the same water footprint is considered as for a refinery.	[73]
4.	Rio Tinto Alcan	180,000 metric tons of calcined product	Sustainability reports for 2012 for Weipa, Yarwun, and Quebec were considered for water intensities. An average water withdrawal value of 4.55 m^3/ton is considered for this operation.	[73, 81-83]
5.	Air Liquide Canada Inc.	----------	The average water value from sustainability reports for the years 2008 and 2013 is 0.12558 Mm3/yr for a single plant. Since the water consumption coefficient is always less than the water withdrawal coefficient, and due to the lack of data, water consumption is considered as the water withdrawal. This may give the values for water withdrawal as lower than actual.	[84, 85]

Table 11 (continued)

Sr. #	Companies	Production capacities	Water withdrawal coefficients and assumptions	Ref. #
Strathcona County				
6.	Suncor Energy Edmonton Refinery	Processes approximately 140,000 barrels per day of crude oil	The water withdrawal coefficient used is 1.75 m^3/m^3.	[73-79]
7.	Air Products Canada Ltd.	Hydrogen production at the capacity of approximately 175 MMSCFD from two reformers. Expansion to additional 150 MMSCFD is expected by 2015. Hydrogen production at the capacity of approximately 175 MMSCFD from two reformers. Expansion to additional 150 MMSCFD is expected by 2015	175 MMSCFD = 4 955 448.15 cubic meters per day - Assuming 365 working days in an year = 4 955 448.15 * 365 = 1808.73858 Mm^3 - 1 kg = 11.126 m^3 of H_2 => 1808.73858 Mm^3 = 162.56863 M Kg - Total water consumption in H_2 plant = 18.8 l/Kg H_2 = 0.0188 m^3/kg H_2 Since the water consumption coefficient is always less than the water withdrawal coefficient, and due to a lack of data, water consumption is considered as the water withdrawal. This may give the values for water withdrawal lower than actual.	[73, 86]
8.	Northern Lights Upgrader	Bitumen upgrading capacity of 150,000 barrels per day	The water withdrawal coefficient for bitumen upgrading is 0.7 m^3/m^3.	[87-90]
9.	Agrium Inc. - Redwater	Produces 720,000 tons of urea	The direct water withdrawal coefficient of urea is 4.9 m^3/tons.	[91, 92]
10.	Sturgeon Refinery	150,000 bpd of crude bitumen	The water withdrawal coefficient used is 1.75 m^3/m^3.	[73-79]

Table 11 (continued)

Sr. #	Companies	Production capacities	Water withdrawal coefficients and assumptions	Ref. #
Strathcona County				
11.	Evonik Canada Inc.	Current capacity of 600, 000 metric tons of H_2O_2 per year	Assuming both facilities produce H_2O_2 equally, the production capacity of the Alberta plant is 300,000 metric tons per year. Water intensity is not available in the corporate responsibility reports, but specific water consumption of the product is given. Since the water consumption coefficient is always lower than the water withdrawal coefficient, and due to a lack of data, water consumption is considered as the water withdrawal. This may show the values for water withdrawal as less than actual. The average specific water consumption from 2006 to 2009 is 37.25 m^3/ton of the product.	[93, 94]
12.	Williams Energy Canada ULC	Produces 2 million barrels of propane	Since the petrochemical industry produces hydrocarbons like ethylene and polyethylene, the industry's water coefficient is considered to be the same as for a refinery.	[95]
13.	ATCO Power - Scotford	170 megawatt (MW) Scotford Cogeneration Plant	Capacity factor for natural gas power plant = Total net generation / Max. capacity * 100 = 3187 / 6845 *100 = 46.5%.water withdrawal coefficient = 0.96 L/KWh. It is assumed that this plant will be a conventional gas - NGCC with cooling tower.	[73, 96, 97]
14.	ATCO Pipelines	----------	The values from 2009 to 2013 (with missing values for 2011 and 2012) were obtained through a personal communication. The avg. value of 6743.67 m^3/yr is used.	[98]

Table 11 (continued)

Sr. #	Companies	Production capacities	Water withdrawal coefficients and assumptions	Ref. #
Strathcona County				
15.	ATCO Power	400 megawatt (MW) natural gas fired power generation station	Capacity factor for natural gas power plant = Total net generation / Max. capacity * 100 = 3187 / 6845 *100 = 46.5%. Water withdrawal coefficient = 0.96 L/KWh. It is assumed that this plant will be a conventional gas - NGCC with cooling tower.	[73, 96, 97]
City of Fort Saskatchewan				
16.	Umicore Canada Inc.	The production capacity is not known for this plant so we have used the same production capacity as Sherrit International Corp.	The water coefficient for cobalt could not be found, so water use for nickel is used. The direct water use coefficient is 8.9 m^3/ton. The coefficient includes mining and concentrator, smelting, and refining. Since the water consumption coefficient is always lower than the water withdrawal coefficient, and due to a lack of data, water consumption is considered as the water withdrawal. This may give the values for water withdrawal as lower than actual.	[99]
17.	Sulzer Metco (Canada) Inc.	The production capacity is not known for this plant so we have used the same production capacity as Sherrit International Corp.	The water coefficient for cobalt could not be found, so water use for nickel is used. The direct water use coefficient is 8.9 m^3/ton. It includes mining and concentrator, smelting, and refining. Since the water consumption coefficient is always lower than the water withdrawal coefficient, and due to a lack of data, the water consumption is considered as	[99]

Table 11 (continued)

Sr. #	Companies	Production capacities	Water withdrawal coefficients and assumptions	Ref. #
City of Fort Saskatchewan				
17.	Sulzer Metco (Canada) Inc.	The production capacity is not known for this plant so we have used the same production capacity as Sherrit International Corp.	the water withdrawal. This may give the values for water withdrawal as lower than actual.	[99]
18.	Sherrit International Corp.	Sherritt's 2009 production was 33,500 tonnes/yr of nickel and 3500 tonnes/yr of cobalt	The water coefficient for cobalt could not be found, so water use for nickel is used. The direct water use coefficient is 8.9 m^3/ton. It includes mining and concentrator, smelting, and refining. Since the water consumption coefficient is always lower than the water withdrawal coefficient, and due to a lack of data, the water consumption is considered as the water withdrawal. This may give the values for water withdrawal as lower than actual.	[99, 100]
19.	Ferrus Inc.	----------	For CO2 purification units, data are not available. Data of water consumption are taken from the 2013 Air Liquide Sustainability report.	--------
20.	Praxair Inc.	----------	Capacities are not available. The water per year for the air separation units of Air Liquide is used with the same assumptions.	--------

Table 11 (continued)

Sr. #	Companies	Production capacities	Water withdrawal coefficients and assumptions	Ref. #
City of Fort Saskatchewan				
21.	MEGlobal	1.0 million metric tons per year of ethylene glycol	The water footprint for mono and diethylene glycol could not be found, so the water coefficient for ethylene glycol was used. The water consumption for ethylene glycol is 314 m^3/ton. Since the water consumption coefficient is always lower than the water withdrawal coefficient, and due to a lack of data, the water consumption is considered as the water withdrawal. This may give the values for water withdrawal as lower than actual.	[73, 101]
22.	Agrium Inc. - Ft. Sask.	430,000 tons of granular urea	The direct water withdrawal coefficient of urea is 4.9 m^3/ton.	[73, 92]
23.	Dow Chemical Canada ULC	Around 1.4 million tons of product i.e. hydrocarbons, ethylene, polyethylene	Since it is petrochemical industry producing hydrocarbons water coefficient for the refinery is considered.	[73]
24.	Keyera Energy	30,000 barrels per day and an expansion of NGL fractionation and storage facility is expected in Fort Saskatchewan to double the facility's existing C3+ fractionation capacity to 65,000 barrels per day till 2016	Since the petrochemical industry produces hydrocarbons, the water coefficient from the refinery is considered.	[102]

Table 11 (continued)

Sr. #	Companies	Production capacities	Water withdrawal coefficients and assumptions	Ref. #
City of Fort Saskatchewan				
25.	Plains Midstream Canada	Combined processing capacity of the Bakersfield, California and High Prairie, Alberta is approximately 28,000 barrels per day	Assuming that both plants are of the same capacity, the value comes out to be 14,000 barrels per day. Since the petrochemical industry produces hydrocarbons, the water coefficient from the refinery is used.	[103]
26.	Aux Sable Canada Ltd. Heartland Off gas Plant	The 20 MMCFD Heartland off gas Plant ("HOP") started its operation in September 2011. It is Alberta's first company to produce ethane and hydrogen from off gas stream coming from an upgrader or refinery.	Due to the absence of a water footprint, the water coefficient for producing hydrogen by natural gas steam reforming is used. The production of other gases such as ethane is not considered. Total water consumption in H2 plant = 18.8 l/Kg H2 = 0.0188 m3/kg H2. Since the water consumption coefficient is always lower than the water withdrawal coefficient, and due to a lack of data, the water consumption is considered as the water withdrawal. This may give the values for water withdrawal as lower than actual.	[86, 104]
27.	Western Hydrogen Ltd.	Western Hydrogen is under pilot testing phase. 200 MSCFD of H2 is the initial capacity of the plant. It produced H2 for the first time in Sept. 2013 by molten salt gasification (MSG). Target is	Given the lack of water footprint data for MSG, it is assumed that the water coefficient is the same as for producing hydrogen by natural gas steam reforming. Total water consumption in H2 plant = 18.8 l/Kg H2 = 0.0188 m3/kg H2. Since the water consumption coefficient is always lower than the water	[86, 105]

Table 11 (continued)

Sr. #	Companies	Production capacities	Water withdrawal coefficients and assumptions	Ref. #
City of Fort Saskatchewan				
28.	Western Hydrogen Ltd.	to make this plant commercial and to produce 5000 kg/d H_2 in future	withdrawal coefficient, and due to a lack of data, the water consumption is considered as the water withdrawal. This may give the values for water withdrawal as lower than actual.	[86, 105]
Lamont County				
29.	Western Asphalt Products	---------	Due to the lack of production capacity data, McAsphalt's data were used.	-------
30.	Maxim Deerland Power Corp.	Capacity of 190 MW	Capacity factor for natural gas power plant = Total net generation / Max. capacity * 100 = 3187 / 6845 *100 = 46.5%. water withdrawal coefficient = 0.96 L/KWh. It is assumed that this plant will be conventional gas - NGCC with cooling tower.	[73, 96, 97]
31.	Bunge Canada	The proposed expansions will double the capacity of 850 metric tons a day by 2014.	The water footprint considered is 0.5 m3/ton.	[106, 107]

Table 11 (continued)

Sr. #	Companies	Production capacities	Water withdrawal coefficients and assumptions	Ref. #
Sturgeon Industrial Park				
32.	McAsphalt	The total annual production is the average value i.e. (7+30)/2 = 18.5 TPH * 365days *24 hrs = 162.06 tons/yr.	Specific water consumption by Lafarge Cement Plant is: Cement = (317 + 313.8) / 2 = 315.4 l/ton Aggregate = (213.7 + 116.4) / 2 = 165.05 l/ton Concrete = (103.4+113.2) / 2 = 108.3 l/ton Total water footprint = 315.4 + 165.05 + 108.3 = 588.75 l/ton = 0.58875 m^3/ton.	[108, 109]
33.	Momentive Speciality Chemicals Inc.	The production capacity of this facility is unknown. Another similar plant opened by Hexion Chemicals has a rated capacity of 150 million pounds per year. It produces the same product and is located in the same area. So its data is considered for this plant.	The direct water footprint for cement is 2.4 m^3/ton.	[92, 110]
34.	Prospec Chemicals	Manufactures 7000 metric tons of xanthates annually	Since xanthate is a type of salt, the water footprint for pure salt was used, i.e., 2.27 m3/ton. This figure includes manufacturing, raw materials, energy, and packaging. This water footprint figure overstates the total water withdrawal in this case.	[73, 92]

Table 11 (continued)

Sr. #	Companies	Production capacities	Water withdrawal coefficients and assumptions	Ref. #
Sturgeon Industrial Park				
35.	Magnum Cementing Services	It provides cementing services. The production capacity is not known so Lehigh Edmonton Plant is considered. It produces 1,300,000 metric tons annually with a plant capacity of 1,500,000 tons. Since Magnum is not a cement plant and nothing is known about it, we have assumed 50% of the production of Lehigh. i.e. 650000 tons.	The direct water footprint for cement is 2.4 m^3/ton	[92, 111]

2.5.3.2 Assumptions

The following are the assumptions for the industrial sector for all the four river basins:

1. Most of the water allocated from the South Saskatchewan sub-basins is consumed and a small percentage returned back to the source, and the impact on the aquatic environment is evident. Thus, a South Saskatchewan River Basin Water Management Plan was approved in 2006. This plan was supported by a provincial ministerial order and a Crown Reservation issued by regulation under Section 35 of the Water Act in 2007. According to the water management plan, all three sub-basins (i.e., the Bow, Oldman, and South Saskatchewan) are effectively closed to new surface water license applications [19]. So this study does not consider any industrial expansion in the Bow River region.
2. The other sub-sectors (coal-mining, cooling, and other industrial activities) account for a small percentage of the total water allocation in the Athabasca and Peace regions industrial sector, so it is assumed that the values of the total allocation will remain the same as in 2005.
3. The water coefficients for the industrial heartland are assumed to remain the same throughout the study period due to the data limitation. Water consumption values are considered where the water withdrawals for the plants were not available. This assumption may understate actual water withdrawal, as the water consumption coefficient is always less than the water withdrawal coefficient.

2.5.3.3 WEAP demand tree

The demand tree for the industrial sector for all river basins is shown in Figure 22. The consumption and demand priority for the industrial sector is entered for each of river basin. The demand tree data input for the industrial sub-sectors (forestry and cooling for the Bow, Peace and Athabasca rivers) is given in Figure 23. Integrated framework development of industrial sector is shown in Figure 24.

The demand data input of the industrial sub-sectors of the North Saskatchewan River Basin (chemical plants, fertilizer plants, manufacturing plants, coal fired and natural gas power plants) is shown in Figures 25 and 26. The annual activity levels for all the chemical, manufacturing, and fertilizer plants considered depend on their production units. For example, the fertilizer plant produces tonnes of urea, the refineries produces barrels of oil per day, and the hydrogen plants produce million standard cubic feet of hydrogen per day. The annual water use, i.e., water intensity for each plant unit considered, is shown in Table 11.

The annual activity level for the power generation sector, i.e. coal-fired or natural gas power plants is taken in MW. The corresponding water withdrawal coefficients required in these power plants are mentioned in detail in Table 11.

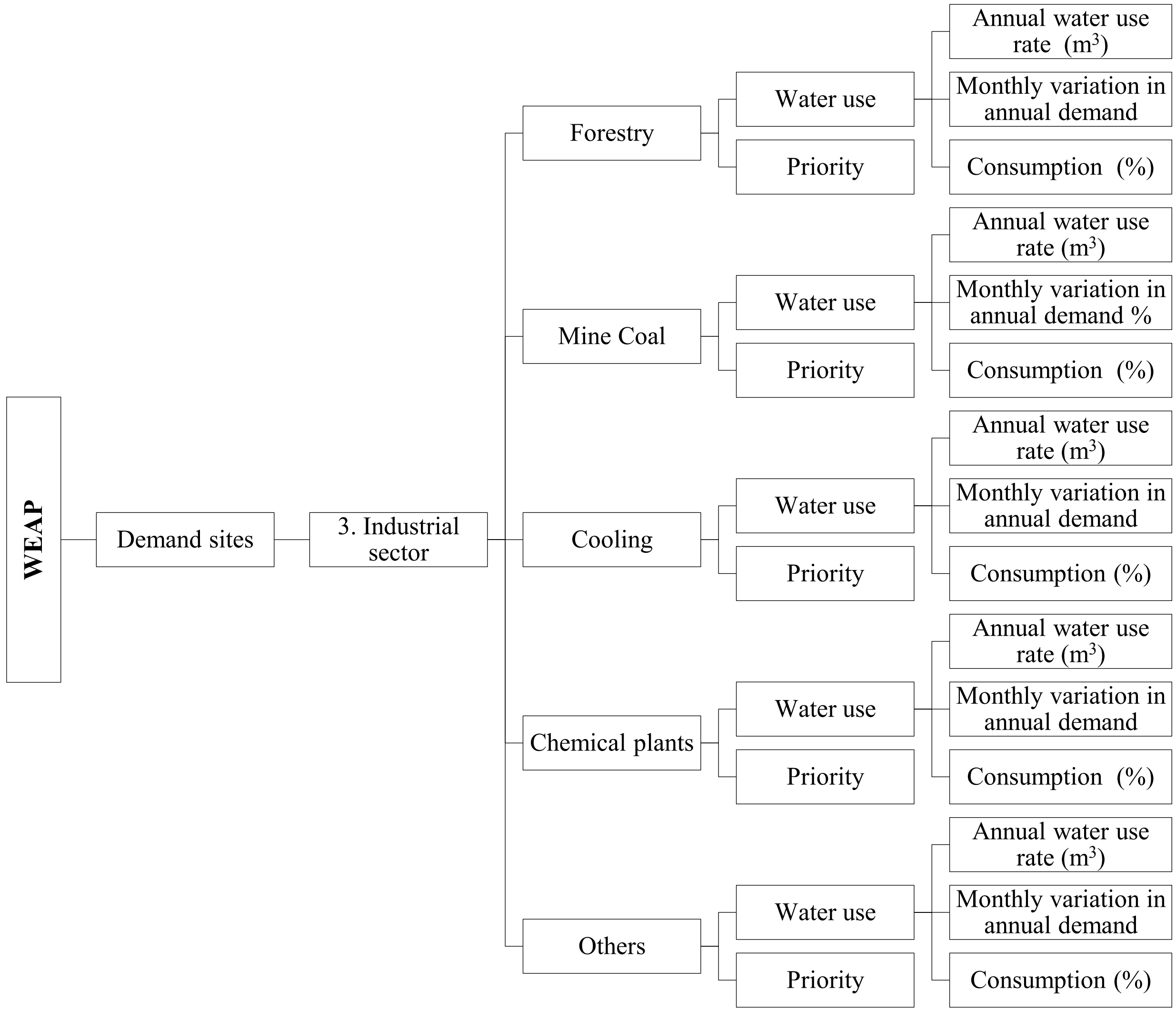


Figure 22: Framework development and input parameters for the industrial sector in the WEAP model

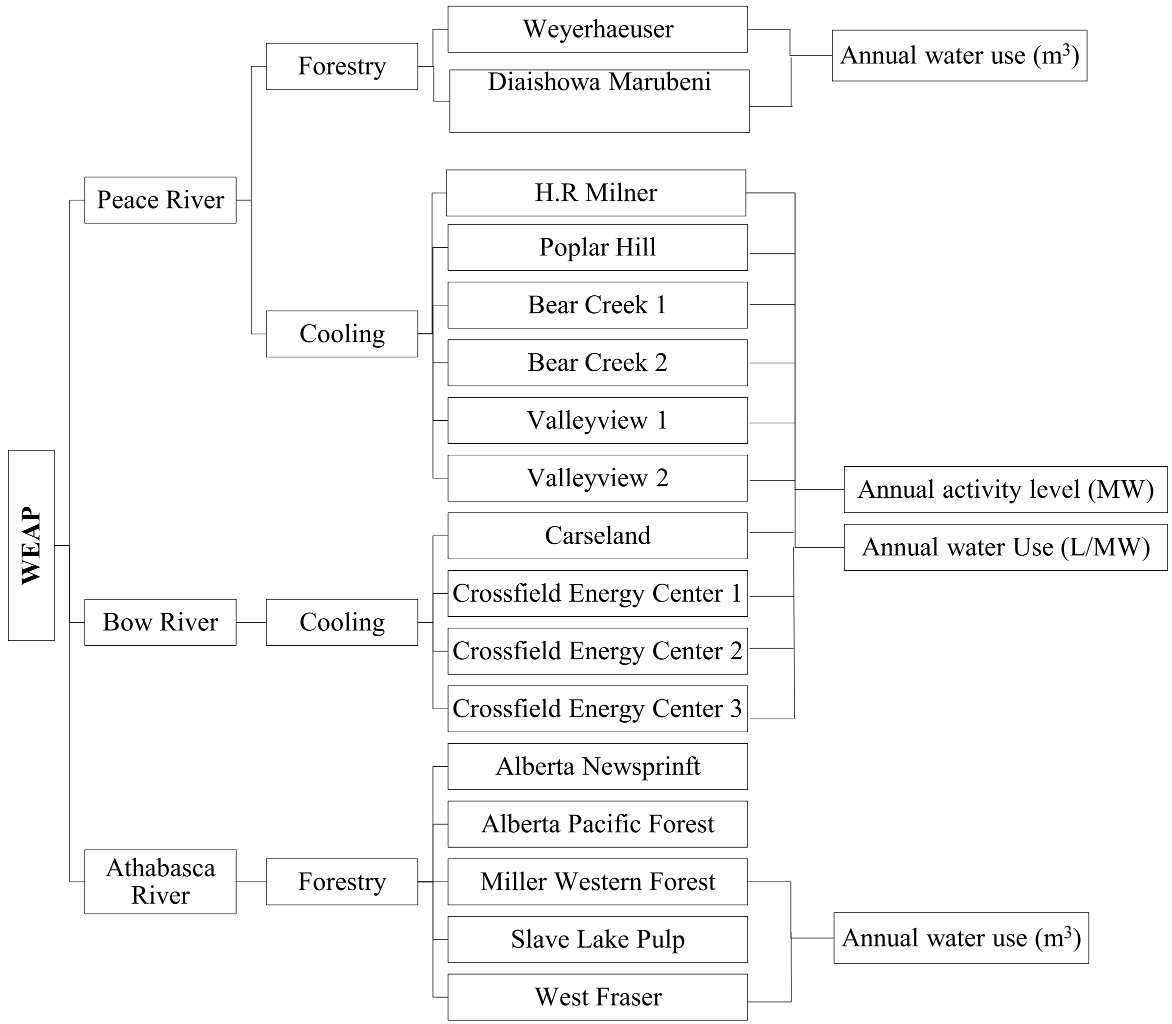


Figure 23: Industrial sub-sectors: Forestry and cooling framework development and input parameters for the Bow, Peace and Athabasca river basins

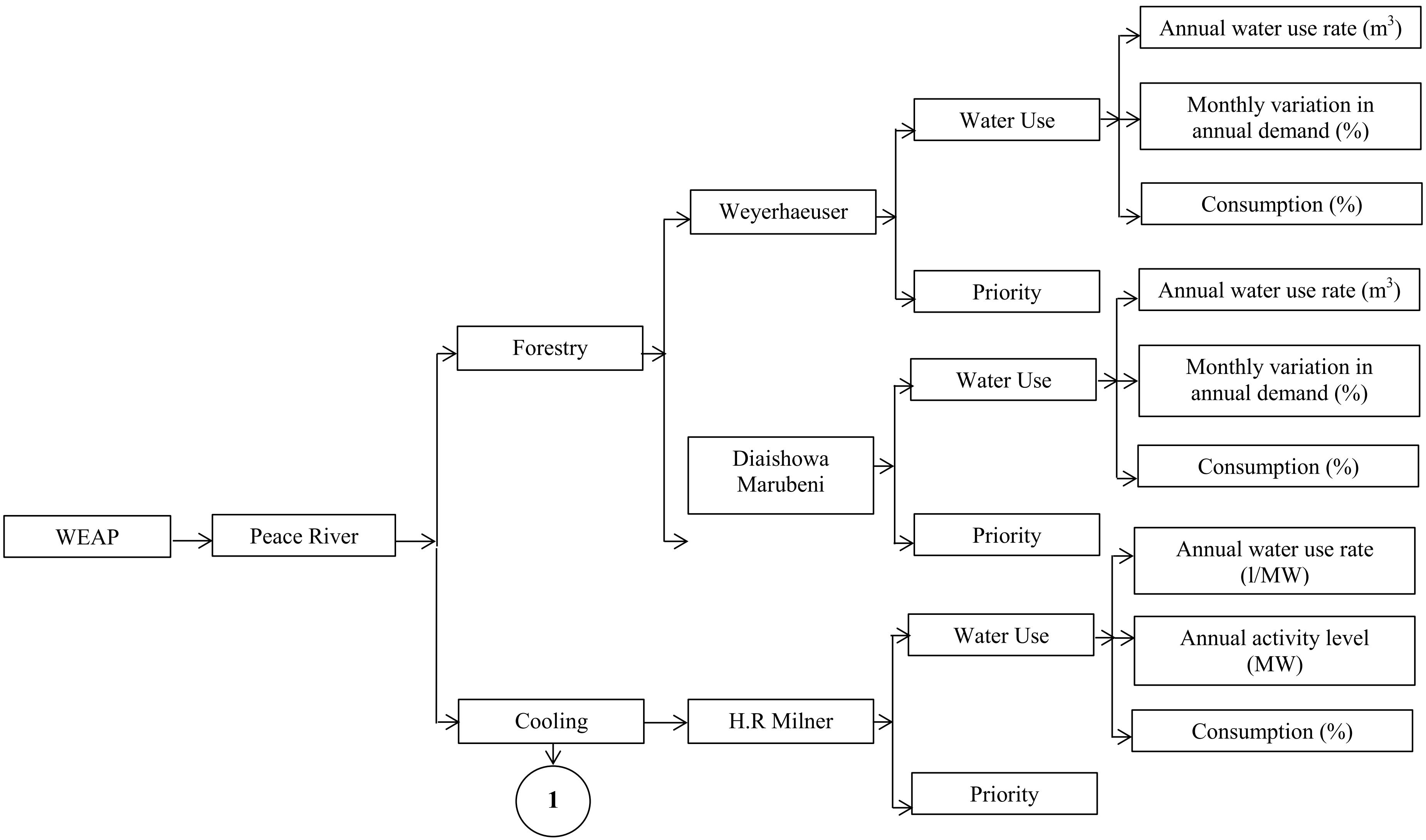
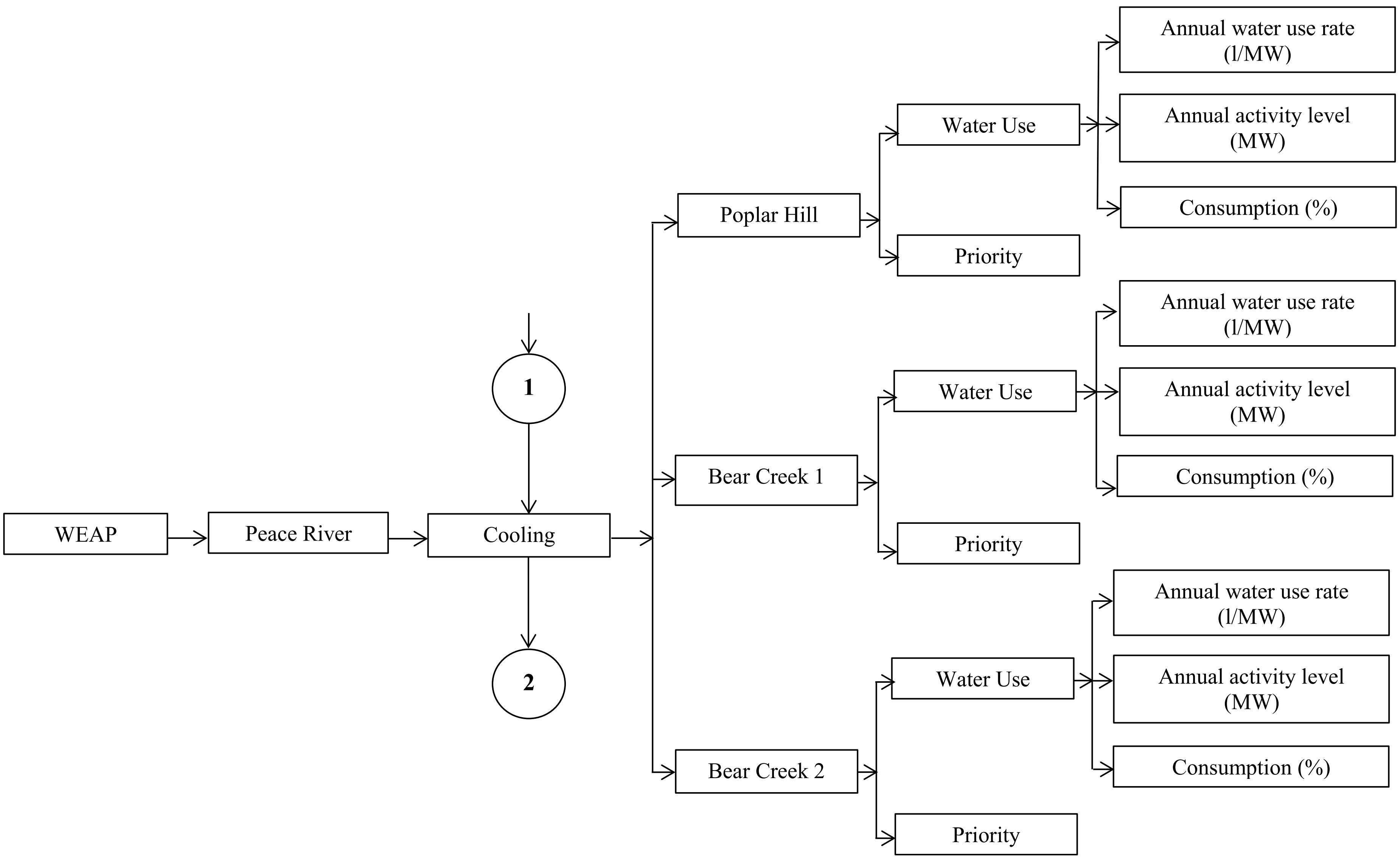


Figure 24: Overall framework development of industrial sector in WEAP



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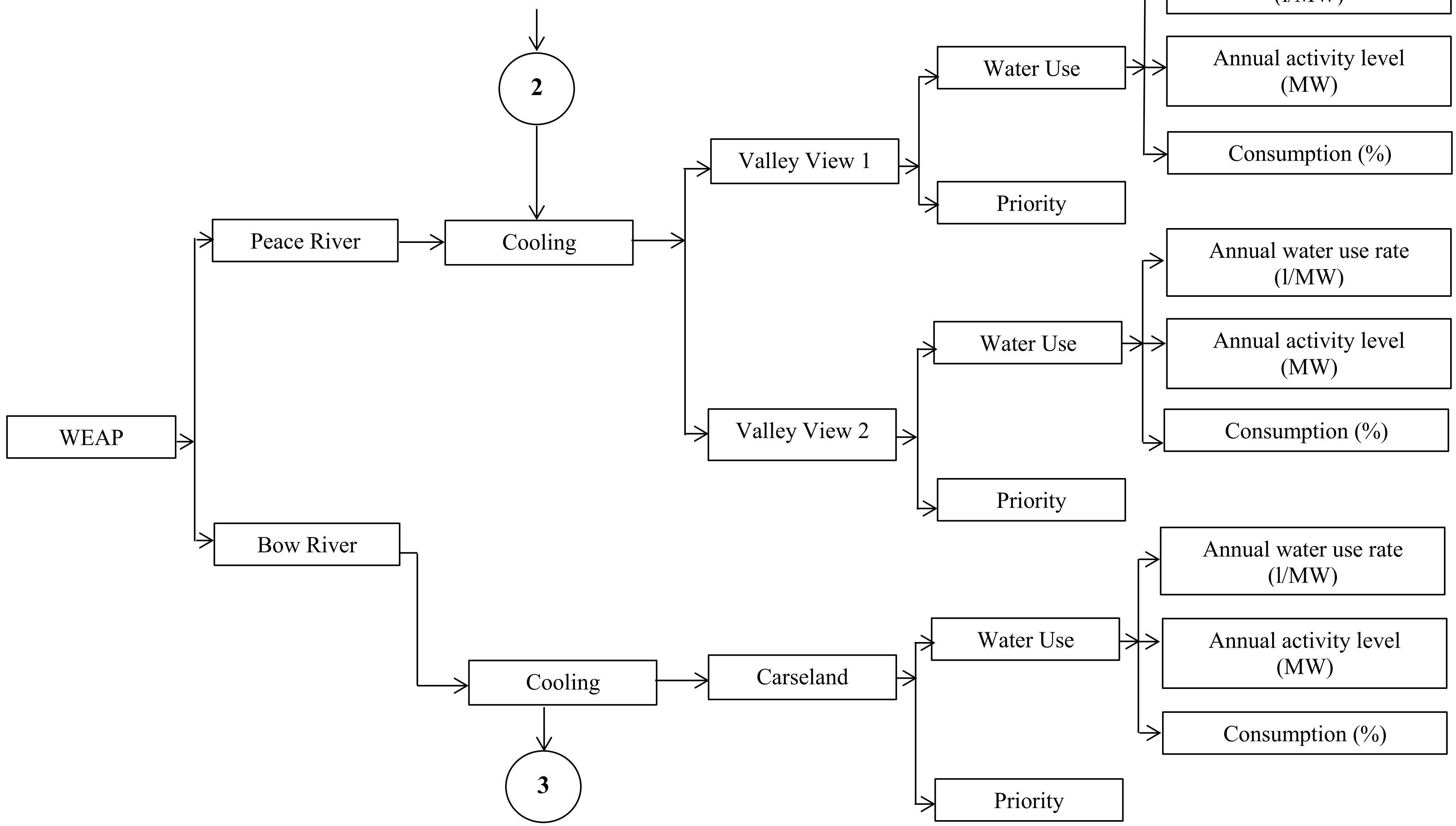

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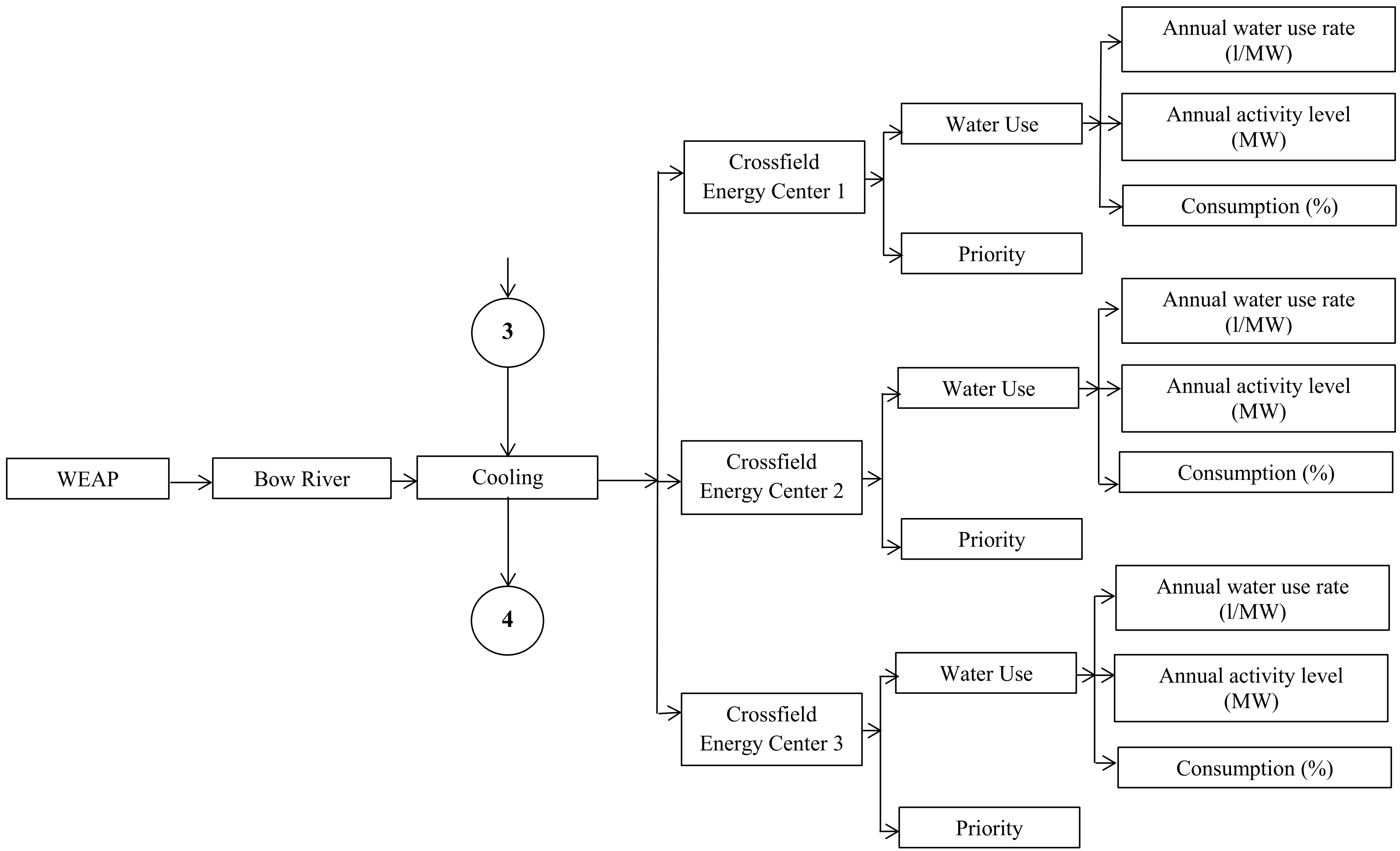

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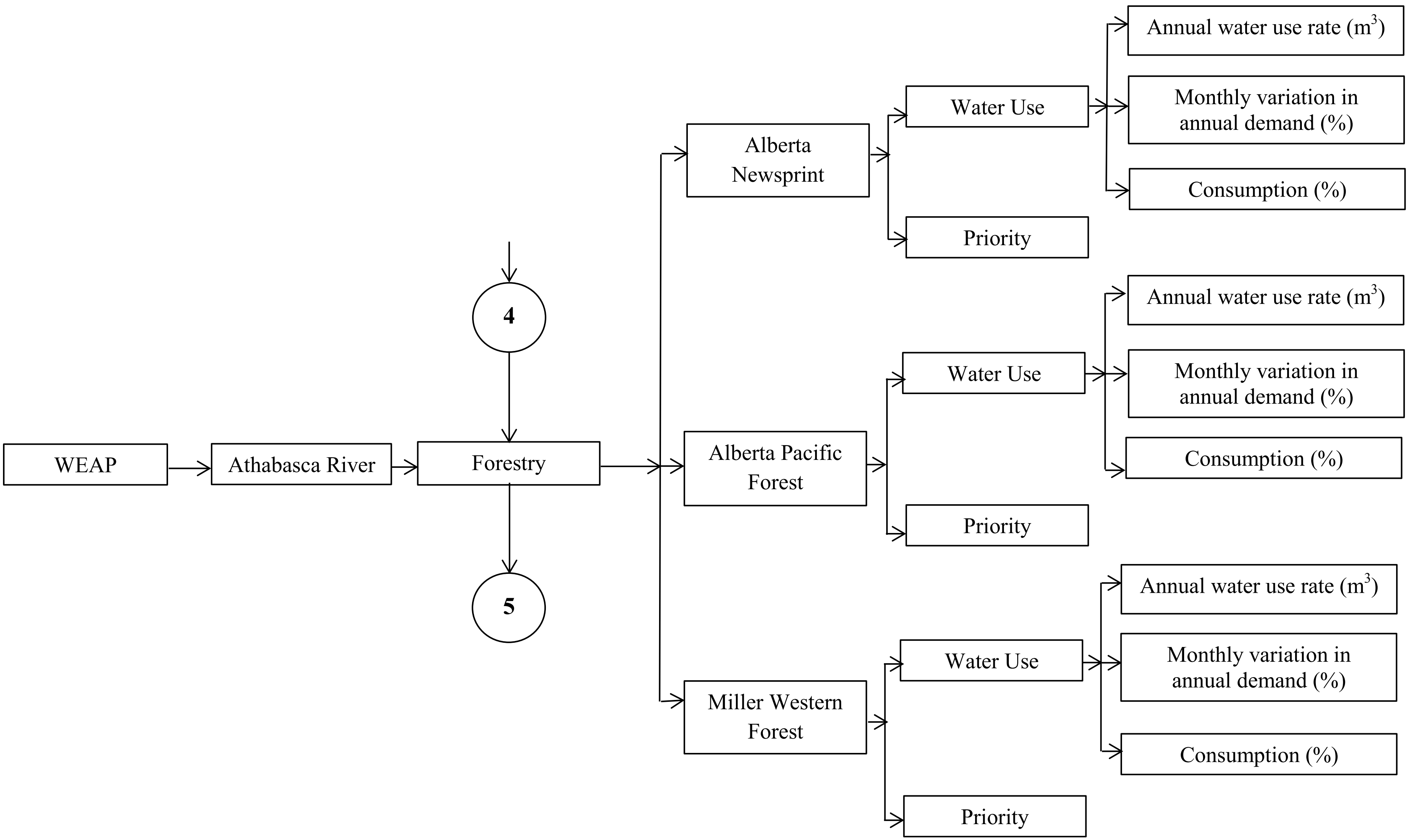

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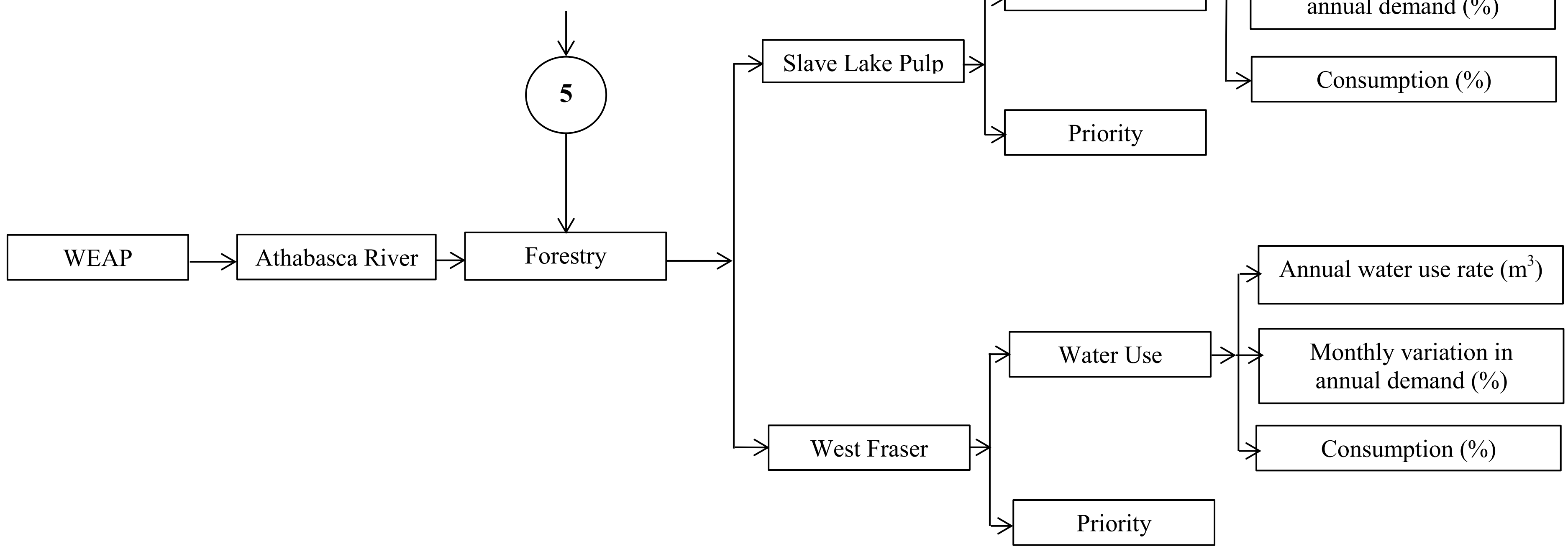

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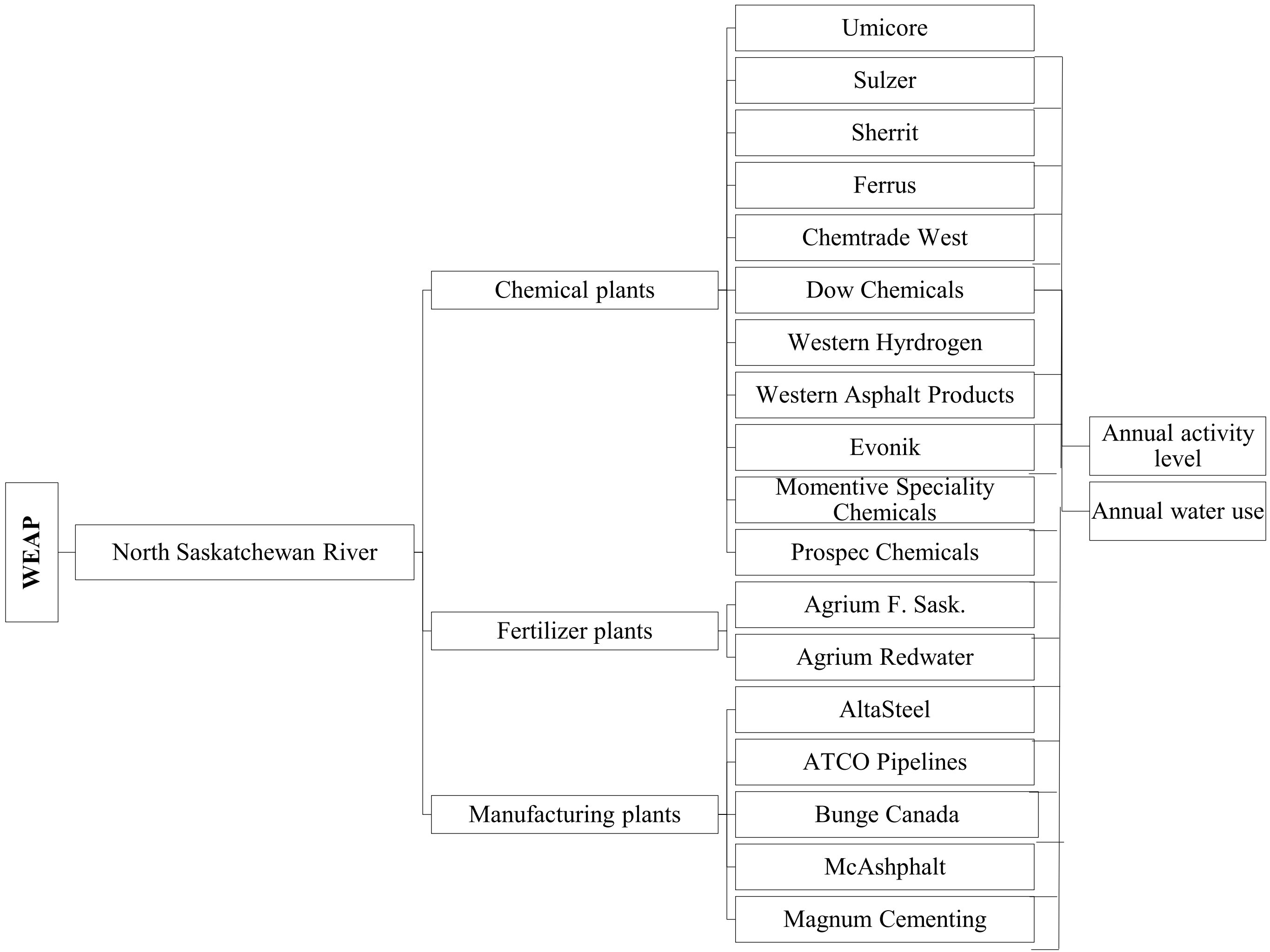


Figure 25: Industrial sub-sectors: Chemical, fertilizer, and manufacturing plants' demand tree for the North Saskatchewan River Basin

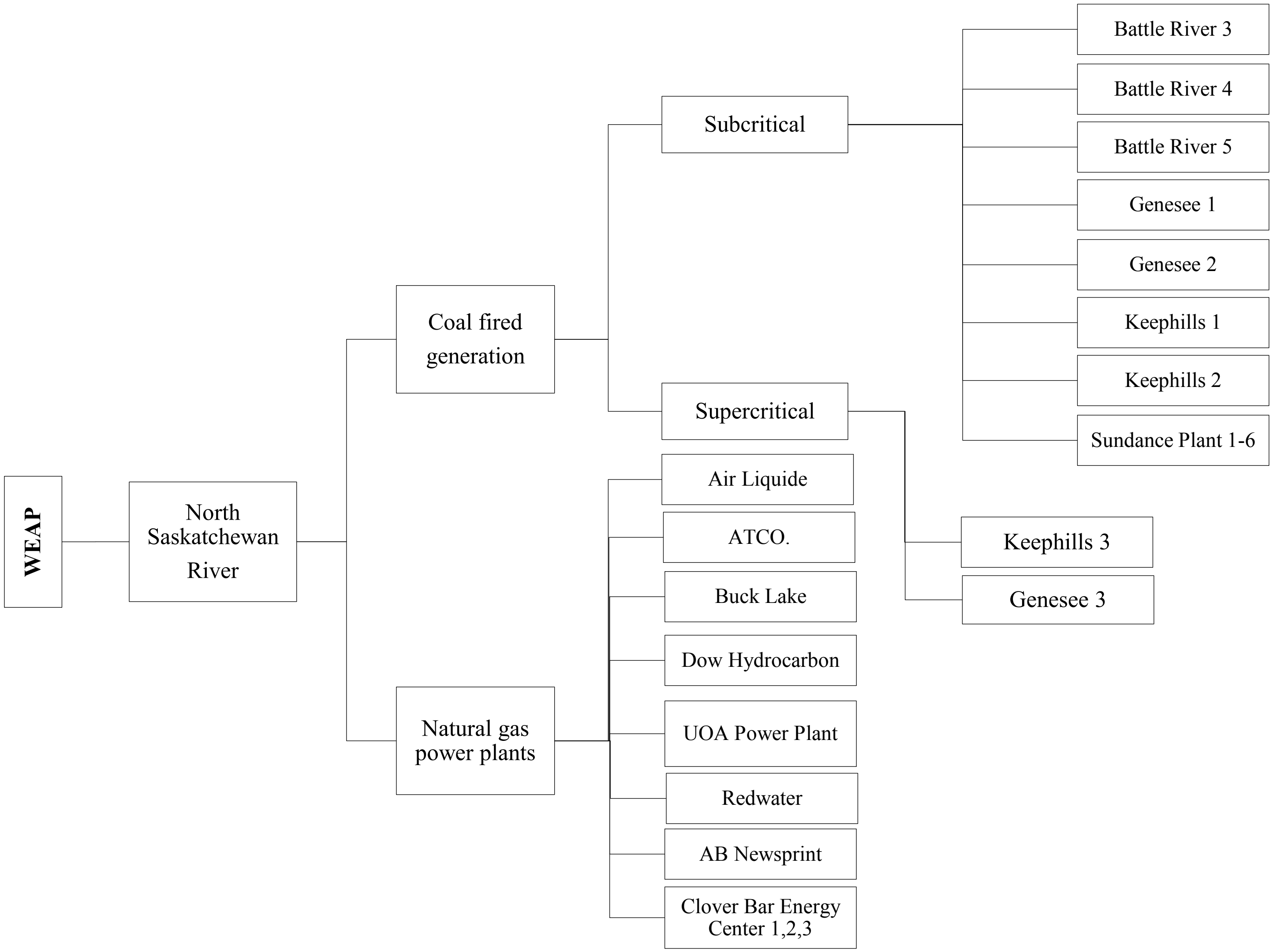


Figure 26: Industrial sub-sectors: Coal fired and natural gas power plants demand tree for the North Saskatchewan River Basin

2.5.4 Petroleum sector

2.5.4.1 Framework development and input parameters

For the petroleum sector for all river basins, the following information was incorporated into the model:

1. The North Saskatchewan River region petroleum sector consists of gas/petrochemical plants, injection, and other petroleum sub-sectors. There are four refineries operating in this region: Imperial Oil, Suncor, Shell Canada, and Husky Asphalt [73]. Table 12 shows these companies and their production capacity. All values are incorporated in WEAP modeling.

Table 12: Refineries in the North Saskatchewan region [78]

Sr. No.	Refinery	Production capacity (barrels/day)
1.	Imperial Oil	185,000
2.	Suncor	187,000
3.	Shell	110,000
4.	Husky Asphalt	25,000

2. The petroleum category has been allocated a small percentage (around 1%) of the total water allocation for the Bow River region [13]. All of Alberta's surface mining is in the Athabasca region, whereas in situ mining is done in the Athabasca, Cold Lake and Peace river areas [112]. The companies taking part in in situ activities are divided by river basin. Around 55 oil companies participate in bitumen extraction through in situ [113]. The following information was gathered and the data were input into the WEAP model:
   - Number of licenses for each company to extract bitumen
   - Amount of bitumen extracted against each licensee for each company
   - Division of companies' licenses on the basis of methods of bitumen extraction (primary, cyclic steam simulation [CSS] in which the same well is used for steam injection and bitumen extraction, steam assisted gravity drainage [SAGD] in which steam injection and bitumen extraction are carried through two separate wells, experimental, or other)

- The average water withdrawal coefficient for primary is considered to be the same as the extraction of conventional oil, i.e., 0.65 m^3/m^3 [114-116], CSS is 0.74 m^3/m^3 [87, 88, 117], and SAGD is 0.33 m^3/m^3 [87, 88, 118, 119].

3. Bitumen surface mining data for five companies (Suncor, Syncrude, Shell, Canadian Natural Resources Limited [CNRL], and Imperial Oil) were assessed and incorporated in the WEAP model based on the following:
    - The annual amount of bitumen extraction by each company.
    - Water withdrawal coefficients for each company from the years 2005 to 2012 are available except from CNRL Horizon. Shell has the lowest water withdrawal coefficient, i.e., 1.2 m^3/m^3 in 2011, followed by Syncrude with 1.56 m^3/m^3 in 2012 [120, 121].
4. There are four upgraders operating in the Athabasca River region: the Syncrude, Suncor, Opti or Nexen, and CNRL Horizon upgraders. The Shell Scotford upgrader operates in Fort Saskatchewan in the North Saskatchewan River region [122]. The amount of bitumen upgraded by each upgrader was used as an input to WEAP. The water coefficient for bitumen upgrading for the Shell Scotford upgrader is 0.5 m^3/m^3 [120]. The data entered in WEAP for bitumen extraction through surface and in situ mining are from 2002 to 2012.
5. 47.5 MCM of water was diverted for enhanced oil recovery in 2001. 78% of 47.5 MCM (37.1 MCM) came from fresh (non-saline) water resources. The remaining 22% (10.4 MCM) came from saline water sources. 72.5% (approx. 26.9 MCM) of the fresh water sources came from surface water and the remaining 27.5% (10.2 MCM) from ground water [14]. Around 49% of the fresh water was diverted for in situ mining in 2012 compared to 78% in 2001 [14, 123].

2.5.4.2 Assumptions

The following are the assumptions for the petroleum sector for all four river basins:

1. About one-third of the Cold Lake oil sands area lies within the North Saskatchewan region, but bitumen extraction done there is through cold heavy oil production with sand (CHOPS), which requires no steam [78] and hence so little water that it is not included in

our input data. For simplicity, bitumen extraction in the Cold Lake region is considered to be part of the Athabasca region for this model.

2. An average of around 2.62 cubic meters of water is required to extract one cubic meter of bitumen through surface mining [87-89, 114, 119, 121, 124, 125]. The water coefficients for Shell are assumed to be 2.62 m^3/m^3 from 2002 to 2005 and for CNRL, 2.62 m^3/m^3 from 2002 to 2012, as no data for these time periods were available. .
3. The average water coefficient assumed for bitumen upgrading for all the upgraders except for the Shell Scotford upgrader is 0.79 m^3/m^3 [87-90]. The average water coefficient for bitumen refining for all the refineries is considered to be 1.75 m^3/m^3 [74-77, 79, 87].
4. The gas/petrochemical plants and other petroleum sub-sectors in the Peace River region have a very small percentage of water demand, so their water allocation values for 2005 are considered for the base year. Water allocation for gas/petrochemical plants and other petroleum sub-sectors in the Peace River region and the petroleum sector in the Bow River region are assumed to remain constant throughout the study period.

2.5.4.3 WEAP demand tree

The demand tree for the petroleum sector for all river basins is shown in Figure 27. The gas and petrochemical plants have been further classified (see Table 11). The annual activity levels and water intensities have been added. The demand tree data input for the petroleum sub-sectors oil mining and upgraders for the Athabasca River Basin is given in Figure 28. Bitumen mining is considered to be part of oil mining. Bitumen can be recovered from surface or in situ mining. Five companies extract bitumen through surface mining, whereas around 55 companies mine bitumen through in situ [112, 113]. In situ mining is further classified based on bitumen recovery method. Recovery methods include CSS, SAGD, and primary and enhanced recovery schemes. Some of the companies that do in situ mining include Shell Canada Limited, Murphy Oil Company Limited, Cenovus Energy, CNRL, StatOil Canada Limited, Suncor Energy Incorporation, and Nexen Incorporation. All of the companies were divided according to bitumen recovery method and then further segregated into the number of licenses provided to recover bitumen from a particular method. The amount of bitumen recovered by each licensee is entered in WEAP for the years 2002 to 2012. Figure 29 shows the overall WEAP framework and demand tree development of the petroleum sector for the Athabasca River Basin.

The demand tree data inputs for the petroleum sub-sectors for the Peace and North Saskatchewan river basins are given in Figures 30 and 31, respectively. Figure 30 shows all the companies in the Peace River Basin along with their methods of bitumen recovery and the input parameters that were entered in the WEAP model. Figure 31 shows all the demand sub-sectors for the petroleum sector in the North Saskatchewan River Basin. There are four refineries operating in this region and a Shell Scotford upgrader.

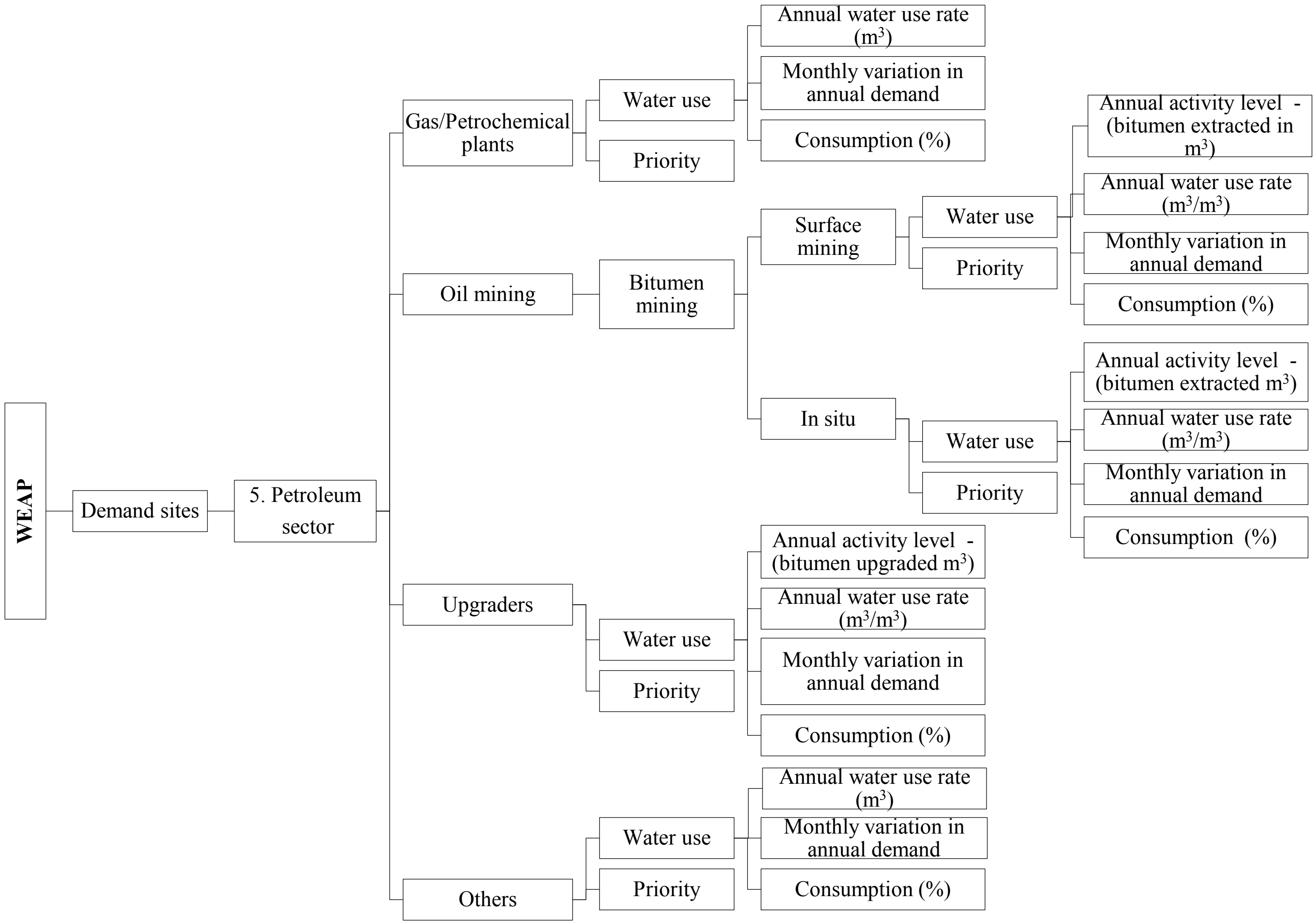


Figure 27: WEAP framework development and input parameters for the petroleum sector

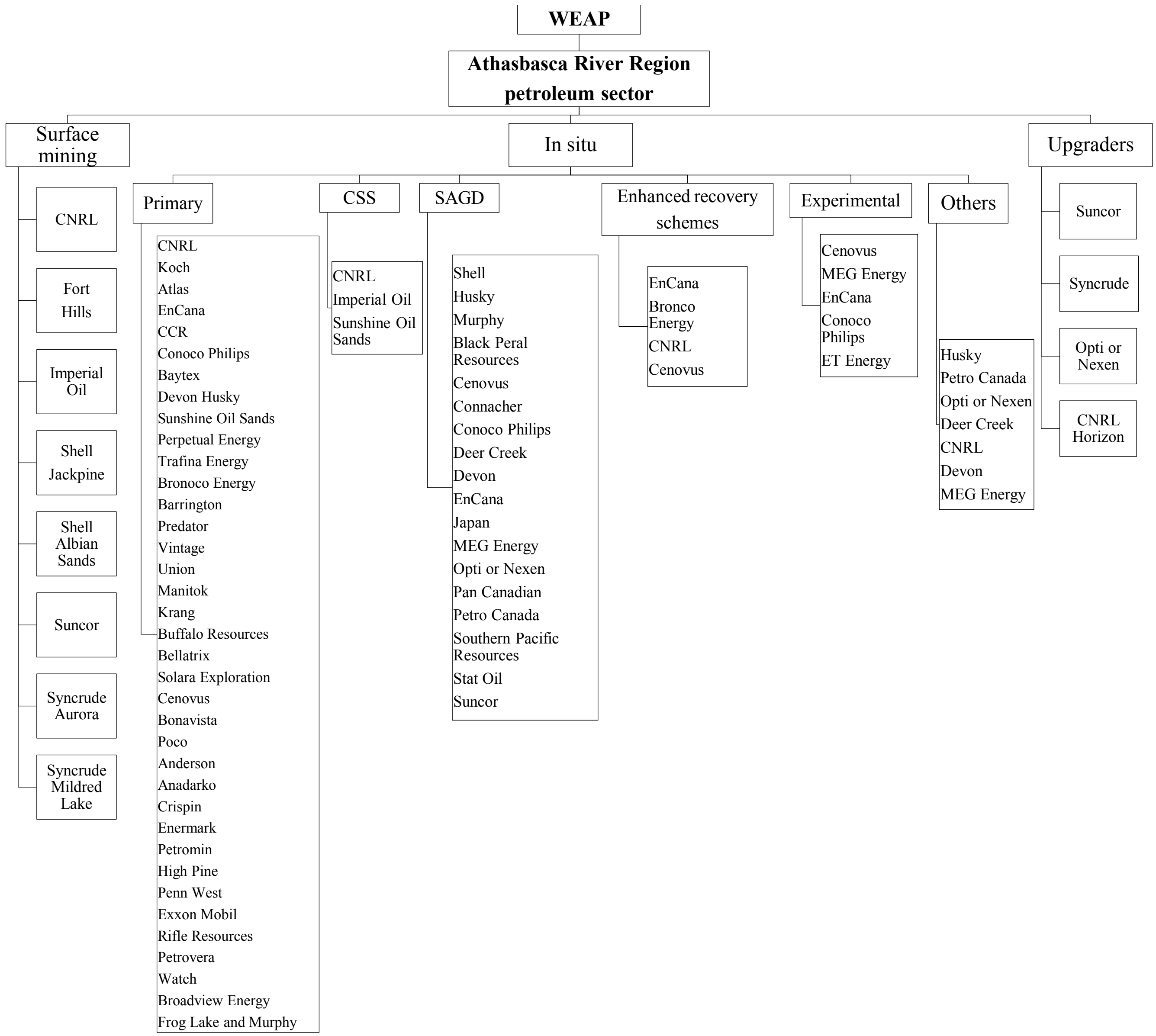


Figure 28: Petroleum sub-sectors: Oil mining and upgrader demand data tree for the Athabasca River Basin

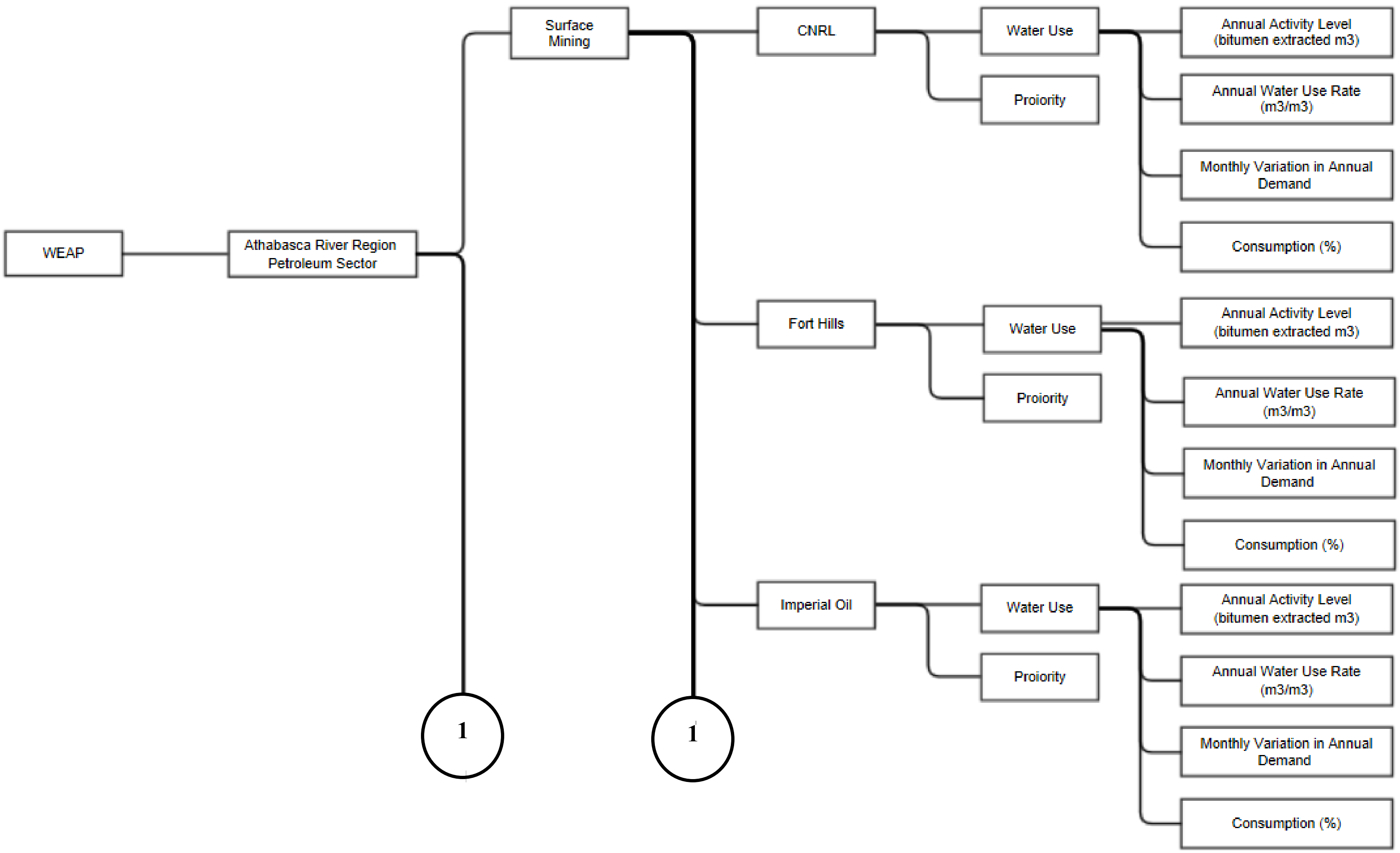
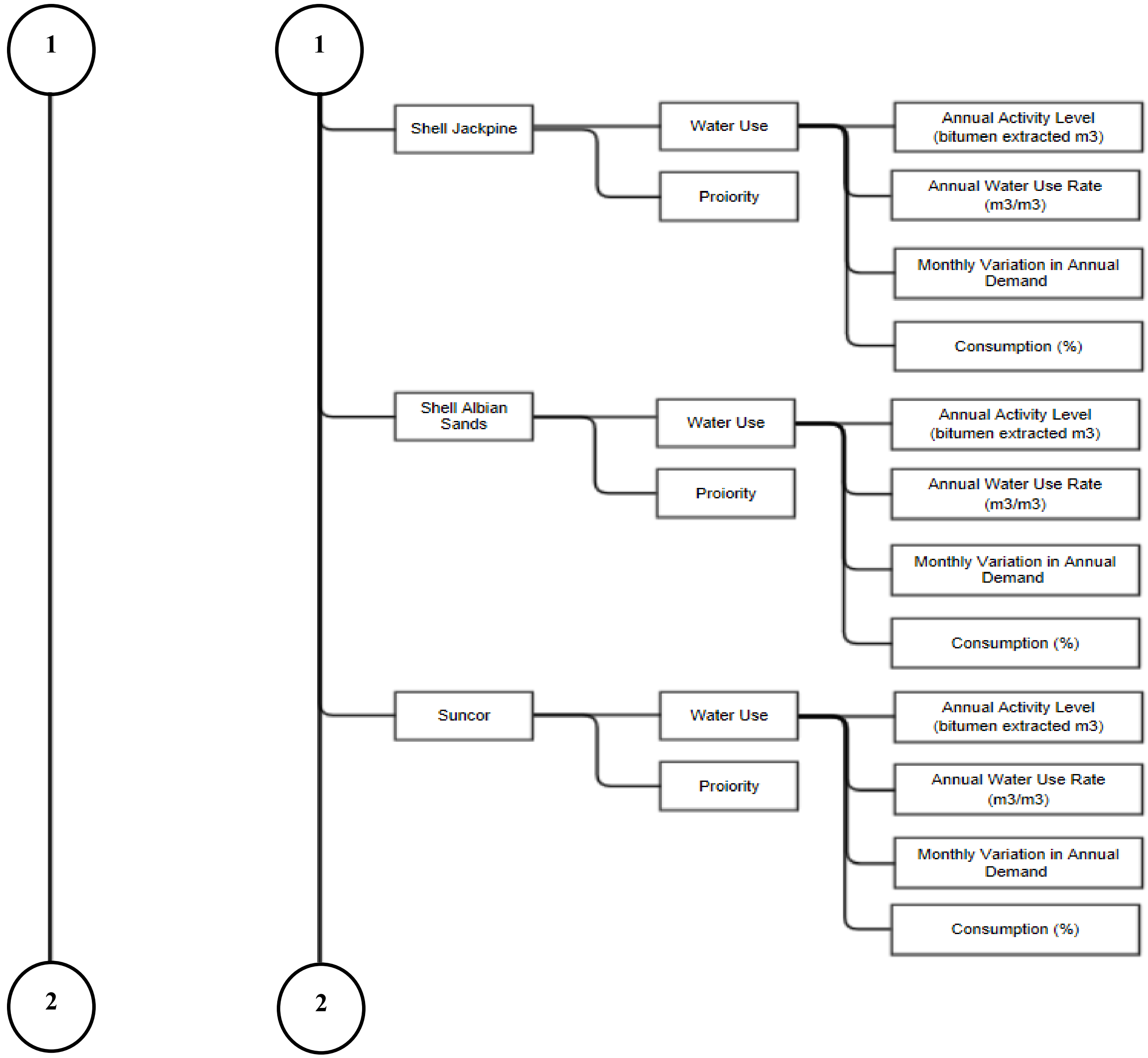


Figure 29: Overall WEAP framework development and demand tree for the petroleum sector for the Athabasca River Basin



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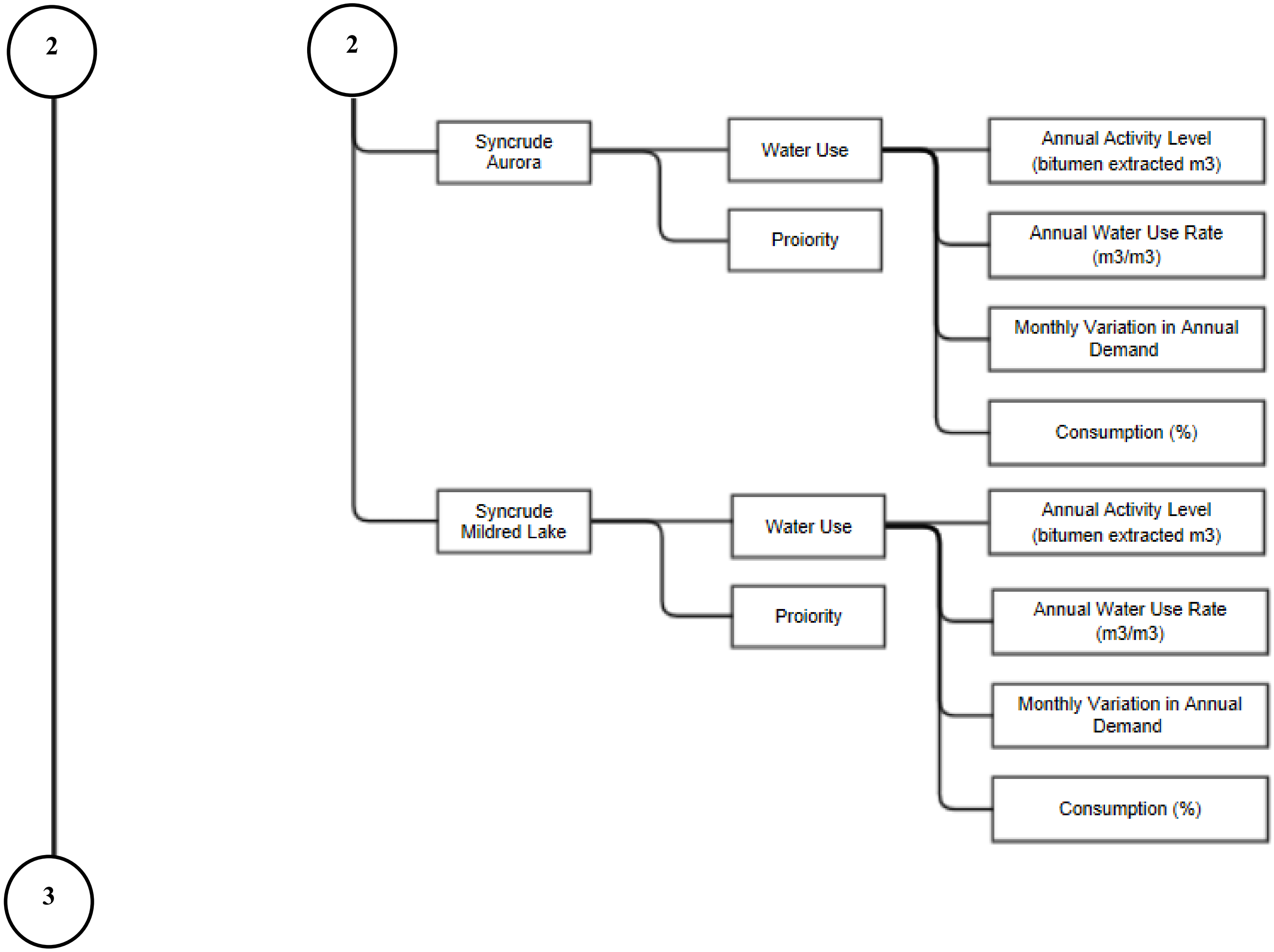

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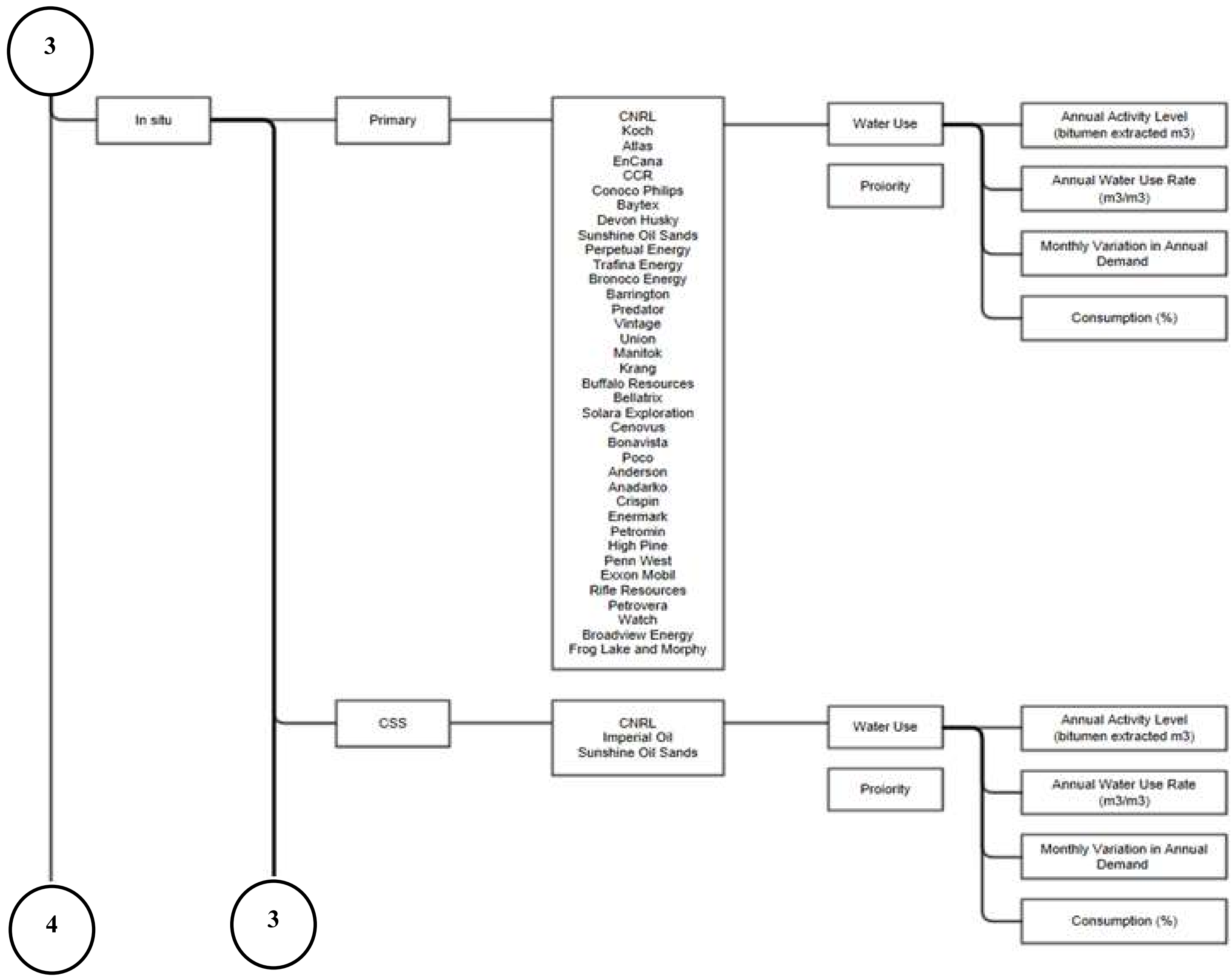

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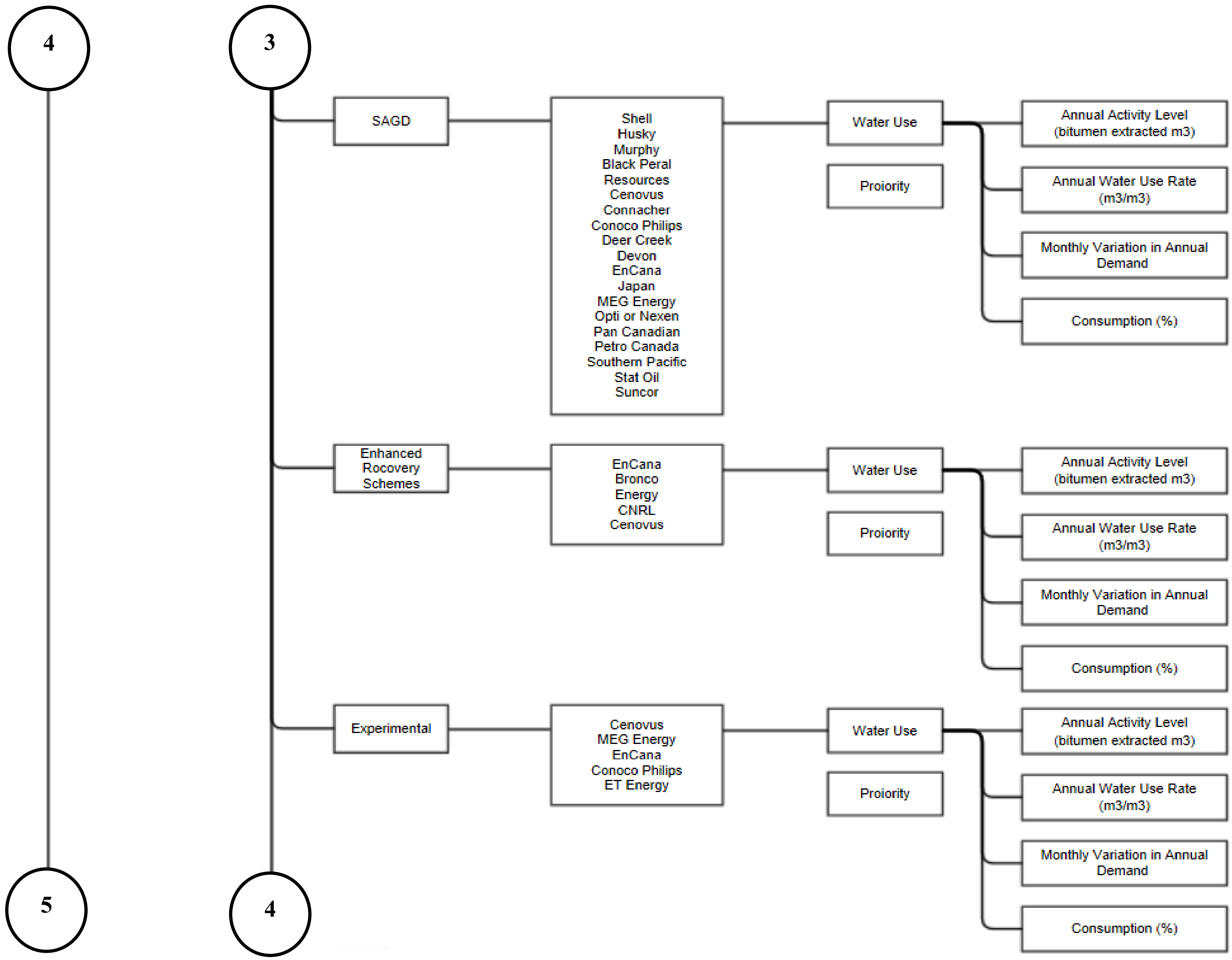

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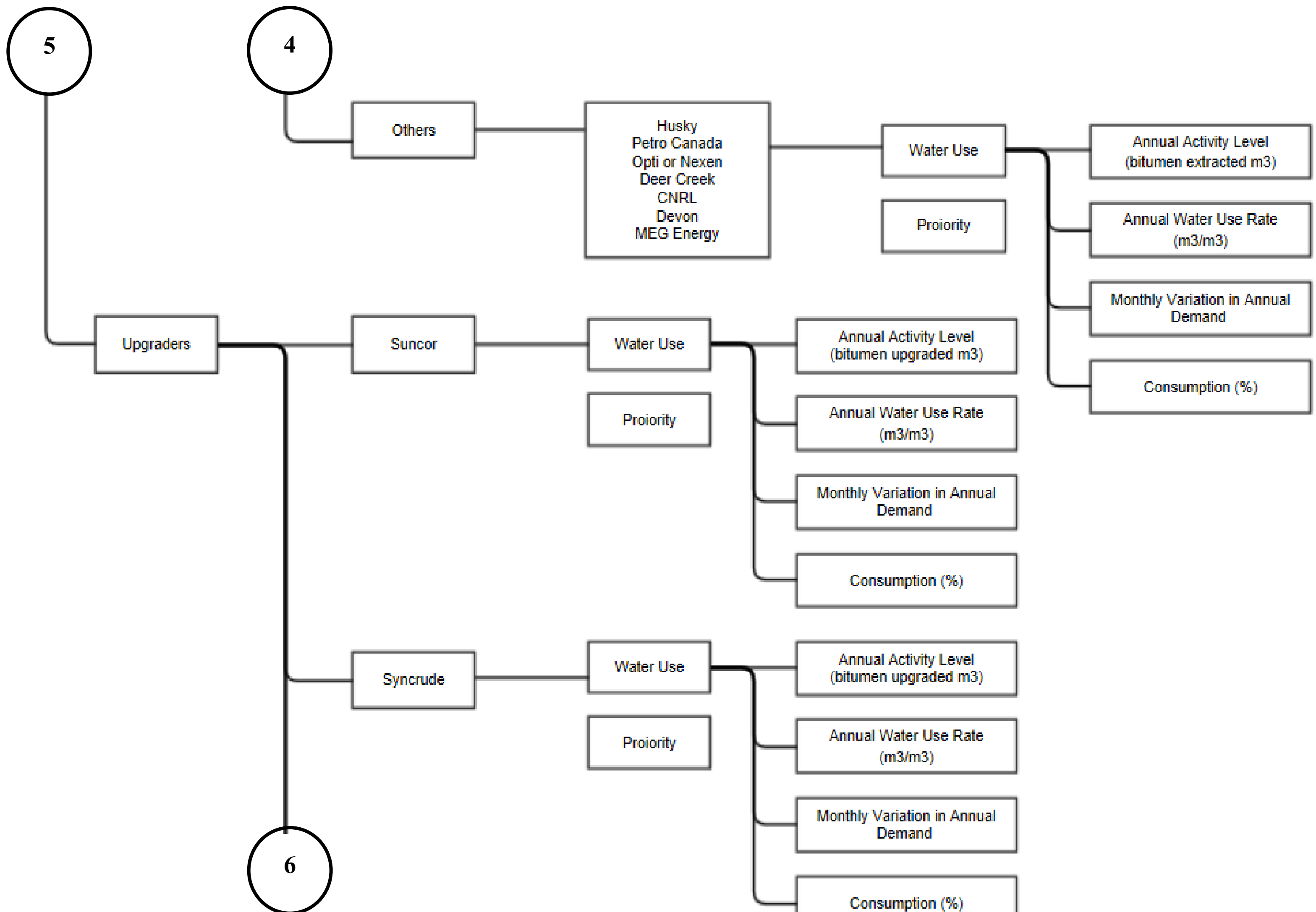

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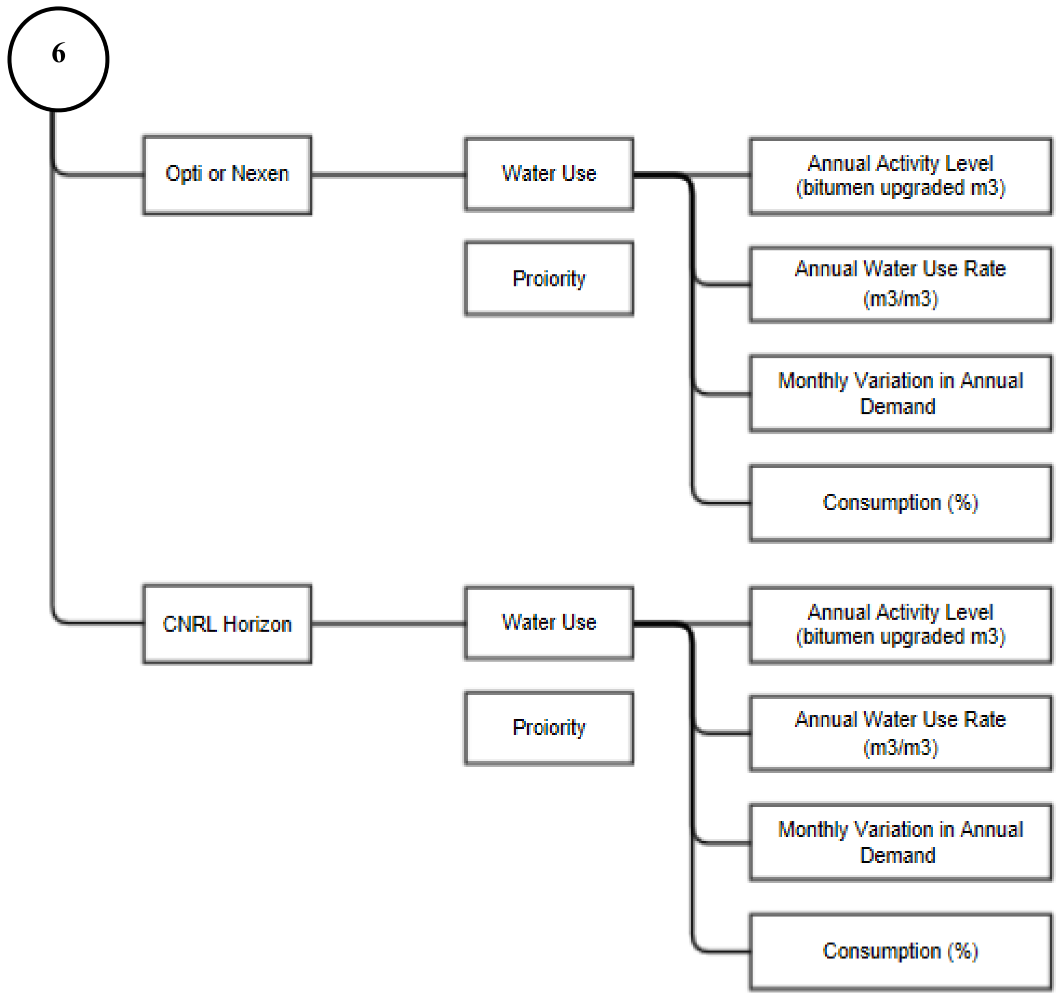

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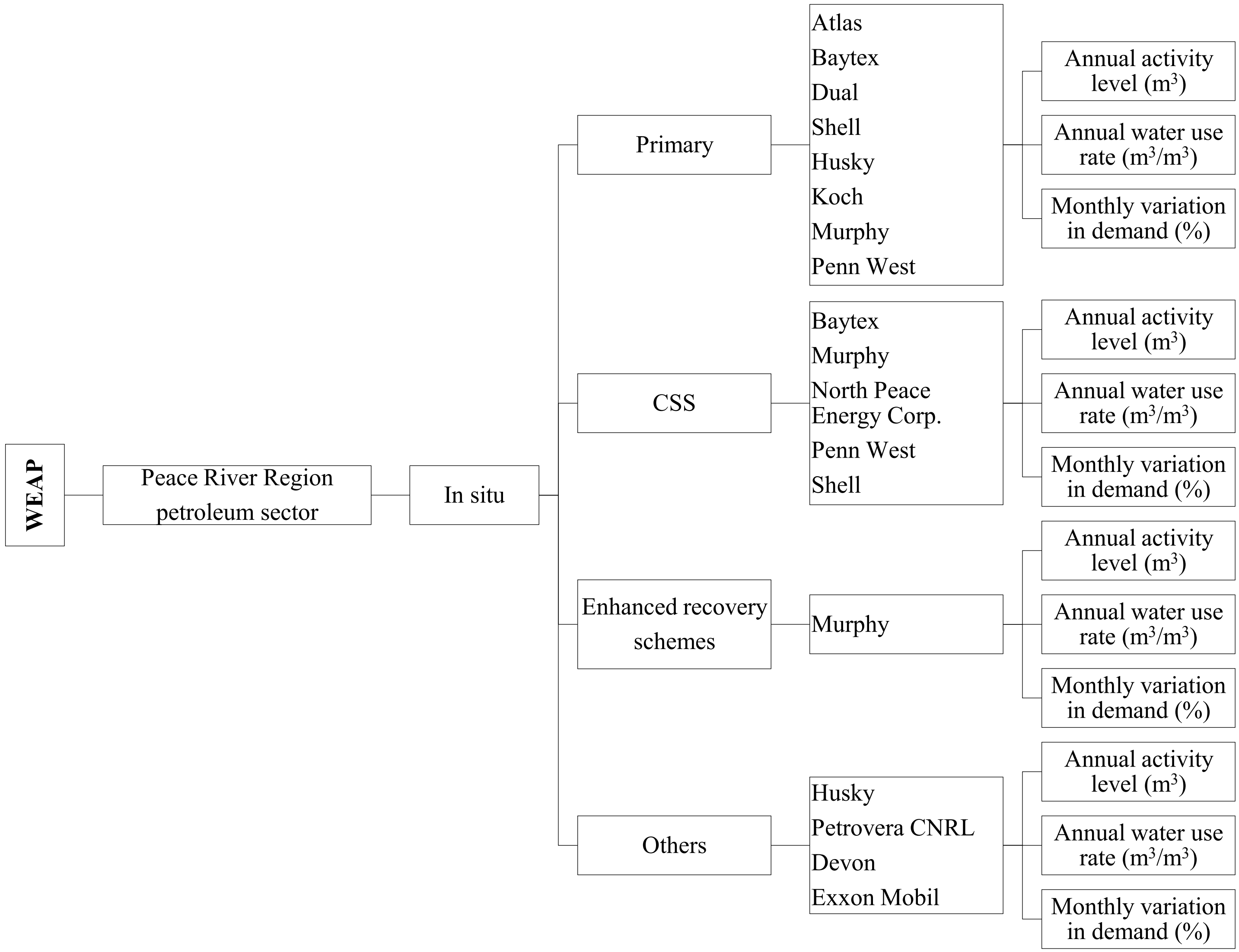

Figure 30: Petroleum sub-sector: Oil mining demand tree for the Peace River Basin

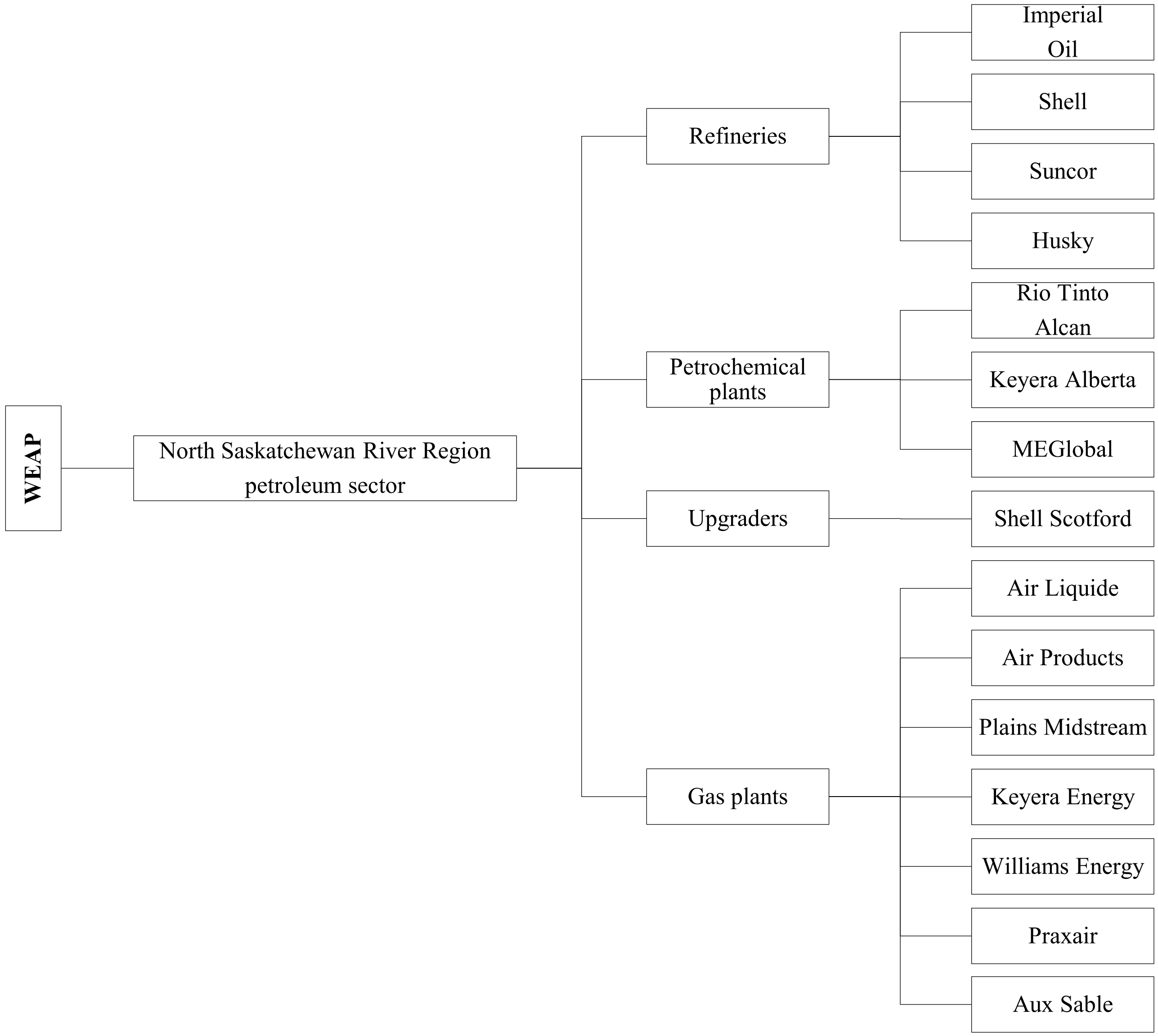

Figure 31: Petroleum sub-sector demand tree for the North Saskatchewan River Basin

2.5.5 Commercial sector

2.5.5.1 Framework development and input parameters

The commercial sector sub-sectors are shown in Table 4. For the framework development of the commercial sector of all river basins, the following input parameters were considered:

1. Three subsectors – gardening, aggregate washing, and golf courses – make up to about 77% of the total water allocation for the commercial sector in the North Saskatchewan River Basin [13].
2. In the Bow River Basin, the sub-sectors parks & recreation, golf courses, and food processing account for about 90% of the total water allocation for the commercial sector [13].
3. About 86% of the total water allocation for the commercial sector in the Peace River Basin goes to the sub-sectors golf courses, gardening, and other [13].
4. The golf courses, aggregate washing, and other commercial uses are responsible for about 76% of the total water allocation for the commercial sector in the Athabasca River Basin [13].
5. The commercial sector accounts for around 1% of the total water allocation for each of the four river basins [13]. The values of water allocation for 2005 for the sub-sectors of the commercial sector are considered as the input data to the WEAP model for 2009.

2.5.5.2 Assumptions

The increase in water demand of major sub-sectors has been considered while other sub-sectors with very low water demand are assumed to stay constant [13]. The following are the assumptions for the commercial sector for all four river basins:

1. The water demand for the sub-sectors (gardening, aggregate washing, and golf courses) is projected over the time horizon. The water required for the remaining sub-sectors (parks and recreation, food processing, bottling, dust control, etc.) remains constant throughout the forecast period for the North Saskatchewan River Basin [13].

2. It is assumed that the water required by the sub-sectors other than parks & recreation, golf course and food processing remain constant throughout the projection period in the Bow River basin [13].
3. The water required by all the sub-sectors remains constant throughout the forecast period in the Peace River Basin except for the major sub-sectors (golf courses, gardening, and other) [13].
4. For the Athabasca River Basin, it is considered that the water required by the sub-sectors other than golf courses, aggregate washing and other commercial uses remains constant throughout the study period [13].

2.5.5.3 WEAP demand tree

The demand tree for the commercial sector for all river basins is shown in Figure 32, and the tree shows the sub-sectors that are the major water consumers. The sub-sectors of "other categories" includes all the demand sites that have minor water requirements, for example, dust control, bottling, and construction. Annual water use has been entered in the WEAP model.

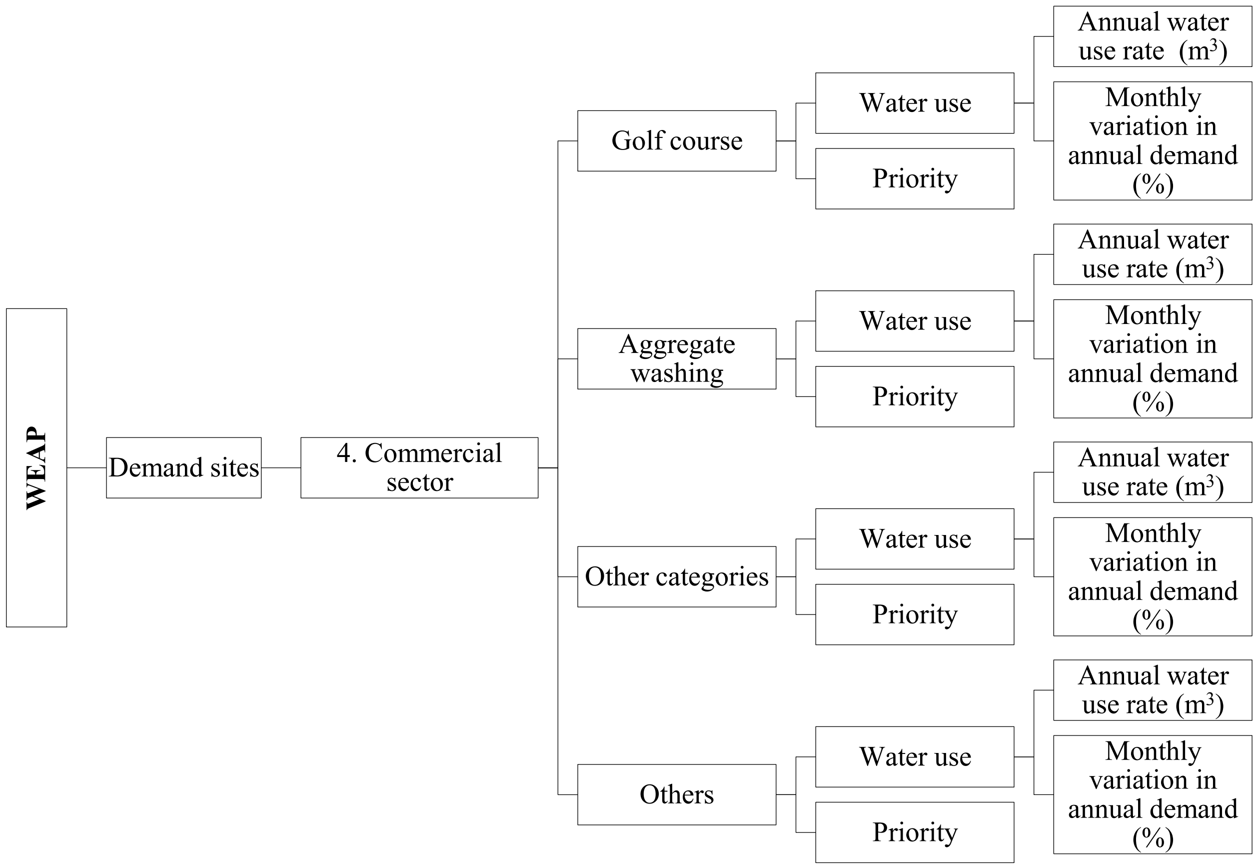

Figure 32: Framework development and input parameters for the commercial sector for the WEAP model

2.5.6 "Other" sector

2.5.6.1 Framework development and input parameters

The "other" sector comprises the sub-sectors water management, habitat, water conservation, and specified uses. For the "other" sector of all the river basins considered in this study, the following input is used in the WEAP model:

1. The "other" sector accounts for only 2%, 1%, 39%, and 7% of the total water allocations of the North Saskatchewan, Bow, Peace, and Athabasca river regions, respectively [13].
2. AMEC's 2005 water allocation values for the sub-sectors of "other" sector are used as the input parameters to the WEAP model [13].

2.5.6.2 Assumptions

The following are the assumptions for the "other" sector for all four river basins:

1. Due to the limited available information for the "other" sector in the Peace and Athabasca river regions, it is assumed that the water required for water management activities and specified activities will remain constant throughout the forecast period.

2.5.6.3 WEAP demand tree

The demand tree for the "other" sector is shown in Figure 33. The figure shows the framework development and the input parameters entered in the WEAP model. The annual water use rate has been added for all the sub-sectors. Consumption and priority have been inserted into the model for the sector as a whole for each river basin.

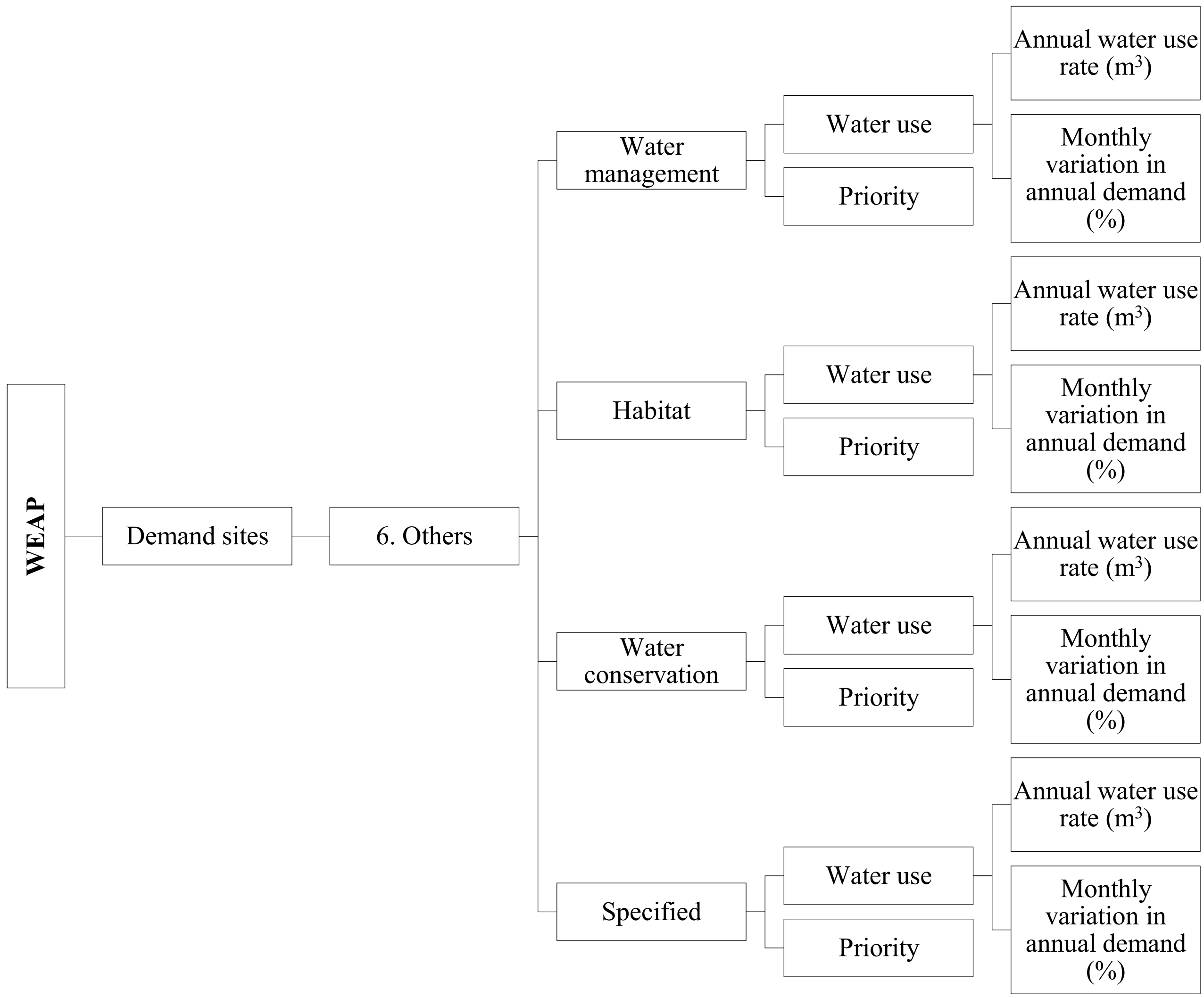

Figure 33: "Other" sector demand tree in the WEAP model

2.5.7 Demand priorities for the demand sectors

The demand sectors competing for water from the same source are allocated water according to their demand priorities [48]. According to the provincial Water Act, priority is given on a first-in-time, first-in-right basis [15]. In this analysis, individual license priorities are not addressed. Rather, all the similar water demands are considered in a single demand node. For example, all houses, office buildings are considered in municipal sector rather than considering different priorities for all houses or buildings on the first-in-time, first-in-right basis. The demand priorities assumed for different sectors in the WEAP model are given in Table 13. There are no sectorial priorities given by Alberta Environment so these priorities were assumed on the importance of a sector (such as municipal or "other" sector for water conservation are more important than other demand sectors) and the highest sectorial activity percentage in that particular basin. The number "1" indicates the highest priority and "3" indicates the lowest.

Table 13: Water demand priorities

Sectors	North Saskatchewan River	Bow River	Athabasca River	Peace River
Municipal	1	1	1	1
Agriculture	2	2	2	2
Industrial	2	2	3	3
Petroleum	3	3	2	2
Commercial	3	3	3	3
Other	1	1	1	1

The WEAP model for Alberta portrays the optimistic/ideal results for the water flow of the river basins (as climatic conditions are not considered) due to which the water demands by all the sectors are satisfied by their respective river sources. Demand priorities have a more significant role if there is a water shortage in any year (e.g., drought conditions). In that case, the WEAP model would first allocate water to the high priority sectors by limiting the water supply to the low priority sectors.

2.6 Alberta's WEAP model validation

In the previous sections, the input data, assumptions, and the approach to developing the WEAP framework for Alberta were discussed. The water intensities for different sub-sectors, the annual activity levels, and consumption percentages were used to develop the demand side of the model in WEAP.

This study provides a detailed insight of the water demand and supply patterns. It describes the major demand sectors and sub-sectors. Although the research approach is much more detailed than any other study, it also includes the WEAP model validation. In order to validate the model, water demand and use for the years 2005 to 2009 for all the sectors except for the petroleum sector are compared to the values available in different published reports. For the petroleum sector, the WEAP model uses existing data for the years 2002 to 2012 to validate the model. In the following sections, validation will be discussed on the basis of sectors for all the river basins.

2.6.1 Municipal sector

Figures 34 and 35 below show how the WEAP model captures the trend of water demand for the considered river basins for Alberta's municipal sector. In Figure 34, the water demand values calculated by WEAP for 2005 are very close to the values published by AMEC Report [13] except for the water demand in the Bow River region. The main reason for this difference is that AMEC's values considered for model validation are the licensed allocation values whereas WEAP calculates the actual diversion on the basis of population and region-specific per capita water use. The licensed water allocation is always usually a lot higher than the actual water diverted.

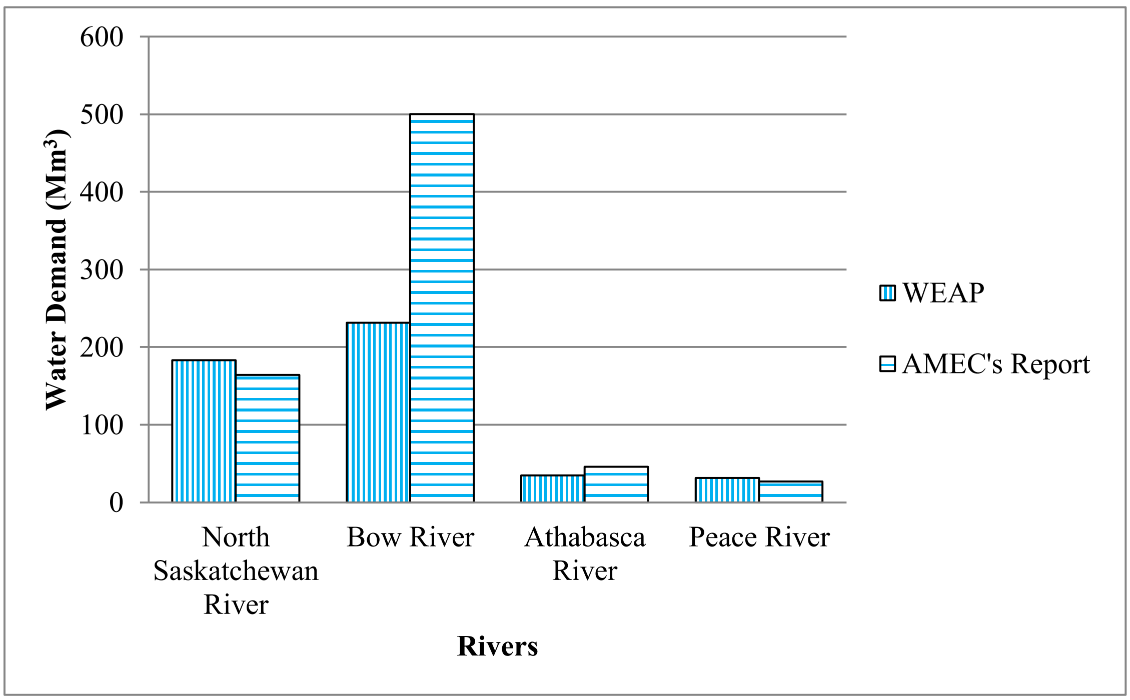

Figure 34: Municipal sector licensed water allocation for the four major rivers in Alberta in 2005

Figure 35 gives actual water diversion values from the WEAP model and AMEC's report. The reason for the differences in the values by the WEAP model and AMEC is that the values from AMEC's report understate the actual diversion because not all license holders report their actual water diversions to Alberta Environment WURS [13]. This effect is quite prominent in case of the Athabasca River Basin.

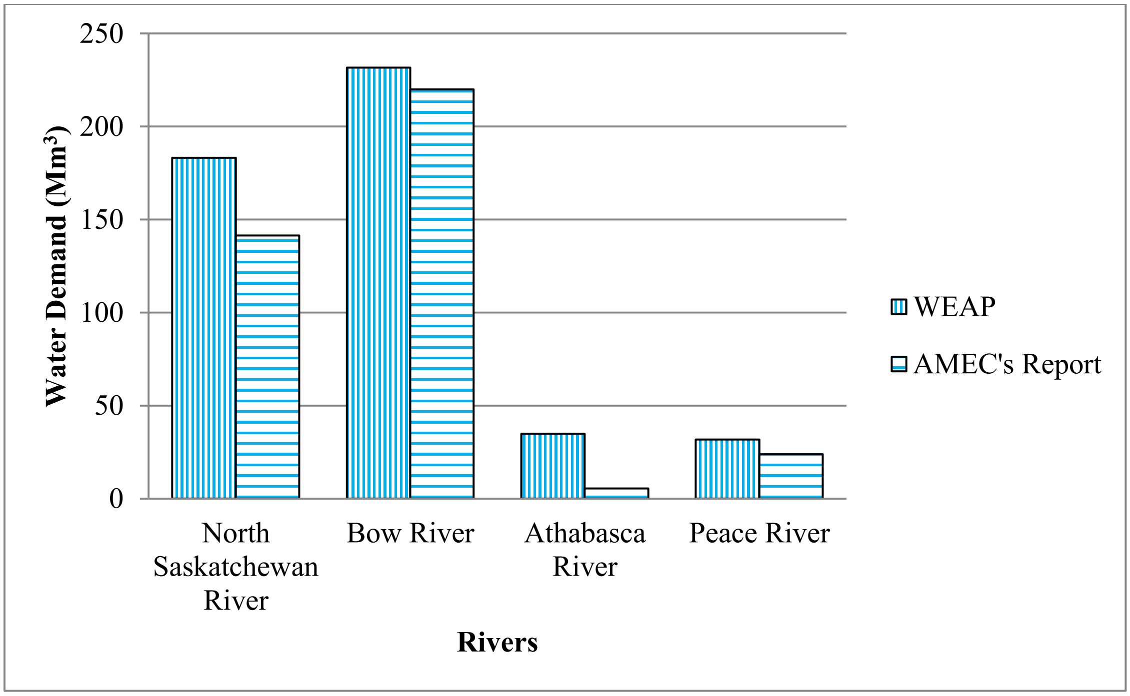

Figure 35: Municipal sector actual water diversion for Alberta's four major rivers in 2005

The municipal water withdrawal values for the Bow River Basin are given in Table 14. The water demand in 2030 calculated by WEAP is for the reference scenario, which is based on the medium population growth rate. The percentage difference in the WEAP model and AMEC's values is around 23% in 2008 and 15% in 2030. The projected values published by AMEC are for surface water only whereas WEAP calculates the total water withdrawal for both surface and groundwater. This is also one of the reasons for the variation between the model and AMEC's report.

Table 14: Municipal water withdrawal values for the Bow River Basin

	Water withdrawal (Mm^3)	
	2008	**2030**
AMEC	199.27	307.391
WEAP model	245.91	261.45
Percentage difference	23%	15%

2.6.2 Agriculture sector

Figure 36 shows that the water demand values calculated by WEAP for 2005 are very close to the values published by AMEC. The percentage difference between these two set of values, called the estimated error, is in the range of 5-21%. AMEC's values considered for model validation are the licensed allocation values whereas WEAP calculates the actual values on the basis of livestock population and its per capita water use as well as the number of acres irrigated for each crop and the crops' water intensities. The actual water diversion values are not available. So in the absence of data, licensed water allocations are used for model validation. The licensed water allocation is always usually much higher than the actual water diverted.

Water withdrawal for irrigation in the Bow River region in 2008 was 961.436 Mm^3 [15]. The WEAP model calculated it to be 979.33 Mm^3 with a percentage error of 1.8%. Water withdrawal for livestock in the Bow River region in 2008 was 8.006 Mm^3 [15]. The WEAP model calculated it to be 7.44 Mm^3 with a percentage error of 8.3%.

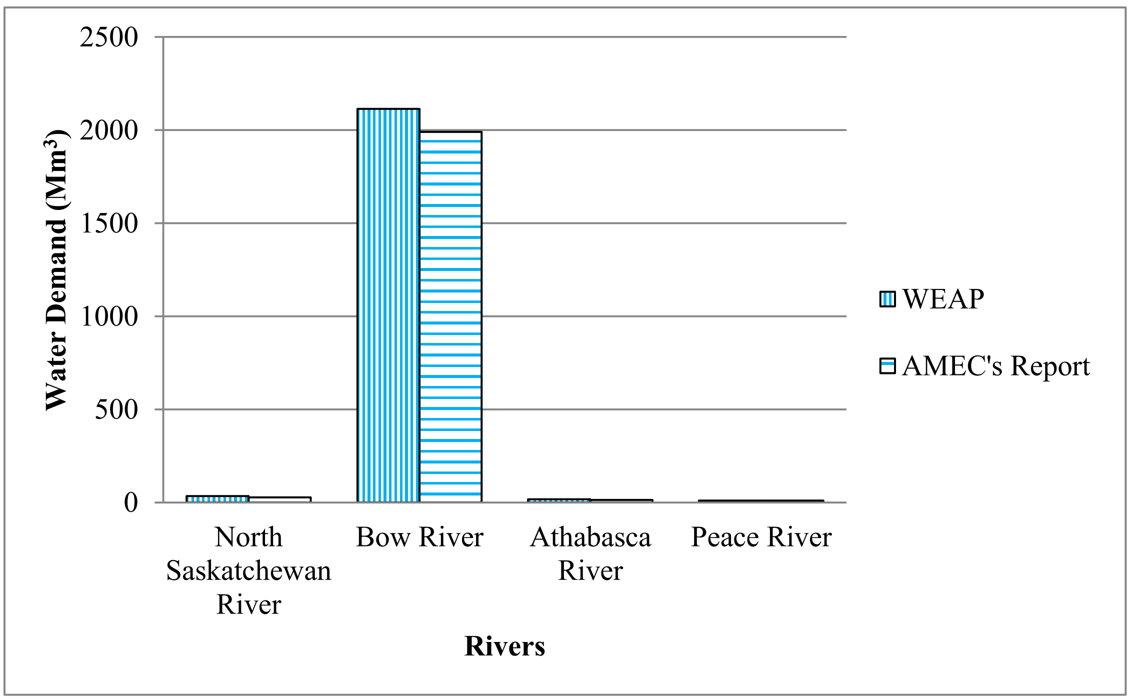

Figure 36: Agriculture sector water demand for Alberta's four major rivers in 2005

2.6.3 Industrial sector

In 2005, 82% of the total water allocation in the North Saskatchewan River Basin was for the industrial sector. In the industrial sector of this river basin, the estimated water use in 2005 is 64.952 Mm^3 for 16 out of the 22 licenses issued for cooling [13]. If equal allocations for these 22 licenses are assumed, then the water use is 89.309 Mm^3. The WEAP model calculates the water withdrawal for thermal power generation or cooling to be 106.96 Mm^3. The WEAP value is in the range of licensed water use and estimated water use reported by AMEC for all the river basins, which indicates the reliability of the model in the absence of actual water withdrawal figures for 2005. Moreover, the estimated water use by AMEC does not include all the licensees. For the Athabasca River Basin, only 1% of the total water allocation is for the industrial sector, so its value has been taken from AMEC's report.

2.6.4 Petroleum sector

Figure 37 shows the comparison of WEAP-Alberta model, Canadian Association of Petroleum Producers (CAPP) [123] and the Pembina Institute estimated water demand projections. The reference scenario with expected improvements in water coefficients is considered for validation. The other sub-sectors are not so significant in terms of water demand, so they have not been considered in validation. The water coefficients used in the WEAP model are specific to the operating companies for surface mining, whereas those used by CAPP and the Pembina Institute [123, 125] are average water coefficients based on the extraction technique (surface mining or in situ). The main reason for the difference in the projected values is the improvements in bitumen extraction water coefficients for the WEAP model whereas no improvements in water coefficients have been considered in the reports published by CAPP and the Pembina Institute.

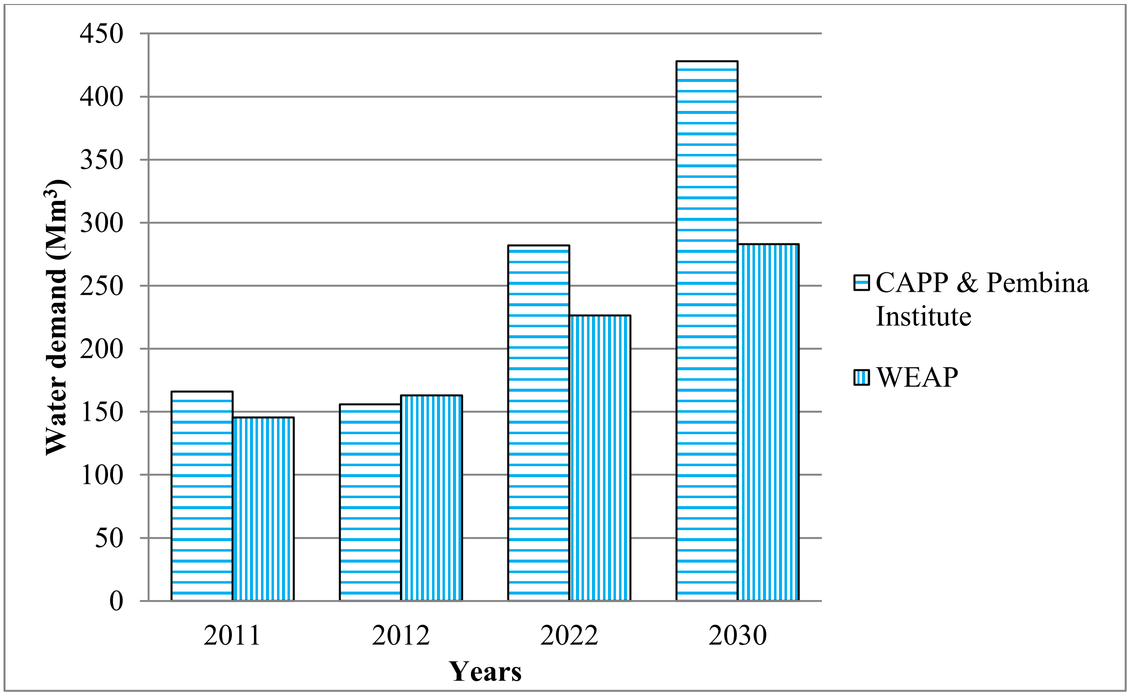

Figure 37: Alberta's oil sands water demand

2.6.5 Commercial and "other" sectors

The commercial sector of the four major river basins account for around 1% of the total water allocations [13]. The source of data for the commercial and "other" sectors is AMEC [13] so no validation is required.

Alberta's WEAP model validation indicates that the developed WEAP model is reliable enough to capture the trend of the varying water demand patterns for the various demand sectors.

Chapter 3: Development of Energy Scenarios in WEAP Model for Alberta

3.1 Introduction

The methodology for development of WEAP model for Alberta's four major rivers was presented in Chapter 2. The input data and assumptions for demand sectors, supply resources, and model validation were discussed in the previous sections. It was shown that the developed model is capable of estimating water withdrawal, return, and consumption for the six demand sectors and their sub-sectors. In this chapter, the step of developing scenarios is explained and the corresponding scenario results are discussed.

3.2 The development of scenarios in WEAP for Alberta

The development of scenarios in WEAP includes three steps: setting the objective for the scenario, identifying water reduction or conservation options applicable to the sector or any of the sub-sectors, and combining these options together to form an integrated scenario.

The scenarios considered in the WEAP model are consistent with the goals targeted by the local governmental bodies of the river regions and the projections forecasted by the Government of Alberta, other agencies and organizations like AMEC, CAPP, and the Pembina Institute. Any model that projects future values is vulnerable to uncertainties in assumptions and limitations to the study. Similarly, it is also difficult to predict the exact trends for the factors (i.e., social, economic, political, and environmental) affecting water demand in any sector.

The scenarios for the municipal, agriculture, commercial, and "other" sectors, are categorized as low and high growth scenarios in addition to the reference scenario. The low growth scenario assumes that Alberta grows at a slower rate in these four sectors than the rate observed in previous years. For the reference scenario, the increase in activity levels is consistent with the increasing rate observed in recent years. The high growth rate scenario presents a highly optimistic level of increase in the activity levels of the demand sectors. For the industrial sector, industrial expansion based on the upcoming projects and expected coal power plants' retirements are incorporated in the reference scenario. The bitumen production and water coefficient forecast in the petroleum sector calculate the water savings achieved if the bitumen extraction processes become more water efficient over the forecast period. The projections, and results obtained for each scenario developed in the WEAP model for the different sectors are analyzed in the following sections and summarized in Table 15.

Table 15: Input parameters, assumptions and key results of various scenarios developed in the WEAP model

Sr. #	WEAP scenarios	Projections	Water improvement efficiency	WEAP model assumptions	WEAP model - water demand (MCM) in 2050	Main source(s) of data
Municipal sector						
1	Low growth population	Population increases at an average annual rate of 0.95% [58]	Improvements in per capita water use over the forecast period: • North Sask. – 55% • Bow – 46% • Peace – 58% • Athabasca – 58%	1. Communities with water licenses of 100 dam^3 or more considered [13] 2. The North Saskatchewan and the Bow river basins have the same per capita water use as that of Edmonton and Calgary respectively 3. Alberta's average per capita water use for 2009 assumed for the Athabasca and Peace river basins	401 (23% less than the reference scenario value of 2050)	Alberta Population Projections - Govt. of Alberta Finance and Enterprise Environment Canada Statistics Canada
2	High growth population	Population increases at an average annual rate of 2.64% [58]			772 (48% more than the reference scenario value of 2050)	
Agriculture sector						
3	Low growth rate	10% more irrigation district expansion in the Bow River Basin Annual livestock population increase: • North Sask. – 0.5% • Bow – 1.2% • Peace – 0.5% • Athabasca – 0.5%	4.2% improvement in irrigation water requirement	1. Adequate amount of forage available in the North Saskatchewan and Athabasca river basins to support a modest increase in the livestock population	1359.19 (4% less than the reference scenario value of 2050)	Water Resources Branch, Irrigation and Farm Water Division, Alberta Agriculture and Rural Development AMEC

Table 15 (continued)

Sr. #	WEAP scenarios	Projections	Water improvement efficiency	WEAP model assumptions	WEAP model - water demand (MCM) in 2050	Main source(s) of data
Agriculture sector						
4	High growth rate	20% more irrigation district expansion in the Bow River Basin 1% annual increase in water requirement for Peace River Basin Annual livestock population increase: • North Sask. – 2.2% • Bow – 3.2% • Peace – 2.2% • Athabasca – 2.2%	4.2% improvement in irrigation water requirement	1. Adequate amount of forage available in the North Saskatchewan and Athabasca river basins to support a modest increase in the livestock population	1514.58 (7% more than the reference scenario value of 2050)	Water Resources Branch, Irrigation and Farm Water Division, Alberta Agriculture and Rural Development AMEC
Industrial sector						
5	Industrial growth based on GDP projections	The average real GDP growth projections considered are 2.3% annual GDP growth from 2013 to 2018, 1.7% from 2019 to 2030 and 1.8% from 2031 to 2050	Retirement and substitution of coal power plants with natural gas power plants 2% annual water efficiency improvement in pulp mills for Athabasca and Peace river basins	1. The Bow, Oldman, and South Saskatchewan river basins are effectively closed to new surface water license applications so no industrial expansion considered in the Bow River region 2. Water consumption values considered where the water withdrawals for the industrial heartland plants not available	428.68 (41% more than the reference scenario value of 2050)	Alberta Electricity System Operator (AESO) ERCB

Table 15 (continued)

Sr. #	WEAP scenarios	Projections	Water improvement efficiency	WEAP model assumptions	WEAP model - water demand (MCM) in 2050	Main source(s) of data
Petroleum sector						
6	In situ dominant bitumen extraction	84% in situ share in bitumen extraction by 2050 16% surface mining share in bitumen extraction by 2050	57% improvement in surface mining water coefficient by 2035 and another 33% improvement by 2050 53% improvement in in situ water coefficient by 2035 and another 19% improvement by 2050	1. Bitumen extraction in the Cold Lake region considered to be part of the Athabasca region for this model	814.93 (35% less than the reference case value of 2050)	ERCB CAPP The Pembina Institue AMEC

Table 15 (continued)

Sr. #	WEAP scenarios	Projections	WEAP model assumptions	WEAP model - water demand (MCM) in 2050	Main source(s) of data
Commercial sector					
7	Low growth rate	***North Saskatchewan River Basin*** Water requirement increases: • gardening activities - 0.5% annually • aggregate washing - 1.2% annually • golf courses - 20% till 2050 ***Bow River Basin*** Water requirement increases: • parks & recreation - 0.4% annually • golf courses - 23% than the current use till 2050 • food processing - 0.5% annually ***Peace River Basin*** Water requirement increases: • other commercial activities - 1.2% annually • golf courses - 34% of its current use till 2050 ***Athabasca River Basin*** Water requirement increases: • golf courses - 19% from its current use till 2050 • aggregate washing - 1.2% annually • other commercial activities - 1.2% annually	1. The percentage of water demand for each sub-sector remains constant throughout the forecast period for each river basin.	75.77 (44% less than the reference case value of 2050)	AMEC

Table 15 (continued)

Sr. #	WEAP scenarios	Projections	WEAP model assumptions	WEAP model - water demand (MCM) in 2050	Main source(s) of data
Commercial sector					
8	High growth rate	***<u>North Saskatchewan River Basin</u>*** Water requirement increases: • gardening activities - 3% annually • aggregate washing - 3.2% annually • golf courses - 100% till 2050 ***<u>Bow River Basin</u>*** Water requirement increases: • parks & recreation - 2.5% annually • golf courses – 4.6 times the current use till 2050 • food processing - 2.5% annually ***<u>Peace River Basin</u>*** Water requirement increases: • other commercial activities - 3.2% annually • golf courses – 3.7 times of its current use till 2050 • gardening – 1.2% annually ***<u>Athabasca River Basin</u>*** Water requirement increases: • golf courses – 2.5 times of its current use till 2050 • aggregate washing - 3.2% annually • other commercial activities - 3.2% annually	1. The percentage of water demand for each sub-sector remains constant throughout the forecast period for each river basin.	773.95 (477% more than the reference case value of 2050)	AMEC

Table 15 (continued)

Sr. #	WEAP scenarios	Projections	WEAP model assumptions	WEAP model - water demand (MCM) in 2050	Main source(s) of data
"Other" sector					
9	Low growth rate	***North Saskatchewan River Basin*** Water requirement increases: • water management activities - 2% every five years • habitat enhancement - 2% every five years ***Peace River Basin*** Water requirement increases: • habitat enhancement activities - 2% every five years ***Athabasca River Basin*** Water requirement increases: • water management activities - 2% every five years	1. The percentage of water demand for each sub-sector remains constant throughout the forecast period for each river basin.	246.37 (5% less than the reference case value of 2050)	AMEC
10	High growth rate	***North Saskatchewan River Basin*** Water requirement increases: • water management activities - 22% till 2025 and further increases by 22% of the value in 2025 till 2050 • habitat enhancement - 5% every five years ***Peace River Basin*** Water requirement increases: • water management activities - 5% every five years ***Athabasca River Basin*** Water requirement increases: • water management activities - 20 times greater than the current level by 2050.	1. The percentage of water demand for each sub-sector remains constant throughout the forecast period for each river basin.	289.54 (11% more than the reference case value of 2050)	AMEC

3.2.1 Municipal sector

3.2.1.1 Reference scenario

The cities of Calgary and Edmonton account for around 70% of Alberta's population [58]. Calgary has a per capita water use of around 512 lpcd [60]. According to the 30-in-30 conservation goal for Calgary, the aim is to lower the per capita water use to 350 lpcd in next 30 years [60]. This objective can be attained by introducing universal metering, leak detection devices, water saving awareness programs, water efficient washing machines, and low water use toilets [60]. Three different scenarios to achieve this targeted reduction in Calgary's per capita water use are shown in Table 16. Scenario A from the following table is part of the reference scenario.

Table 16: Scenarios to achieve the 30-in-30 conservation goal in Calgary [60]

Scenario	Per capita water use
A (Universal metering and leak detection only with no water conservation programs)	Reduces to 453 lpcd by 2015 and then decreases to 350 lpcd by 2033.
B (Universal metering and leak detection with planned water conservation programs)	440 lpcd by 2015 and then reduces to 350 lpcd by 2033.
C (Universal metering, leak detection, widespread adoption of low water toilets and washing machines, and planned water conservation programs)	424 lpcd by 2015 and then decreases to 350 lpcd by 2033.

The total water use per capita for Alberta is to be reduced to 341 lpcd by 2020 according to the "New Water Conservation, Efficiency and Productivity Targets" set by AUMA [62]. So the total per capita water use for the North Saskatchewan, Peace, and Athabasca regions is assumed to follow the water efficiency target set by AUMA.

The population in 2009 was 1319441, 1326422, 255263, and 281024 for the North Saskatchewan, Bow, Peace, and Athabasca river basins, respectively [57]. The population in each river basin is projected to increase by 64.86% till 2050 with an average annual increase of

1.6215% [58]. Table 17 below gives the population and water coefficient projections for the reference scenario.

Table 17: Population and per capita water use projections for reference scenario in the WEAP model

Parameter/Year	2009	2020	2030	2040	2050
Population					
North Saskatchewan River	1,319,441	1,574,822	1,849,642	2,172,418	2,551,523
Bow River	1,326,422	1,583,155	1,859,428	2,183,912	2,565,023
Athabasca River	255,263	335,243	393,586	462,112	542,597
Peace River	281,024	304,670	357,838	420,283	493,627
Per capita water use (liters per capita per day)					
North Saskatchewan River	370	341	283	225	167
Bow River	517	424	367	350	277
Athabasca River	395	341	283	225	167
Peace River	395	341	283	225	167

The following scenarios are developed in addition to the reference scenario.

3.2.1.2 Low growth scenario

The population in each river basin is projected to increase from its base year value by 37.837% till 2050 with an average annual increase of 0.945% [58].

3.2.1.3 High growth scenario

The population in each river basin is projected to increase by 105.405% till 2050 with an average annual increase of 2.635% [58].

3.2.1.4 Scenario results

The summarized results estimated by the WEAP model for the municipal sector are shown in Table 18. The results for the Bow River Basin (shown in Table 17 below) indicate that 9% of water demand will be increased by 2050 under reference scenario. The water demand for the North Saskatchewan, Athabasca and Peace river basins will decrease by 13%, 18% and 15% respectively. This decrease is due to the improvement in per capita water use over the forecast period due to which the water demand is decreasing despite the increasing population. The water demand results for scenarios B and C for 30-in-30 conservation goals for Calgary do not show much variation than the reference scenario because the final target for the scenarios A, B and C (i.e. 350 lpcd) is the same with a little change in intermittent goals.

Table 18: Reference scenario water demand (MCM) for the municipal sector for the four river basins in the WEAP model

Scenario	2009	2020	2030	2040	2050
North Saskatchewan River	204.5	224.9	219.2	204.7	178.6
Bow River	248.9	257.5	261.5	291.3	271.6
Athabasca River	40.5	41.7	40.6	37.9	33.1
Peace River	44.5	45.6	44.6	42.2	37.8

In the low growth scenario, the water demand varies between 538 MCM in 2009 to 401 MCM in 2050 (Table 19). The water demand increases from 538 MCM in 2009 to 772 MCM in 2050 in the high growth scenario. The overall water requirement for the municipal sector decreases by 26% in the low growth scenario due to the decrease in per capita water use. The water demand in reference scenario increases from 2009 to 2040 by 7% and then decreases by 10% till 2050. In high growth scenario, the water demand rises by 44%. The variation in water demand is directly coupled to the decreasing per capita water use and increasing growth rates of population.

Table 19: The WEAP model cumulative water demand (MCM) for the municipal sector for four major river basins in Alberta

Scenarios	2009	2020	2030	2040	2050
Low growth scenario	538	531	495	473	401
Reference scenario	538	570	566	576	521
High growth scenario	538	633	692	776	772

The percentage difference of demand site inflows and outflows for the municipal sector from 2009 to 2050 is given in Table 20. The water inflow from the North Saskatchewan River varies from around $\pm$30% for low and high population growth rates. The overall consumption in this sector lies in the range of -174% to 242% under low and high scenarios. The negative percentages represent the decrease in inflow or outflow whereas the positive percentages denote the increase. The outflow (return flow) to the Peace River Basin increases from 168.73% to 219% from low to high growth rate scenarios. A reduction in inflow from the Peace River Basin in reference scenario is also evident indicating the declining water demand because of improved per capita water use. The inflow from and outflow to the Bow River Basin is highest as its projected water use per capita by 2050 is 277 lpcd which is still more than that of the other river basins.

Table 20: Demand site inflows and outflows for the river basins for the municipal sector in the WEAP model (2009-2050)

Demand site inflows and outflows	Low growth scenario (%)	Reference scenario (%)	High growth scenario (%)
Inflow from Athabasca River	-37.89	-18.37	22.55
Inflow from Bow River	-15.83	9.13	61.45
Inflow from North Saskatchewan River	-33.52	-12.68	31.01
Inflow from Peace River	-31.27	-15.08	18.86
Outflow to Athabasca River	-162.11	-181.63	222.55
Outflow to Bow River	-184.17	209.13	261.45
Outflow to North Saskatchewan River	-166.48	-187.32	231.01
Outflow to Peace River	-168.73	-184.92	218.86
Consumption	-173.72	-195.69	241.75

The water withdrawn (inflow), return flow (outflow), and consumption for all rivers under the reference scenario for the municipal sector are represented in Figure 38. The WEAP model works on the principle of equating demand and supply so Figure 38 indicates that the water demand increase over time with an increase in overall water consumption, thus reducing the amount of water returning to the river source.

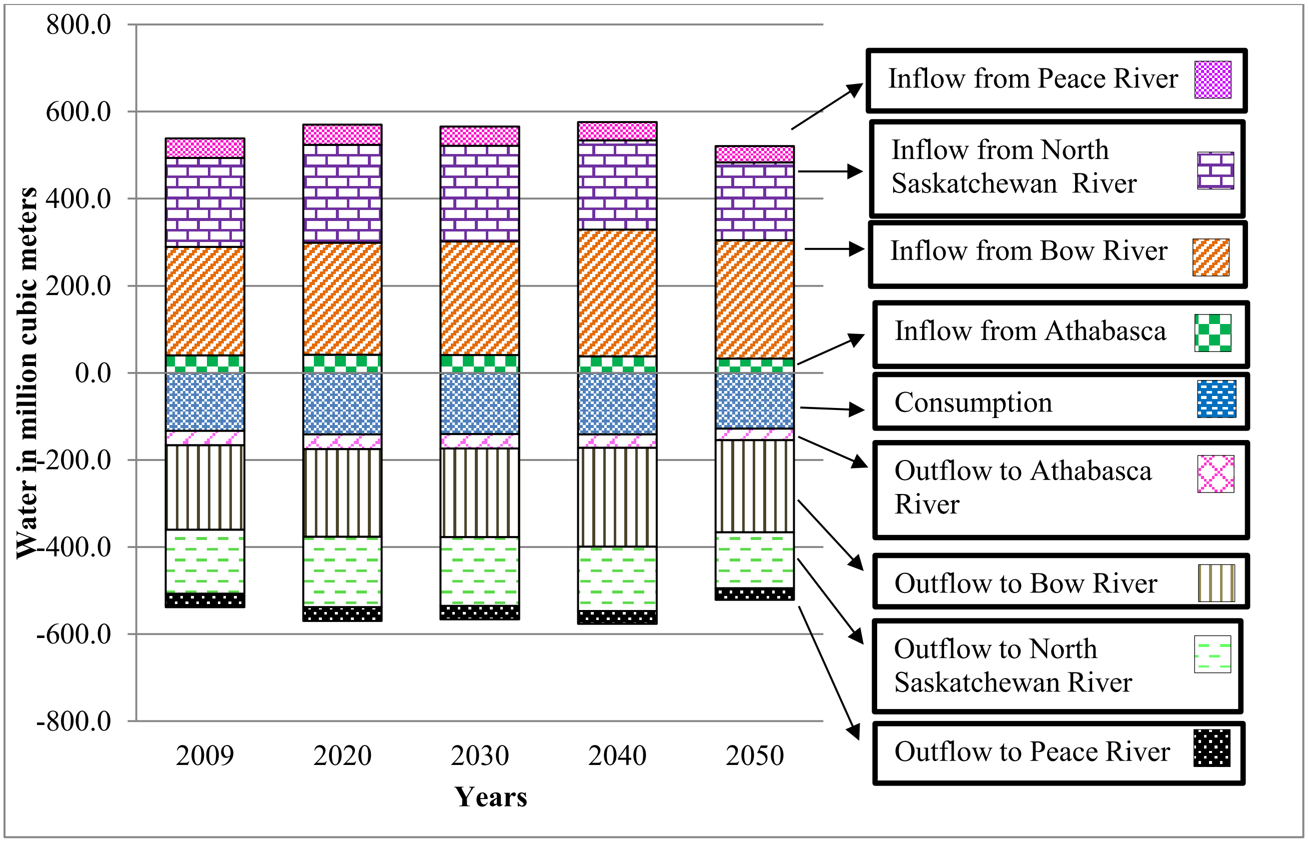

Figure 38: **Demand site inflows and outflows for the municipal sector for the reference scenario**

The coverage of this sector as calculated by the WEAP model under the reference, low and high growth rate scenarios is 100%. The full coverage indicates that there is no unmet water demand.

3.2.2 Agriculture sector

3.2.2.1 Reference scenario

In 2002 the Irrigation Water Management Study Committee showed that a 10-20% expansion beyond the expansion limit of 239,170 ha can be accommodated in the Bow River Sub-basin with the use of water-efficient technology, and increased water recycling [15]. The average district irrigated area from 2004 to 2007 in the Bow River Sub-basin was 9.5%, which is lower than the limit defined in the regulation. The irrigation district expansions to 2050 are anticipated to be 10%, 14%, and 20% higher than the limit defined by the 1991 regulation for Bow River [15]. The reference scenario is developed based on the following data:

- The irrigation district expansion by 2050 is assumed to be 14% more than the limit defined by the 1991 regulation for Bow River for this scenario [15]. The livestock population increases by 2.2% every year [13].
- For Peace River region, it is assumed that there is 0.5% increase in water requirement for irrigation every year. The livestock population increases by 1.2% every year [13].
- In the Athabasca River Basin, the livestock population increases by 1.2% every year [13].
- The livestock population increases in North Saskatchewan River region by 1.2% every year [13].

A number of studies [126, 127] using different methodologies and assumptions provide projections for future climate conditions in Alberta. The water requirement in agriculture sector is dependent on the precipitation. The climate changes expected in the future years will likely affect the length of the growing season in the agriculture sector [128]. So considering the resulting variation in precipitation due to the climate changes is viable for water demand study of agriculture sector. According to the study conducted by Barrow and Yu for Prairie Adaption Research Collaborative (PARC), the range of annual precipitation will vary between -10 to 15% by 2050 and is expected to increase further by 15% till 2080 under the four scenarios ((cooler, wetter),(cooler, drier), (warmer, wetter), (warmer, drier)) considered [128, 129]. Taking the precipitation factor into account, the net irrigation requirement will decrease from 433 mm 2014 to 405 mm in 2050 based on the precipitation projections of a total 0.52% decrease by 2020 and a total of 2.1% increase from 2020 to 2050 [129]. Table 21 below gives the irrigated acres of land and irrigation water requirement projections for the reference scenario.

Table 21: Acres irrigated in the Bow River Basin and irrigation water use projections for reference scenario from the WEAP model

Parameter/Year	2009	2020	2030	2040	2050
Acres irrigated					
Bow River Basin	211,479	214,428	222,452	230,775	239,409
Irrigation water requirement (mm)					
Bow River Basin	423	431.75	422.77	413.97	405.36

The following low and high growth scenarios for agriculture sector are developed in addition to the reference scenario.

3.2.2.2 Low growth scenario

- The irrigation district expansion till 2050 is considered to be 10% more than the limit defined by the 1991 regulation for the Bow River [15]. The livestock population increases by 1.2% annually [13].
- For the Peace River region, it is assumed that there is no increase in water requirement for irrigation and available forage is sufficient to support limited livestock expansion, whereas the livestock population increases by 0.5% every year [13].
- The livestock population increases by 0.5% every year in the Athabasca River Basin [13].
- In North Saskatchewan River region, the livestock population increases by 0.5% every year [13].

3.2.2.3 High growth scenario

- The irrigation district expansion till 2050 is up to 20% more than the limit defined by the 1991 regulation for Bow River [15]. The livestock population increases by 3.2% annually [13].
- For Peace River region, it is assumed that there is 1% increase in water requirement for irrigation every year, whereas the livestock population will increase by 2.2% every year [13].
- The livestock population increases in the Athabasca River Basin by 2.2% every year [13].
- The livestock population increases by 2.2% every year in North Saskatchewan River region [13].

It is assumed that there will be no increase in irrigation water requirement and that the available forage will support modest livestock expansion in the North Saskatchewan and Athabasca river basins, but the Peace River Basin will see increases of 0, 0.5%, and 1%, respectively, in water requirement for irrigation in the three considered scenarios (low, reference and medium) as mentioned above [13].

3.2.2.4 Scenario results

The water demand for the agriculture sector decreases for the reference scenario considered, as can be seen in Table 22. This is mainly because of the expected increase in precipitation in the Bow River Basin. The increased precipitation reduces the net water irrigation requirement. For the low growth scenario, the water demand declines from 1477.76 MCM to 1359.19 MCM over the study period (Table 22). For the reference and high growth scenarios, the water requirement varies from 1478.77 MCM and 1480.06 MCM to 1417.69 MCM and 1514.58 MCM, respectively.

Table 22: The WEAP model water demand (MCM) for the agriculture sector for the four major river basins in Alberta

Scenario	2009	2020	2030	2040	2050
Low growth scenario	1477.76	1336.22	1343.89	1351.35	1359.19
Reference scenario	1478.77	1348.77	1370.66	1393.37	1417.69
High growth scenario	1480.06	1367.43	1411.95	1460.45	1514.58

Table 23 shows the water demand for the agriculture sector in the Bow River Basin. In all the three scenarios, the water demand decreases from the 2009 reference value to 2020 and then increases till 2050. The increase in district irrigation and livestock population in Bow region is the reason for increased water demand over the forecast years. The prominent decrease of water demand from 2009 to the future projected years is the reduced water required (m^3/acre) because of the increased precipitation. The water demand for irrigation was reduced to 544.74 MCM in 2010 because of the increased precipitation in 2010 making the net irrigation requirement to only 90 mm compared to the average of 362 mm [69]. Water demand for the agriculture sector decreases by 9% by 2020 (from 1423.34 MCM to 1289.86 MCM) under the reference scenario compared to the water demand in 2009 (Table 23) and then increases by 4.5% by 2050.

Table 23: The WEAP model water demand (MCM) for the agriculture sector in the Bow River Basin

Scenario	2009	2020	2030	2040	2050
Low growth scenario	1423.05	1280.22	1286.66	1292.82	1299.30
Reference scenario	1423.34	1289.86	1308.19	1326.89	1346.70
High growth scenario	1423.65	1304.01	1340.60	1379.28	1421.28

For the forecast period, the demand site inflow for the Bow River Basin for the agriculture sector decreases from 8.7% in low growth scenario to 0.17% in high growth scenario while the overall consumption decreases by around 4% under the reference scenario as shown in Table 24. The decrease in inflow from the Bow River Basin shows the reduced water requirement due to the increased precipitation. The negative percentages represent the decrease in inflow or outflow whereas the positive percentages denote the increase. Since the WEAP model works on the water demand and supply balance, all the inflows will balance the outflows and overall consumption.

Table 24: **Demand site inflows and outflows for the river basins for the agriculture sector in the WEAP model**

Demand site inflows and outflows	Low growth scenario (%)	Reference scenario (%)	High growth scenario (%)
Inflow from Athabasca River	9.69	27.36	63.88
Inflow from Bow River	-8.70	-5.39	-0.17
Inflow from North Saskatchewan River	10.45	29.49	68.75
Inflow from Peace River	6.41	25.50	58.71
Outflow to Athabasca River	9.69	27.36	63.88
Outflow to Bow River	-8.70	-5.39	-0.17
Outflow to North Saskatchewan River	10.45	29.49	68.75
Outflow to Peace River	6.41	25.50	58.71
Consumption	-8.02	-4.13	2.34

The water withdrawn, return flow, and consumption for all rivers under the reference scenario for the agriculture sector are highlighted in Figure 39. The consumption percentage increases with time from 2020 to 2050 but decreases overall from 20009 to 2050 as can be seen in Figure 36. The coverage of this sector as calculated by the WEAP model under the low, reference, and high growth rate scenarios is 100%.

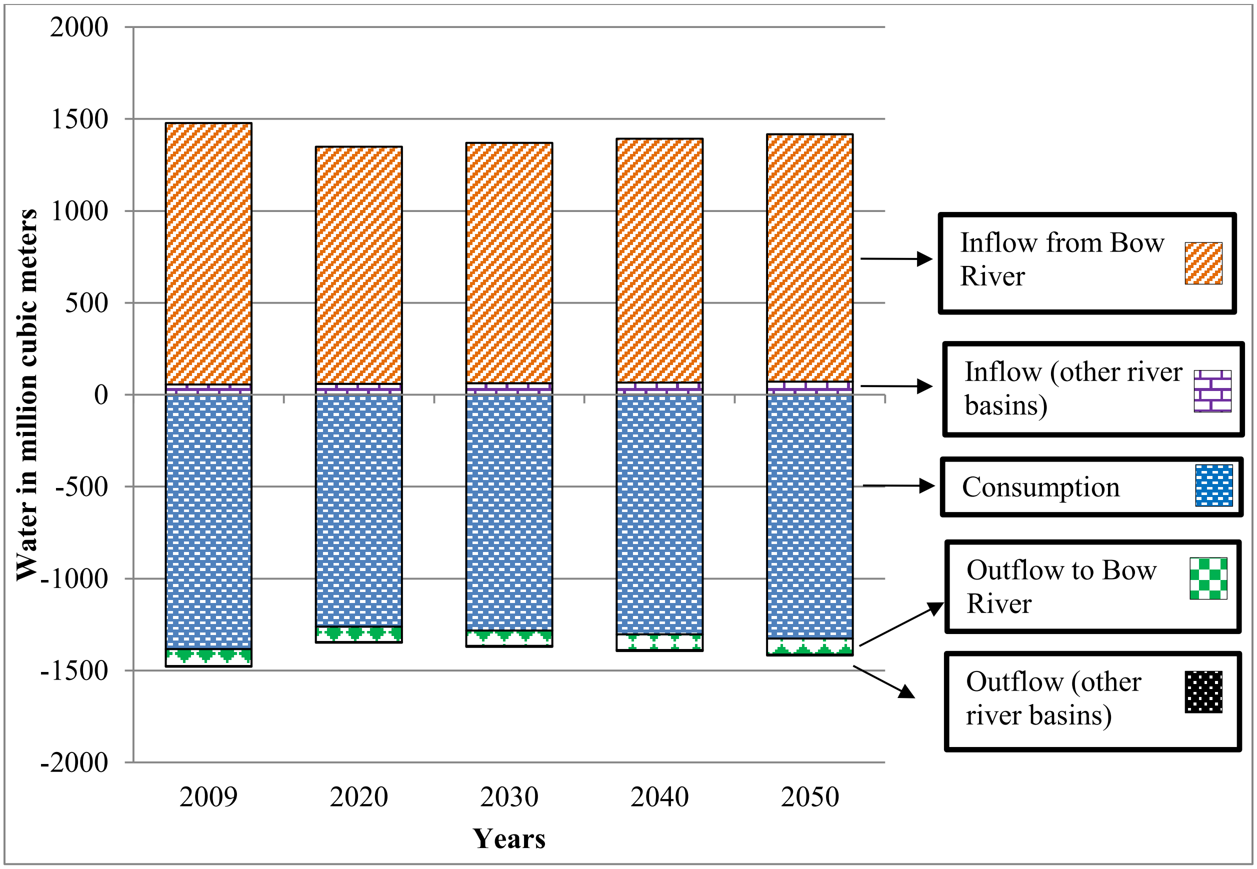

Figure 39: **Demand site inflows and outflows for the agriculture sector for the reference scenario**

3.2.3 Industrial sector

3.2.3.1 Reference scenario

According to the federal legislation, any coal unit commissioning after June, 2015 will need to comply with the carbon dioxide (CO_2) emissions restriction of 375 tonnes of CO_2 per gigawatt-hour (GWh) of electricity produced [130]. To meet this target, carbon capture and storage system (CCS) will be required. Under the same regulation, the currently operating coal power plants will have to follow the set standard at the end of their useful life or the expiry of the Power Purchase Agreement (PPA) whichever is later [130].

The last PPA of a coal unit (subcritical or supercritical) will expire in 2020 [130, 131]. The useful life of the subcritical coal-fired power plants (namely, Battle River 3/4/5, Keephills 1/2 and Sundance 1/2/3/4/5/6), under Alberta regulations, will be over by maximum 2024 whereas the useful life of Genesee 3 and Keephills 3 coal units (supercritical power plants) will be over in 2045 and 2051 [131]. Genesee 1/2 will reach the end of their useful life in 2034 and 2029 [131]. A detailed table for the retirements of coal power plants is provided in the Appendix A (Table A-1).

As per Alberta regulations, all the coal power plants except for Genesee 1/2/3, Keephills 3 and Sheeness 1/2 units that want to operate more than four years after their PPA expiry will be obligated to cut down their emissions by installing more efficient equipment or by any other method [131]. But the federal regulations require the CCS system to be installed between two to ten years after the PPA expiry in order to continue operation [131].

At present the Specified Gas Emitters Regulations, the facilities emitting over one million tonnes of GHGs are required to lessen their emissions by 12% [132]. This can be achieved either by making operations GHG efficient, purchasing credits, contributing to the Climate Change and Emissions Management Fund ($15/tonne) or purchasing credits of performance [132]. A new revision to this regulation (also called 40/40 carbon pricing proposal) is under consideration which will require the companies to reduce GHG emissions by 40% and increase the funding amount from $15/tonne to $40/tonne [133]. In the light of the above points, the installation of CCS as per federal regulations will limit the life of the currently operating coal power plants [131]. Large coal-fired generation plants expire at the PPA expiration [134].

The following factors are considered to develop this scenario and incorporate the industrial expansion by upcoming projects:

- The subcritical power plants (Battle River 3/4/5, and Sundance 1/2/3/4/5/6) are expected to retire by the end of 2020 when the PPA expires whereas Genesee 1/2 may operate beyond their PPA expiry till 2029 as these plants will still have the highest useful life left (around 10 and 14 years) after their PPA expiry in 2020 [134]. Keephills1/2 may operate till 2024 (since they will have four years of useful life left and can operate for four years without emission control system after the PPA expiry under Alberta regulation [131]). The supercritical power plants (Genesee 3 and Keephills 3) will stay operative till the end of their useful life (i.e. 2045 and 2051). Taking the coal unit retirements' target into consideration, a number of natural gas power plants are planned to be in operation in the coming years to satisfy growing electricity needs. The proposed natural gas power plants along with their capacities and expected first operation year are shown in Table 25.

Table 25: **Proposed natural gas power plants in the North Saskatchewan River Basin [73, 135-138]**

Sr. No.	Projects	Maximum capacity (MW)	Scheduled
1.	ATCO Power	400	2017
2.	Maxim Deerland Power	190	2020
3.	Sundance 7	834	2018

- In the North Saskatchewan River Basin, the chemical plant Western Hydrogen is expected to expand its production capacity from 175.2 to 1825 tonnes by 2019 [105]. Bunge Canada is expected to increase its capacity from 281,454.07 to 562,908.13 tonnes by 2014 [139]. Magnum Cementing will be in operation by 2015 [73].
- In the Athabasca and Peace River regions, the annual water demand for pulp mills will decrease by 2%/year by process efficiency improvement [13].
- The water demand for other sub-sectors, for example, hydroelectricity, coal mining, mining other than coal, and other industrial uses, is expected to remain constant for the forecast period as the water demand is very low as compared to other industrial sub-sectors [13].
- According to AESO electricity generation capacity projections, 4.2% annual growth is expected from 2012-2017 and 3.6% from 2018 to 2022 [138]. For the WEAP model, it is assumed that generation capacity will continue to increase annually by 3.6% every year to 2050.

An additional scenario is developed in the WEAP model for the industrial sector as discussed in the subsequent section.

3.2.3.2 Scenario I1: Industrial growth based on GDP projections

Scenario I1 includes all the industrial sector expansions mentioned in the reference scenario in addition to the GDP growth projections. The average real GDP growth projections (Table 26) considered are 2.3% annually from 2013 to 2018, 1.7% from 2019 to 2030, and 1.8% from 2031 to 2050 [140]. This GDP growth rate was not applied to the power sector.

Table 26: **Real GDP growth projections of Canada [140]**

Average annual real GDP growth projections		
2013-2018	**2019-2030**	**2031-2050**
2.3	1.7	1.8

3.2.3.3 Scenario results

WEAP-generated results for these scenarios are presented in Table 27. The table shows that water demand decreases by 24% under reference scenario, from 401.19 MCM to 304.52 MCM, during the span of forecast period. Water demand increases by 7% in scenario I1 from 401.19 MCM to 428.68 MCM because of the incorporation of the AESO projections and the GDP growth rate. The values for 2009 are same for both scenarios because the projections start from 2012 in this case. Coal-fired subcritical power plants consume most of the water. The main reason for the sudden drop in water demand for the scenarios in 2030 is the proposed retirement of coal-fired subcritical power plants, as shown in Table 26. The same dip in water demand is evident in Table 28 due to the retirement of coal-fired power plants within the North Saskatchewan River Basin.

Table 27: Industrial sector's water demand (MCM) from the WEAP model

Scenario	**2009**	**2020**	**2030**	**2040**	**2050**
Reference scenario	401.19	416.17	332.77	319.67	304.52
Scenario I1: Industrial growth based on GDP growth projections	401.19	436.99	380.83	402.40	428.68

The water demand, i.e., 16.93 MCM, stays the same from 2030 to 2040 and then decreases to 8.55 MCM, as shown in Table 28. The reason is the retirement of Genesee 3 supercritical coal-fired plant in 2045 in the North Saskatchewan River Basin. The natural gas power plants water demand in the Bow River Basin increases from 0.93 MCM in 2009 to 2.5 MCM in 2050. The Peace River Basin shows a decrease in water demand from 3.36 MCM in 2009 to 0.96 MCM in 2020. This is due to the expected retirement of the H.R. Milner coal power station.

Table 28: Water demand (MCM) for power generation in four river basins based on the WEAP model

Sub-Sector	2009	2020	2030	2040	2050
Bow River natural gas power plants	0.93	0.93	1.24	1.76	2.50
North Sask. coal-fired power plants	80.15	80.15	16.93	16.93	8.55
North Sask. natural gas power plants	3.74	9.55	12.68	18.06	25.72
Peace River natural gas power plants	3.36	0.96	1.28	1.83	2.6
Total	88.18	91.59	32.13	38.58	39.37

WEAP-estimated demand site inflows and outflows are presented for the reference and GDP projected scenarios in Table 29. The demand site inflow and outflow of water from the Bow River Basin for the industrial sector remains the same from 2009 to 2050. This is because the WEAP model works on the water demand and supply balance i.e. the percentage increase or decrease in inflow or outflow will be the same provided the return flow is constant. The North Saskatchewan River Basin is dominated by the industrial sector so its water flow changes by -3.3% and 70% under both reference and GDP scenarios, respectively. In the Athabasca and Peace river basins, the demand inflow reduces with the assumption that the pulp mills in these regions will improve their operation efficiency with time. This decline is indicated by the negative sign with the percentage in Table 29. The water consumption decrease is mainly coupled with the coal-fired plants retirement.

Table 29: Demand site inflows & outflows for the rivers for the industrial sector based on the WEAP model

Demand site inflows & outflows	Reference scenario: Industrial expansion by upcoming projects (%)	Scenario I1: Industrial growth based on GDP projections (%)
Inflow from Athabasca River	-37.67	-36.23
Inflow from Bow River	7.44	7.44
Inflow from North Saskatchewan River	-3.30	69.66
Inflow from Peace River	-54.34	-53.90
Outflow to Athabasca River	-37.67	-36.23
Outflow to Bow River	7.44	7.44
Outflow to North Saskatchewan River	-3.30	69.66
Outflow to Peace River	-54.34	-53.90
Consumption	-23.95	-2.77

Figure 40 represents the water withdrawn, return flow, and consumption for all rivers under reference scenario for industrial expansion by upcoming projects. The decrease in inflow and outflow along with consumption in 2030 is due to the retirement of nine coal-fired power plants. The coverage of this sector as calculated by WEAP under the above mentioned scenarios is 100%.

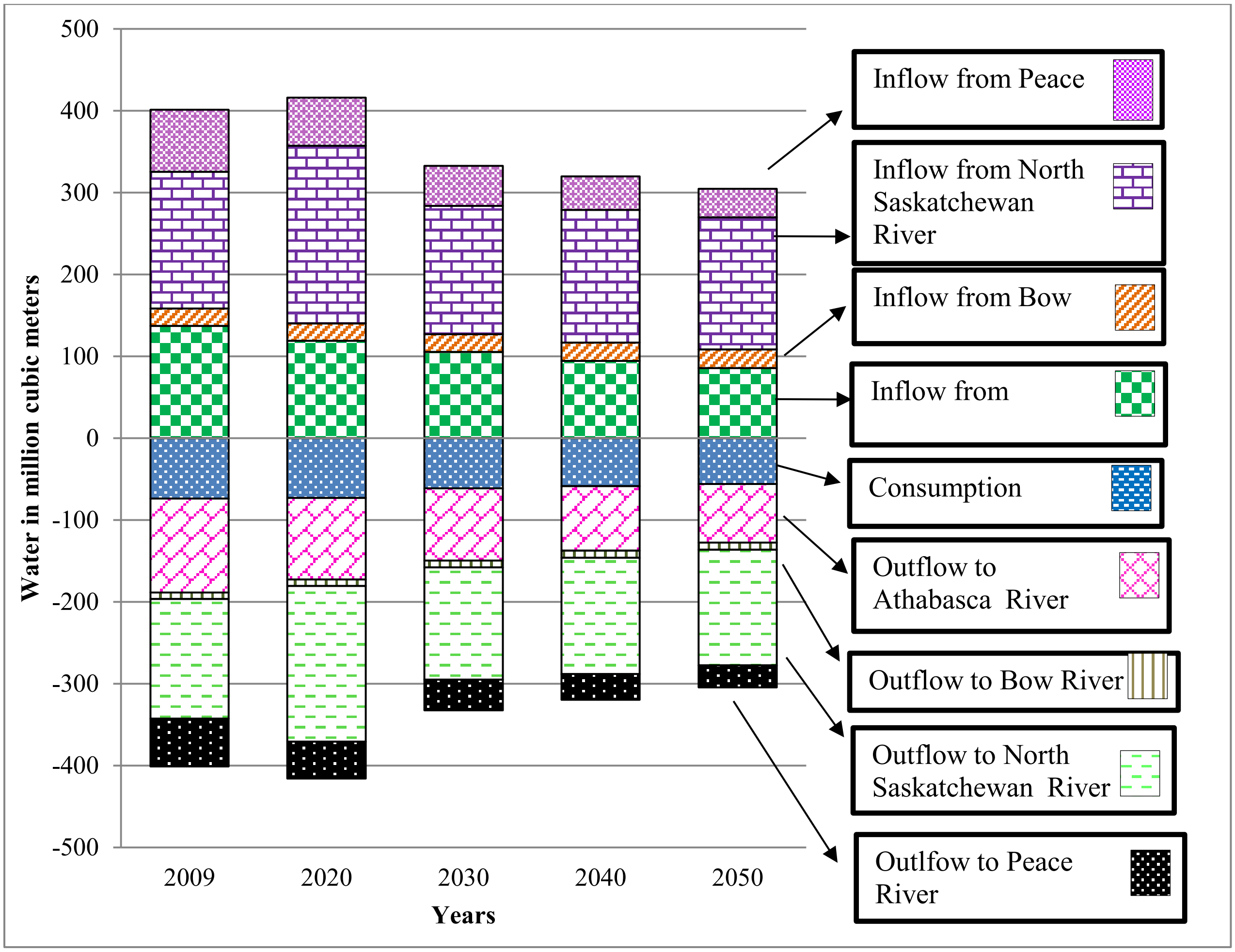

Figure 40: **Demand site inflows and outflows for industrial sector expansion under reference scenario**

3.2.4 Petroleum sector

A reference and an in situ dominant scenario (P1) are developed for the petroleum sector. The reference scenario highlights the water demand results if the sectorial expansion continues with improvement in water coefficients of the current technologies for bitumen extraction. Scenario

P1 calculates the water demand if the in situ method of bitumen extraction becomes more dominant as compared to the surface mining over the forecast period.

3.2.4.1 Reference scenario

The following factors are considered to develop this scenario:

- A study conducted by CAPP reported 28% and 47% improvement in water coefficients of surface mining and in situ from the baseline year (2002-2004 average) to 2015 as shown in the Table 30. The target of improvement in water coefficients incorporated in the WEAP model is based on the targets from Canada's Oil Sands Innovation Alliance (COSIA) and input from the industry experts. In surface mining, the water withdrawal coefficients (m^3/m^3) available for Shell Canada Limited, Syncrude Canada Limited and Suncor Energy are shown in the Figure 41. Of the three companies, Syncrude has shown a somewhat consistent trend. According to the analysis of the past surface mining water coefficients' data of the oil companies, limited water coefficient projections [89, 119, 121, 141-146], and considering COSIA's target (1.5 m^3/m^3 by 2025), 1 m^3/m^3 by 2035 seems to be a reasonable and realistic value that can be achieved by the oil companies in the future years. Assuming 2035 as a saturation point, a further decrease in water coefficient of only 25% (1 to 0.75 m^3/m^3) over the next 15 years (2035-2050) is considered.

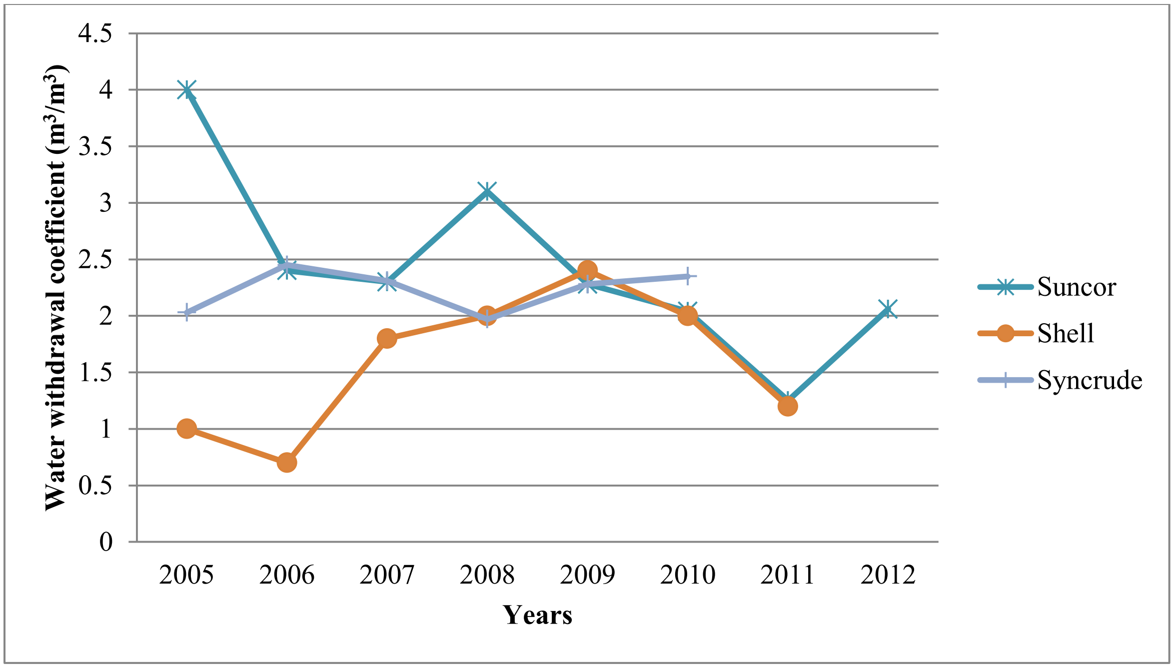

Figure 41: **Historical water withdrawal coefficient trend for three companies [89, 119, 121, 141-146]**

- For in situ, the projected water coefficient from the baseline year (2002-2004 average) to 2015 is 0.3 m^3/m^3 (around 47% of improvement in industry average water use) [147]. The decreasing trend of SAGD water coefficient presents further reduction in coefficient from 0.34 to 0.16 m^3/m^3 by the end of 2035 and reduces further to 0.13 m^3/m^3 by 2050 (Table 30). According to the analysis of the water coefficient data for different companies [118, 148] and considering COSIA's target (0.2 m^3/m^3 by 2025), the targets of 0.16 m^3/m^3 by 2035 and 0.13 m^3/m^3 by 2050 seem to be a reasonable estimate that can be achieved by the oil companies in the future years. The projection of the water coefficients are given in Table 30.

Table 30: Projected water coefficients for surface mining and in situ

Activity type	Baseline (2002-2004) m^3/m^3	CAPP projected value in 2015 m^3/m^3	Improvement	WEAP model projected value in 2035 m^3/m^3	WEAP model projected value in 2050 m^3/m^3
Surface mining	3.18	2.30	28%	1	0.75
In situ	0.63	0.34	47%	0.16	0.13

- ERCB has made projections to 2022 for bitumen extraction through oil sands and in situ mining [149]. According to these projections, surface mining will increase annually by 2.112%, primary by 2.5%, SAGD by 14.2%, and CSS by 2.3% [149].
- The proposed upgraders for the North Saskatchewan River Basin are considered in this scenario and given in Table 31.

Table 31: Scheduled upgraders in the North Saskatchewan River Basin [90]

Sr. No.	Upgrader	Synthetic crude oil (barrels per day)	Scheduled
1.	North American Oil	217,000	2016-2020
2.	Fort Hills	140,000 (Phase 1)	2011
	Sturgeon	140,000 (Phase 2 and 3)	2014-15
3.	Scotford	438,000	2013-2022
4.	Northern Lights	100,000	On Hold
5.	North West	136,000	2010-2016
6.	Total E&P Canada	200,000	2013-2019

- Air Products Canada will undergo expansion from 175 to around 325 MMSCFD of hydrogen production by 2015 [73]. Keyera Energy is expected to more than double its facility's existing C3+ fractionation capacity to reach 65,000 bpd by 2016.
- A forecast from the Alberta Energy and Utilities Board (AEUB) and CAPP shows that oil production in Alberta will decrease by 30% between 2005 and 2015 with a further decline of around 23% by 2020 [13]. The Bow River region is expected to follow the same pattern, so it is assumed that the water demand for oil injection will decrease by 30% until 2050.

An additional scenario is developed in the WEAP model for the petroleum sector as discussed in the sections below.

3.2.4.2 Scenario P1: In situ dominant bitumen extraction scenario

For bitumen extraction overall, the share of surface mining is decreasing as compared to the in situ mining over the past years. The bitumen production from in situ is expected to grow and continually exceed the bitumen amount extracted by surface mining [37]. In the in situ dominant bitumen extraction scenario, rather than following ERCB's projections for surface mining and in situ, the percentage share of in situ and surface mining is extrapolated from the data available for last 14 years (2000-2013) from Alberta Energy Reserves and Demand/Supply Outlook Reports

(ST98). From the data, the share of bitumen extraction through in situ is expected to increase to 84% by the end of 2050, leaving surface mining with a share of only 16%. The detailed graph and values are shown in Appendix A (Table A-2 and Figure A-4). Till 2023, the percentage contribution of bitumen extraction in oil mining is assumed to reach 97% from 78%, whereas conventional oil mining is supposed to be reduced to 3% [33, 38].

3.2.4.3 Scenario results

Table 32 represents WEAP-evaluated water demand for the petroleum sector. The water demand for the petroleum sector for the four river regions increases from 575.07 MCM to 1275.45 MCM, i.e., it more than doubles, by 2050 due to petroleum sector expansion in the province under reference scenario. Most of the water is consumed through bitumen extraction by surface mining, upgraders, and refineries. Considering improvements in the water coefficients for the reference scenario, the water demand for surface mining and in situ activities increase at a slower rate than that of bitumen production. Moreover, by extracting more bitumen from in situ in the in-situ dominant scenario, up to 35% of the water demand can be reduced by 2050 i.e., equivalent to about 433 MCM. It is also important to note that some in situ projects rely completely on saline ground water whereas others use 95% recycled water and require only 5% fresh water for extraction operations [123]. The increased water demand for in situ mining over the forecast period is due to the expected increase in bitumen extraction from in situ.

Table 32: Water demand (MCM) for the petroleum sector based on the WEAP model

Scenario / Years	2009	2020	2030	2040	2050
Reference scenario	575.07	695.64	724.88	834.06	1247.45
In situ - reference scenario	23.52	50.64	96.88	218.27	626.44
Scenario P1: In situ dominant bitumen extraction scenario	575.07	791.28	780.96	784.05	814.93

Scenario results that are generated from the WEAP model are given in Table 33. The water demand increases at a lower rate in Athabasca region through the reduction of the water demand coefficients in surface mining and SAGD in the reference scenario (Table 33). The water demand falls from 747.12 MCM in the reference scenario, i.e., petroleum sector expansion to 290.16 MCM, when in situ reaches to 84% total share in bitumen extraction by 2050 in scenario P1. The water used for in situ mining (e.g., SAGD) comes mainly from recycled or saline ground water sources and needs to be desalinated before use in steam production. With the gradual increase of percentage share of in situ in in situ dominant scenario P1, the water demand reduces from 148.18 MCM to 290.16 MCM by 2050. More water demand reduction is achieved in scenario P1 because the increase in the production of bitumen gets more water efficient by improvement in water coefficients.

Table 33: Water demand (MCM) for the petroleum sector in the Athabasca River Basin based on the WEAP model

	Years				
Scenarios	**2009**	**2020**	**2030**	**2040**	**2050**
Reference scenario	148.18	210.35	234.08	339.26	747.12
Scenario P1: In situ dominant bitumen extraction scenario	148.18	183.17	211.30	245.11	290.16

The demand site inflows and outflows for the petroleum sector from 2009 to 2050 are shown in Table 34. It can be seen that there is a sharp decrease in consumption in reference scenario; this decrease is because of the improving water coefficients in the Athabasca River region. There is no change in the North Saskatchewan, Bow and Peace river basins for reference scenario as no surface mining or SAGD is carried out in these regions. The water flow for the Bow River Basin will decrease with an increase in the oilfield injection as the existing crude oil fields become more mature and there are lesser new fields discovered [13].

Table 34: Demand site inflows and outflows for the river basins for the petroleum sector for the reference scenario estimated by the WEAP model

River Basin	Demand site inflows & outflows (%)
North Saskatchewan River	17.50
Bow River	23.19
Athabasca River	501.17
Peace River	94.50
Consumption	146.75

Figure 42 shows the water withdrawn, return flow, and consumption for all rivers as calculated by the WEAP model under reference scenario of the petroleum sector expansion. Water demand and consumption increase as a result of the petroleum sector expansion. Around 95% of the water demand estimated by the WEAP model for in situ activities is the ground water (with only 5% fresh river water). Thus, the ground water requirement for in situ will rise from 22 MCM in 2009 to 595 MCM in 2050 for the reference scenario. The coverage of this sector as calculated by the WEAP model under all the scenarios is 100%.

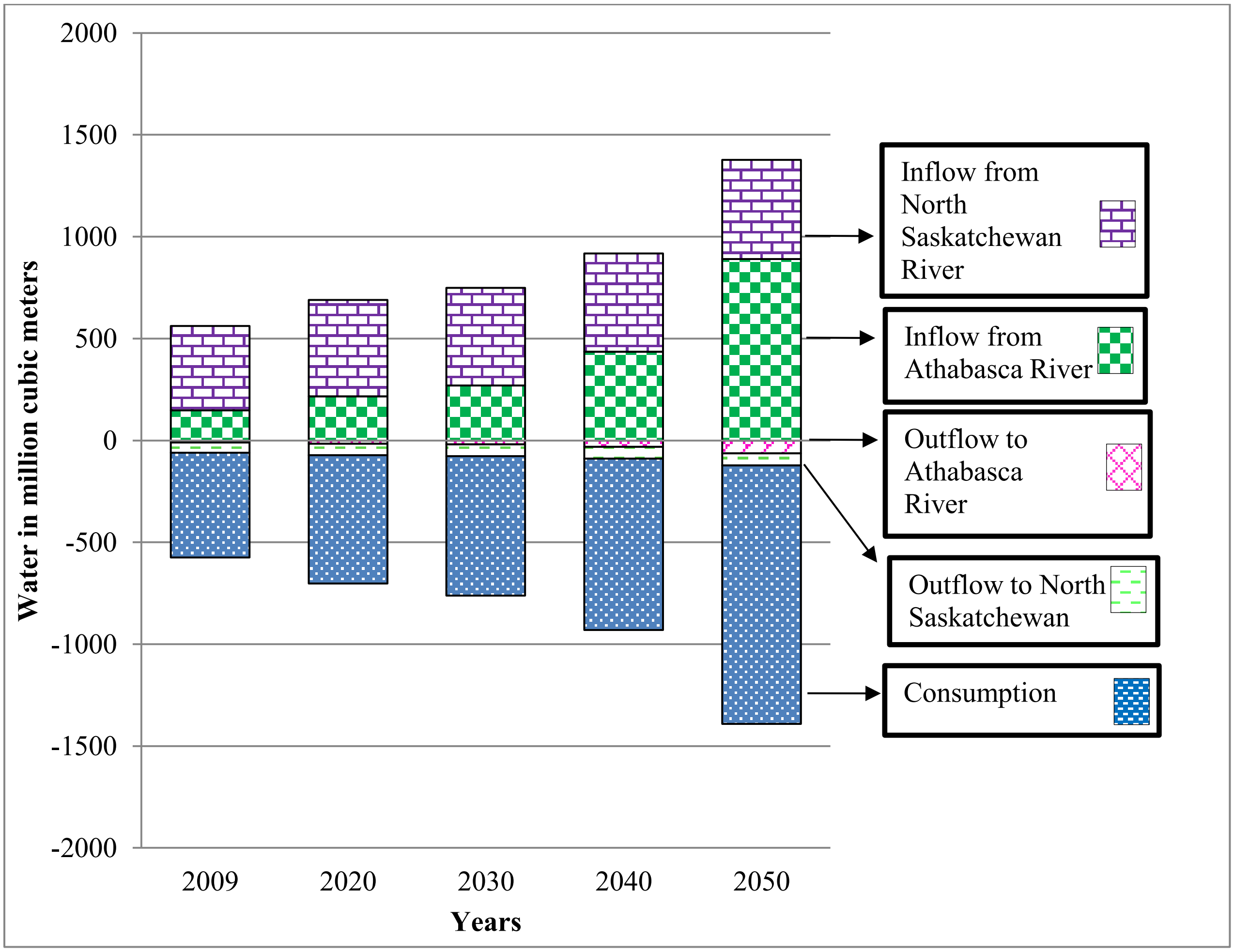

Figure 42: Demand site inflows and outflows for the petroleum sector expansion for petroleum dominant river basins under reference scenario

3.2.5 Commercial sector

For the North Saskatchewan River Basin, the three major water withdrawing sub-sectors, gardening, aggregate washing, and golf courses, account for about 77% of the total water allocation for the commercial sector [13]. The scenario projections will assess the change in water demand trend for only these three sub-sectors. Water demand by the other sub-sectors (bottling, dust-control etc.) of the commercial sector (shown in Table 4) accounts for only 23% of the total water allocation to the commercial sector, a small share compared to that of the three major sub-sectors. Due to the small water allocation share (23%), the water demand for the other sub-sectors of the commercial sector is assumed to remain constant.

The three sub-sectors parks and recreation, golf courses, and food processing in the Bow River Basin comprise about 90% of the total water allocation for the commercial sector [13]. The scenario projections will determine the variation in the water demand trend only for these three sub-sectors. Moreover, the Bow River Basin has been closed for new allocations [150].

For the Peace River Basin, the three sub-sectors (i.e., golf courses, gardening, and “other”) make up about 86% of the total water allocation for the commercial sector [13]. The scenario forecasts will examine the change in water requirement for only these three sub-sectors [13].

The sub-sectors golf courses, aggregate washing, and other commercial uses cover about 76% of the total water allocation for the commercial sector for the Athabasca River Basin [13]. The projections will consider the change in demand for these three sub-sectors [13].

The data source for the commercial sector is AMEC [13]. The projections used to develop the reference scenario are given in Table 35 below.

Table 35: Reference scenario projections for the commercial sector incorporated in the WEAP model

River	Projections
North Saskatchewan	1. The water requirement for gardening activities increases annually by 1.9% [13]. 2. The water requirement for aggregate washing increases annually by 2.2% [13]. 3. The water requirement for golf courses increases by 50% [13] till 2050.
Bow	1. The water requirement for parks & recreation increases annually by 1.2% [13]. 2. The water requirement for golf courses increases by 2.2 times [13] the current use by 2050. 3. The water requirement for food processing increases annually by 1.5% [13].
Peace	1. The water requirement for other sector increases annually by 1.2% [13]. 2. The water requirement for golf courses increases by 2.1 [13] times the current use by 2050. 3. The water requirement for gardening increases annually by 0.5% [13].
Athabasca	1. The water requirement for golf courses increases by 60% [13] from its current use by 2050. 2. The water requirement for aggregate washing increases annually by 2.2% [13]. 3. The water requirement for other commercial activities increases annually by 2.2% [13].

The following low and high growth scenarios (Table 36) for commercial sector are developed in addition to the reference scenario.

Table 36: Projections for low and high growth scenarios for the commercial sector incorporated in the WEAP model

River	Projections
Low growth scenario	
River	**Projections**
North Saskatchewan	1. The water requirement for gardening activities increases annually by 0.5% [13]. 2. The water requirement for aggregate washing increases annually by 1.2% [13]. 3. The water requirement for golf courses increases by 20% [13] by 2050.
Bow	1. The water requirement for parks & recreation increases annually by 0.4% [13]. 2. The water requirement for golf courses increases by 23% [13] higher than the current use by 2050. 3. The water requirement for food processing increases annually by 0.5% [13].
Peace	1. The water requirement for other sector increases annually by 1.2% [13]. 2. The water requirement for golf courses increases by 34% [13] of its current use by 2050. 3. There will be no increase in the water requirement for gardening.
Athabasca	1. The water requirement for golf courses increases by 19% [13] from its current use by 2050. 2. The water requirement for aggregate washing increases annually by 1.2% [13]. 3. The water requirement for other commercial activities increases by annually 1.2% [13].
High growth scenario	
River	**Projections**
North Saskatchewan	1. The water requirement for gardening activities increases annually by 3% [13]. 2. The water requirement for aggregate washing increases annually by 3.2% [13]. 3. The water requirement for golf courses increases by 100% [13] by 2050.
Bow	1. The water requirement for parks & recreation increases annually by 2.5% [13]. 2. The water requirement for golf courses increases by 4.6 times [13] the current use by 2050. 3. The water requirement for food processing increases annually by 2.5% [13].

Table 36 (continued)

High growth scenario	
River	**Projections**
Peace	1. The water requirement for other sector increases annually by 3.2% [13]. 2. The water requirement for golf courses increases by 3.7 times [13] the current use by 2050. 3. The water requirement for gardening increases annually by 1.2% [13].
Athabasca	1. The water requirement for golf courses increases by 2.5 times [13] from its current use by 2050. 2. The water requirement for aggregate washing increases annually by 3.2% [13]. 3. The water requirement for other commercial activities increases annually by 3.2% [13].

3.2.5.4 Scenario results

The water demand estimated by the WEAP model for the commercial sector increases for all three scenarios as shown in Table 37. This is mainly because of the increase of water demand in sub-sectors: golf courses, parks and recreation, and food processing. For low growth scenario, the water demand rises from 61.16 MCM in 2010 to 75.77 MCM in 2050. For high growth scenario, the increase in water requirement is from 67.08 MCM in 2010 to 212.25 MCM in 2050.

Table 37: Cumulative commercial sector water demand (MCM) based on the WEAP model for four river basins in Alberta

Scenarios	2010	2020	2030	2040	2050
Low growth scenario	61.16	64.42	67.93	71.70	75.77
Reference scenario	63.35	73.90	85.84	99.44	115.03
High growth scenario	67.08	91.83	122.33	161.11	212.25

The percentage difference of demand site inflows and outflows for commercial sector obtained by the WEAP model from 2009 to 2050 are presented in Table 38. The water inflow for the four rivers increases from low to high growth rate scenarios along with an increase in consumption. The largest increase is in inflow to the commercial sector by the Bow River Basin i.e., from 19.75% in low growth to 202.56% in high growth scenario. Even with such a big leap in the inflow, the water demand for this sector is less than the licensed water allocation from the Bow

River Basin. The consumption percentage increases from 27.64% in low growth scenario to 237.5 % in high growth scenario.

Table 38: Demand site inflows & outflows from the WEAP model for the river basins for commercial sector

Demand site inflows & outflows	Low growth scenario (%)	Reference scenario (%)	High growth scenario (%)
North Saskatchewan River	27.63	84.40	175.37
Bow River	19.75	118.31	202.56
Athabasca River	32.02	91.68	273.32
Peace River	38.25	117.34	494.04
Consumption	27.64	87.00	237.5

Figure 43 represents the water withdrawn, return flow, and consumption for all rivers for commercial sector under reference scenario. It can be deduced from the figure below that the change in inflow is balanced by the same amount of variation in outflow and consumption to achieve the water demand and supply balance. The coverage of this sector as calculated by the WEAP model under the low and high growth rate and reference scenarios is 100%.

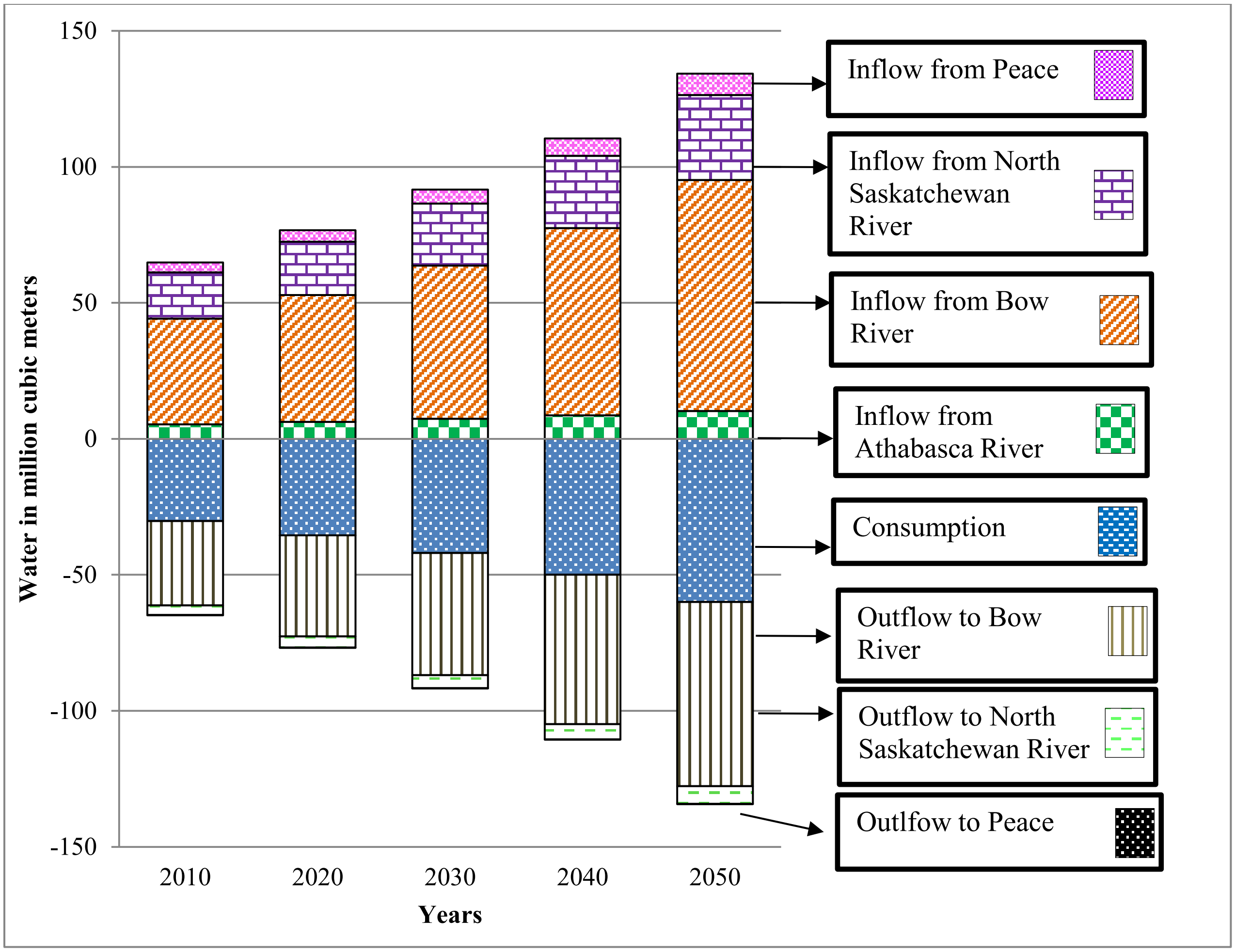

Figure 43: Demand site inflows and outflows for commercial sector for the reference scenario

3.2.6 "Other" sector

For the North Saskatchewan River Basin, it is assumed that water required by the sub-sector 'specified uses' remain constant throughout the projected years [13]. For the Bow River Basin, water demand by this sector is taken to be constant throughout the forecast period [13]. For the Athabasca River Basin, water required for water management and specified activities sub-sectors stays the same throughout the study period. The data source of projections for other sector from 2005 to 2025 is AMEC [13]. The projections used to develop the reference scenario are given in Table 39 below.

Table 39: **Reference scenario projections for the "other" sector incorporated in the WEAP model**

River	Projections
North Saskatchewan	1. The water requirement for water management activities increases by 5% every five years [13]. 2. The water requirement for habitat enhancement increases by 3.5% every five years [13].
Peace	1. The water requirement for water management activities increases by 2.2% every five years [13].
Athabasca	1. The water requirement for water management activities increases by 5% every five years [13].

The following low and high growth scenarios (Table 40) for "other" sector are developed in addition to the reference scenario.

Table 40: Projections for low and high growth scenarios for the commercial sector incorporated in the WEAP model

Low growth scenario	
River	**Projections**
North Saskatchewan	1. The water requirement for water management activities increases by 2% every five years [13]. 2. The water requirement for habitat enhancement increases by 2% every five years [13].
Peace	1. The water requirement for habitat enhancement activities increases by 2% every five years [13].
Athabasca	1. The water requirement for water management activities increases by 2% every five years [13].
High growth scenario	
River	**Projections**
North Saskatchewan	1. The water requirement for water management activities increases by 22% by 2025 [13] and further increases by 22% of the value in 2025 till 2050. 2. The water requirement for habitat enhancement increases by 5% every five years [13].
Peace	1. The water requirement for water management activities increases by 5% every five years [13].
Athabasca	1. The water requirement for water management activities is 20 times [13] greater than the current level by 2050.

3.2.6.4 Scenario results

The water demand calculated by the WEAP model for the "other" sector increases in the range of 8.3-25% for low and high growth rate scenarios as shown in Table 41 below.

Table 41: The WEAP model water demand (MCM) for the "other" sector for four river basins in Alberta

Scenario	2010	2020	2030	2040	2050
Low growth	227.50	231.94	236.56	241.37	246.37
Reference	228.70	235.80	243.44	251.67	260.53
High growth scenario	231.03	243.40	257.16	272.48	289.54

The demand site inflows and outflows as estimated by the WEAP model are given in Table 42 below. Since the water demand is considered to be constant for Bow River, there is no change in the percentage of demand inflow and outflow from 2009 to 2050. The water inflow to and outflow from the other three rivers changes from the low to high growth rate scenarios along with the increase in consumption. For the North Saskatchewan River Basin, the flow variation is from 17.27% in the low growth scenario to 53.66% in the high growth scenario. The consumption increases from 9.24% in low growth, 14.6 % in reference, and 28.02% in high growth scenarios.

Table 42: Demand site inflows and outflows from the WEAP model for the river basins for the "other" sector

Demand site inflows & outflows	Low growth scenario (%)	Reference scenario (%)	High growth scenario (%)
North Saskatchewan River	17.27	45.71	53.66
Bow River	0.00	0.00	0.00
Athabasca River	0.56	1.63	4.18
Peace River	12.95	14.37	36.84
Consumption	9.24	14.60	28.02

Figure 44 shows the water withdrawn, return flow, and consumption for all rivers for the "other" sector under the reference scenario. It can be seen from the figure below that the water flow varies over the time horizon as a result of the expansion in activities of the "other" sector. The coverage of this sector as calculated by the WEAP model under all the "other" sector scenarios is 100%.

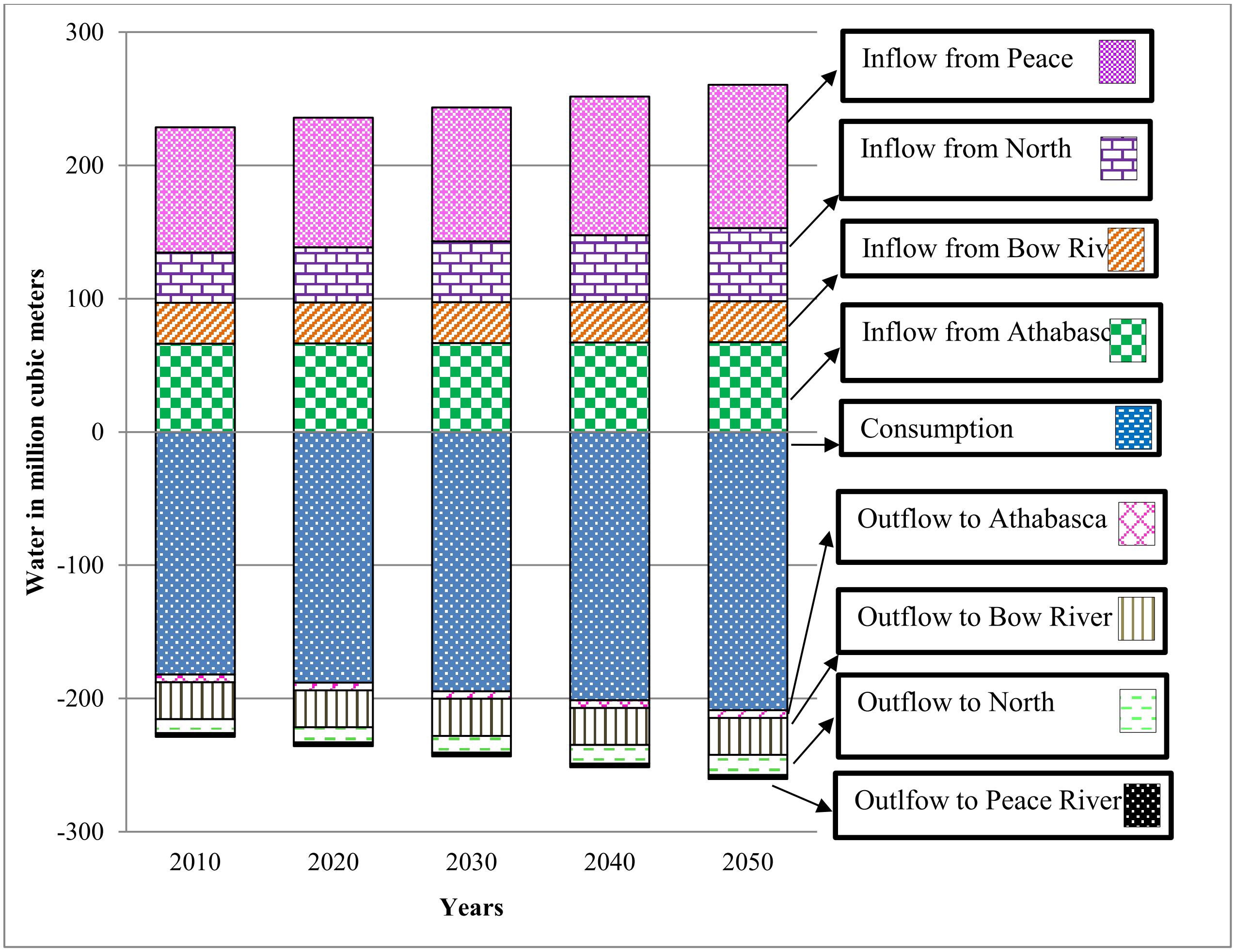

Figure 44: Demand site inflows and outflows for the "other" sector for the reference scenario

3.3 Overall water demand and water use for Alberta's four major river basins

The summarized results generated in the WEAP model on water demand for all developed scenarios compared to the reference scenario are presented in Figure 45.

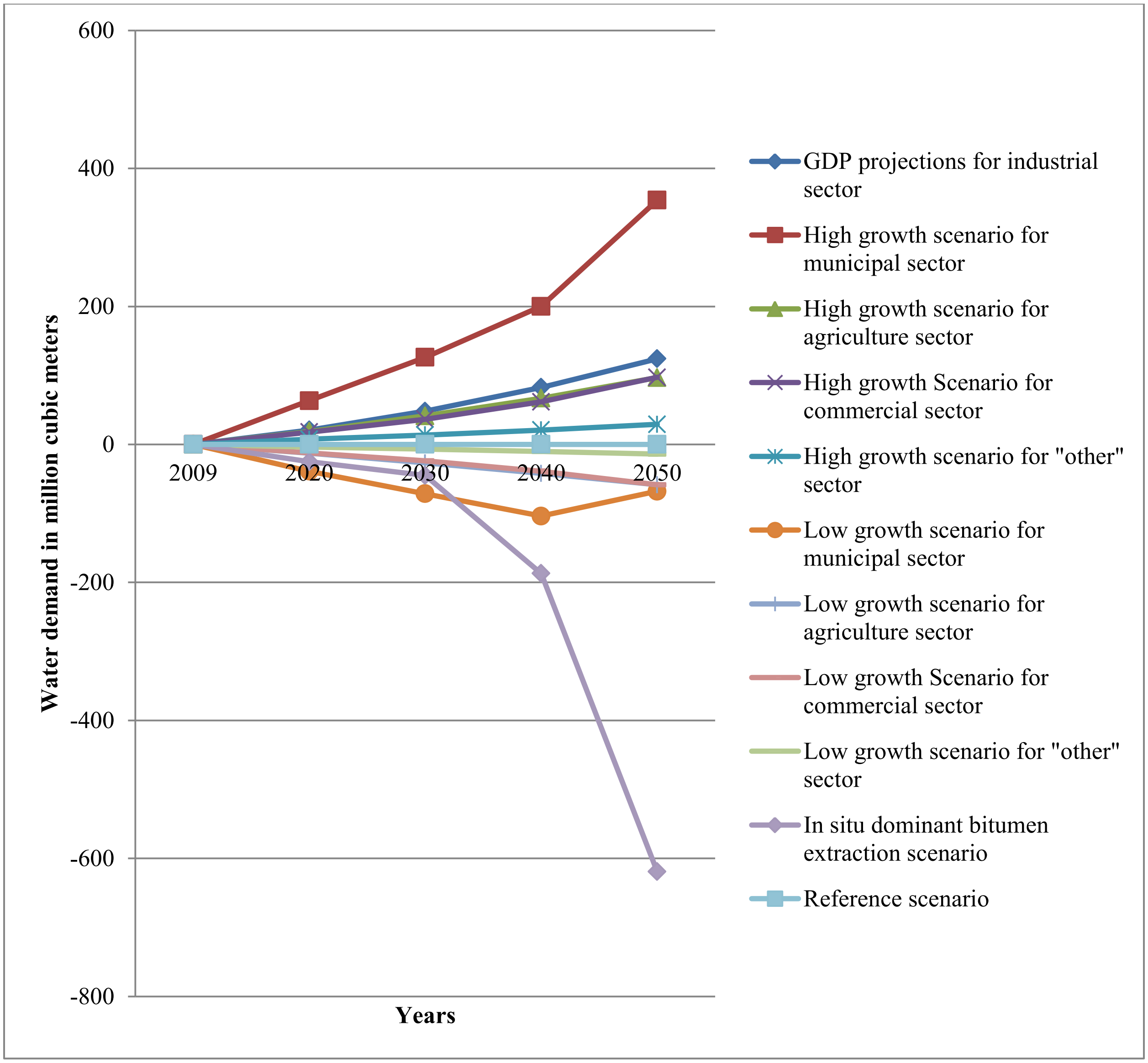

Figure 45: Summarized water demand by scenario compared to the reference scenario

There is a steep decline in the water demand for in situ dominant bitumen extraction scenario relative to the reference scenario (Figure 45). This reduction is because of the increased production capacity of bitumen with the improvement in water withdrawal coefficient for in situ. The water demand values of low growth scenarios for population, agriculture, commercial, and “other” sectors are below the reference case values of water demand in the respective sectors for the forecast period.

For the municipal sector, water demand for the low growth population scenario for all the considered river basins decreases from 538 MCM in 2009 to 401 MCM in 2050 (Figure 42), i.e., a 25% overall decrease in water requirement. The water demand reduces from 2040 to 2050 in the low growth scenario because the per capita water use improves over the forecast period whereas the population increase is lower as compared to reference and high growth scenarios. For the high growth population scenario, the water demand increases from 538 MCM in 2009 to 772 MCM in 2050, that is, an overall increase of around 44% in the water needed to satisfy the population demands. Water demand in the low growth scenario is 23% less than the reference case value of 521 MCM in 2050, whereas water demand in the high growth scenario is 40% more than that of the reference scenario (Figure 45). There is a huge margin available for improvement in per capita water use in the Bow River Basin's municipal sector (e.g., by introducing universal metering and leak detection mechanisms) as its per capita water use is highest among the river basins considered in this study.

Figure 45 shows that water demand for the low growth scenario in the agriculture sector, for all the considered river basins, decreases from 1477.76 MCM in 2009 to 1359.19 MCM in 2050. This indicates that the water demand will decrease by 8% over the forecast period for the low growth scenario. For the high growth scenario, the water requirement for agriculture will increase from 1480.06 MCM in 2009 to 1514.58 MCM in 2050, i.e., 2.3% more than the water required in 2009. The low growth scenario's water demand is around 4% less than the reference scenario value of 1417.69 MCM in 2050. Water demand for the high growth scenario is around 7% more than that of the reference case. More than half the water is consumed in the agriculture sector. Since that sector dominates in water demand in the Bow River Basin, adequate attention is required to implement water efficient technologies to conserve water in the river basin.

Water demand for the reference case for the industrial sector declines from 401.19 to 304.52 MCM. This 24% decrease over the forecast period is mainly due to the retirement of most of the coal-fired subcritical power plants by 2020. The water withdrawal and consumption of the coal-fired power generation is also dependent on the cooling system being used in the plant. Water demand for industrial growth based on GDP projections rises to 428.68 MCM by 2050, as shown in Figure 45. This is a 41% increase in water demand compared to the value in reference scenario in 2050.

The petroleum sector water demand for the four river basins considered in this study is expected to more than double by 2050 due to petroleum expansion in the province from 575.07 MCM in 2009 to 1247.45 MCM in 2050 (Figure 45). For the Athabasca River Basin, the water requirement for the reference scenario grows from 148.18 to 747.12 MCM over the study period. The main water consumers are bitumen extraction through surface mining processes, upgraders, and refineries. The water demand declines from 747.12 MCM in the reference scenario, i.e., petroleum sector expansion to 290.16 MCM, in in situ dominant scenario by 2050. Hence, around 35% of the water demand can be reduced if in situ dominates surface mining over the forecast period. The water demand for surface mining and in situ activities increases at a slower rate than that of bitumen production, indicating efficient water use.

Moreover, recent technology advancements in the bitumen recovery processes allow for more saline ground water in place of fresh water [14]. The bitumen extraction from in situ mining increased by 184% from 2003 to 2012 with a corresponding increase of 55% fresh water. Thus, the increase in bitumen production with less fresh water diversion was attained by a significant increase in the use of saline ground water (from 22% in 2001 to 51% in 2012) and improved rates of recycling water. Some in situ projects rely completely on saline ground water whereas some use 95% recycled water and require only 5% fresh water for extraction operations [123]. The in situ operations are expected to become more water efficient if new technologies, such as a solvent injection to enhance bitumen extraction without adding excess water, are successful [123].

For commercial sector, water demand increases from 61.2 to 75.8 MCM for the low growth scenario, as shown in Figure 45. For the high growth scenario, water demand rises from 67.1 to 212.3 MCM. This huge increase of water demand in the commercial sector is because of the increasing golf courses, food processing, and parks and recreation. The water requirement in 2050 is about 24% less in the low growth scenario compared to the reference case whereas for the high growth scenario, demand increases around threefold.

Water demand increases from 227.5 to 246.4 MCM in the low growth scenario for the “other” sector. For the high growth scenario, water demand grows from 228.7 to 260.5 MCM. The water requirement in 2050 is about 5.4% less in the low growth scenario than the reference case value of 260.53 MCM. For the high growth scenario, water demand increases by 11% over the reference scenario in 2050.

The demand site coverage is 100% for all the sectors of the four river basins considered in the WEAP model for all scenarios. So it can be concluded that the rivers, if they continue with the flows they have had for the past ten years (i.e., there is no drought), will have enough water to fulfil the needs of the different growth scenarios considered.

Although the energy drivers of all the demand sectors are increasing by a certain percentage over the forecast period, water efficiency seems to be improving with time. It can be concluded from the results that the improvements in water efficiencies in different demand sectors slow the rate at which water use could have increased with the projected expansion of the demand sectors.

Figure 46 represents the water withdrawn from all the river basin regions, their return flow, and total consumption for the forecast period for all the sectors for the reference case. The trend shows that the inflows and outflows along with consumption will increase in future to meet expansion in the different sectors. The inflow to the demand site increases from 3285.30 MCM in 2009 to 4029.22 MCM in 2050. The demand site outflow to the river varies from 968.93 to 981.62 MCM over the study time frame. The consumption increases from 2316.37 MCM in 2009 to 3047.60 MCM in 2050.

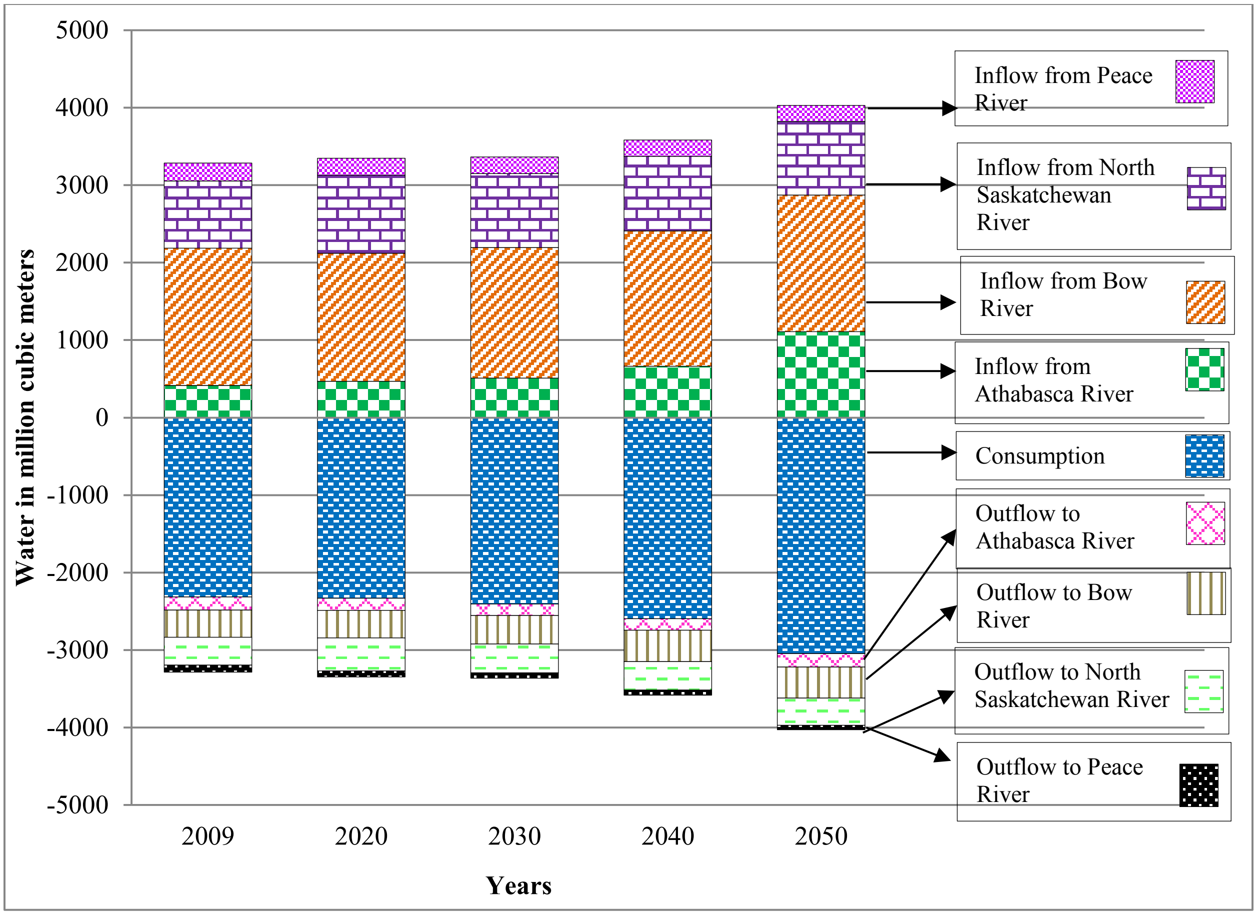

Figure 46: Demand site inflows and outflows for all sectors for the reference case

Figure 47 represents the stream flows of all the rivers as calculated by the WEAP model from 2009 to 2050 under the reference scenario. The annual flow variations of the river basins are between 0.3% and 18% over the forecast period Maximum variation is observed for the Athabasca River Basin by 2050 due to oil sands expansion as increase in water withdrawal will also increase consumption, thus reducing the return flow to the source. For all the sources, the remaining water in the rivers drops with the increase in water demanding activities over the forecast period, as shown in Table 43.

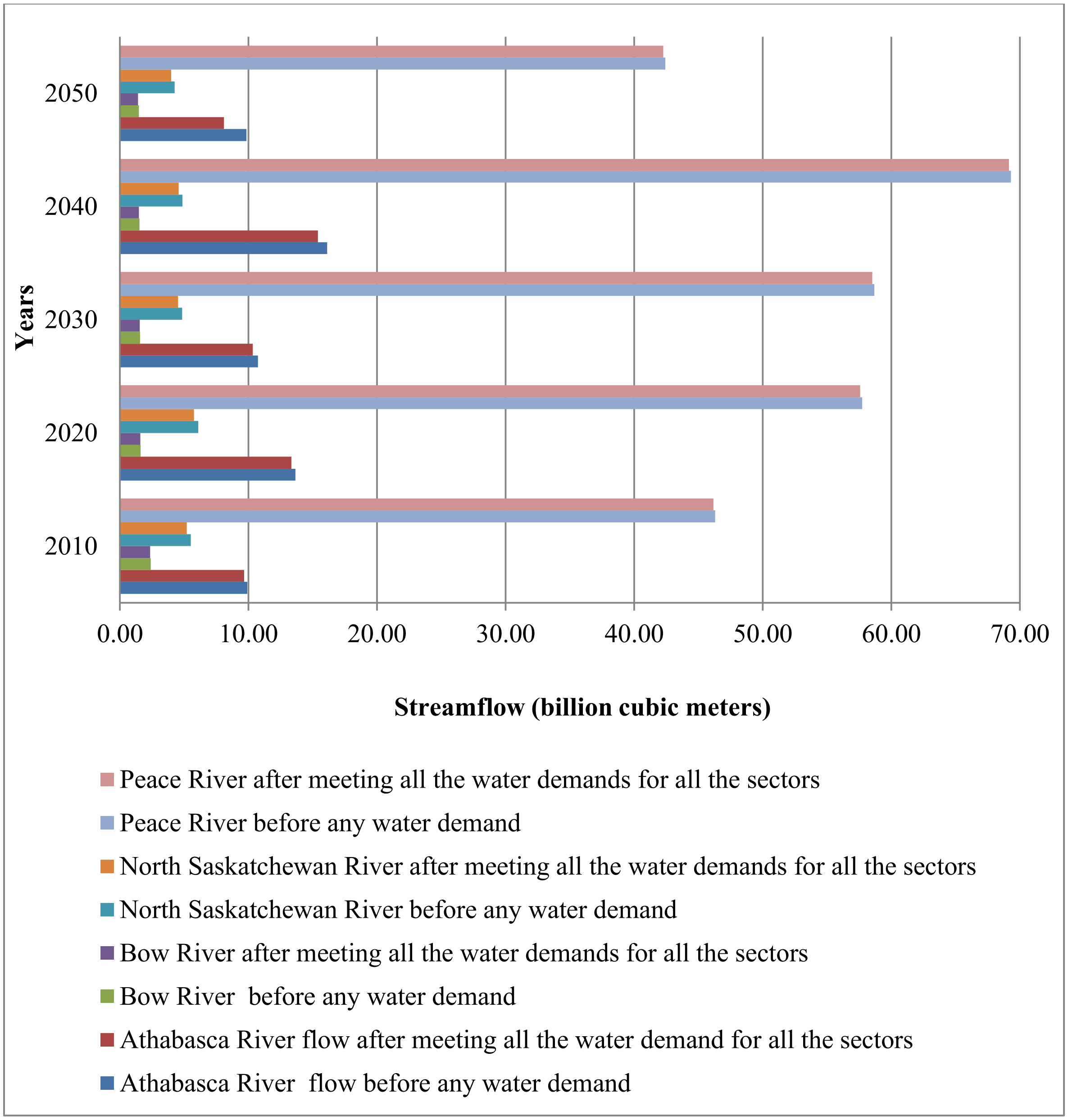

Figure 47: Streamflow of the rivers for the reference scenario

The water remaining in the Athabasca River Basin (both surface and ground water inclusive) is expected to decrease by 9.27% in 2050 mainly because of oil sands expansion under the reference scenario. For the total water demand in the river basins, the water demand for in situ accounts for about 11.33% in 2009 to around 12.76% in 2050. The water used for in situ is saline ground water. Water flow in the Bow River Basin will drop from 2.41 BCM in 2010 to 1.55 BCM by 2050. As the agriculture sector is the dominant water demand sector in this region, this steep decrease in the water body is mainly because of the high consumption rates in the agriculture sector. Moreover, the per capita water use of the Bow River Basin is highest among all the considered river basins, thereby increasing the water withdrawal and consumption. The Bow River water flow will be reduced by 0.65%; water flow in the North Saskatchewan and Peace river basins will be reduced by 9.40% and 0.37% (see Table 43).

Table 43: Percentage reduction in the stream flow of the rivers for the reference scenario

Water Source Region	Flow	2010 (BCM)	Percentage reduction in water in the river (%)	2050 (BCM)	Percentage reduction in water in the river (%)
North Saskatchewan	Water in the river before meeting all the needs	5.52	5.56	4.47	9.40
	Water in the river after meeting all the needs	5.21		4.05	
Bow	Water in the river before meeting all the needs	2.41	2.47	1.55	0.65
	Water in the river after meeting all the needs	2.35		1.54	
Athabasca	Water in the river before meeting all the needs	9.91	2.52	9.82	9.27
	Water in the river after meeting all the needs	9.66		8.91	
Peace	Water in the river before meeting all the needs	46.31	0.30	42.43	0.37
	Water in the river after meeting all the needs	46.18		42.27	

The scenarios' results indicate a number of demand sectors where water use needs to be improved in order to maintain the sustainability and health of the water source. Although the coverage is 100% and there is no reported water shortage by the WEAP model for the developed scenarios, if the climatic conditions (e.g., droughts, warmer temperatures and less precipitation) are considered, there is a high probability that the water supply may be restricted and energy sectors' expansions may be hampered.

In this chapter the expected scenarios that can affect the water demand and supply patterns for Alberta's river basins have been discussed in detail. A summarized table including all the scenarios with respective assumptions and key results can be found in Table 15. However, the integration of the WEAP scenarios with LEAP is required to evaluate the effect on greenhouse gas emissions with increased expansion in different sectors, that is, the development of a water-energy nexus. The oil sands and power sectors' water-energy nexus is considered in the next chapter.

Chapter 4: Development of integrated GHG emissions and water consumption energy scenarios using the WEAP and LEAP models

4.1 Introduction

The complete scenarios' input data and projections along with analysis of the results for water demand, demand site inflows and outflows, overall consumption, river streamflows, and coverage for Alberta's four rivers were presented in Chapter 3. For Alberta, the energy sector plays an important role by contributing directly or indirectly to the GDP, income, employment, and total revenue of the province. The overall energy demand for Canada is shown in Table 44. The largest consumers of energy in the world on a per capita basis are the United States and Canada; these countries consume almost 200 GJ per person, which is equivalent to 32 barrels of crude oil, according to the Environmental Impact Assessment (EIA). This is approximately twice the per capita energy consumption by the other member countries of the Organization for Economic Cooperation and Development (OECD). The energy demand of Canada is controlled by the changes in population, economic development, technology, energy prices, and consumer preferences [21].

Table 44: Secondary energy consumption (in petajoules) in Canada [151]

Demand sector	Years 2005	2007	2009
Residential	1395.3	1438.9	1422.3
Commercial	1162.2	1158.4	1186
Industrial[a]	3244.2	3415.9	3168.4
Transportation	1367.3	1406.8	1405.8

The largest hydrocarbon base in North America is within the province of Alberta. Alberta produces annually about 5 trillion cubic feet of natural gas, 250 million barrels of conventional oil, 500 million barrels of bitumen, and more than 30 million tons of coal. The electricity generation capacity in Alberta is more than 12,000 MW. Electricity demand in the province is growing at twice the national rate. According to Statistics Canada, Alberta is the largest per capita consumer of energy in Canada [21]. As the highest consumer of energy, Alberta has about a 40% share of Canada's total GHG emissions, and this has led to significant focus on reducing its carbon footprint [21]. Climate change through GHG emissions can be combated by opting for

GHG mitigation options such as improving the efficiency of energy systems (i.e., lighting and appliances), process equipment in the industrial sector, vehicle fuel, and primary energy conversion processes in the supply sector [21].

To make well-informed long-term system planning decisions, policy makers and resource managers need to fully comprehend the interconnections between energy and water use and production, or the water-energy nexus. Planning and assessment issues require the strategies to minimize the vulnerabilities around water and energy while mitigating the corresponding GHG emissions. This chapter explains the methodology followed to develop the integrated LEAP-WEAP system scenarios. The integration of LEAP and WEAP models for Alberta provides a customized water-energy analysis on the basis of river basins. For the same input data of the annual activity of the oil sands and power sector, the two integrated modeling environments facilitate in presenting the water demand results along with the variations in energy demand and GHG emissions under various scenarios.

The WEAP methodology has already been described in Chapter 2. The LEAP methodology is explained below.

4.2 LEAP software – A modeling tool

The LEAP model is an integrated computer-based energy-environment modeling tool designed to provide support in evaluating energy policies and sustainable energy plans [21, 152]. It also allows the user to make projections of energy supply and demand over a custom-defined planning horizon (i.e., thirty or fifty years). The software is highly data-intensive and can take into account the energy flow characteristics from reserves to final end use [21].

4.2.1 LEAP modeling method

The LEAP modeling method consists of building the energy demand and supply database and simulating the demand-supply further in the form of various scenarios by changing the key variables (e.g. equipment improvement efficiencies). These scenarios can give valuable insights in terms of emissions and costs for a specific region [153]. The LEAP model consists of four modules (see Figure 48) [21]:

Demand module: The demand module highlights the energy demands for both primary and secondary fuels from sectors and sub-sectors to end uses and devices.

Transformation module: The transformation module deals with the conversion of primary fuel to secondary fuel.

Resource module: The resource module is a record of all the primary and secondary fuels considered.

Technology and Environment Database (TED): TED is a database that keeps track of all the emission factors associated with primary and secondary fuels.

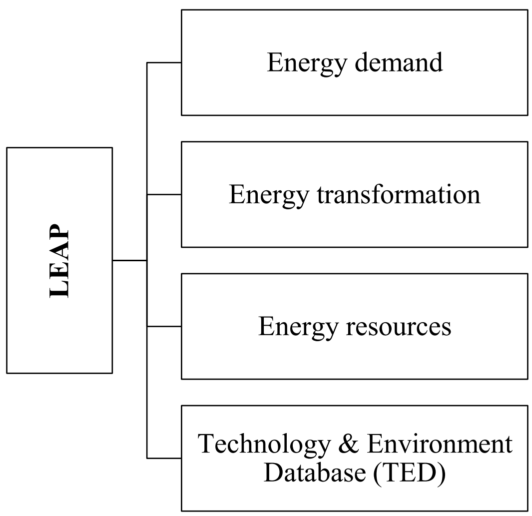

Figure 48: **Framework of the LEAP model [153]**

4.3 LEAP framework for Alberta's model

The transformation and resource modules for Alberta in the LEAP model have already been developed and discussed in detail [21, 153]. A brief summary of that model framework is presented here.

The various input parameters to the LEAP model were analyzed for the development of energy demand and supply modules for Alberta. Many different mathematical expressions for future projections of annual activity levels and energy coefficients were developed based on the data provided by several federal and provincial agencies including Natural Resources Canada, Statistics Canada Energy Division, the National Energy Board, AESO, ERCB, and Capital Environmental Resource Inc. (CERI) [153]. For LEAP-WEAP integration, the reference case scenario of the LEAP model is used. For overall methodology of LEAP-WEAP integration, refer to Figure 11 of Section 1.4 in Chapter 1.

4.3.1 LEAP demand module for Alberta's model

Each of the energy demand sectors in the LEAP model is further segregated based on the final end-use, which is then further divided on the basis of the type of primary or secondary fuel it uses, e.g., natural gas or electricity. The input values include the annual activity level, energy intensity of the activity and environmental data corresponding to various branches [153]. Figures 49 and 50 show the energy demand tree for surface and in situ mining in Alberta.

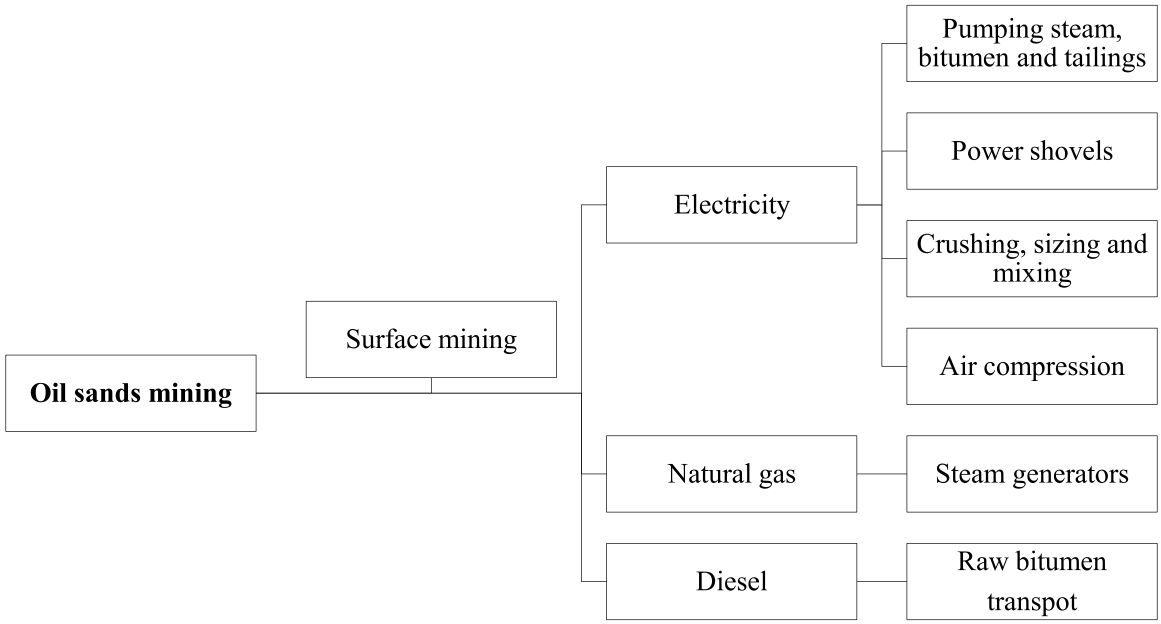

Figure 49: **Energy demand tree for surface mining in the oil sands sector for Alberta as developed in the LEAP model [154]**

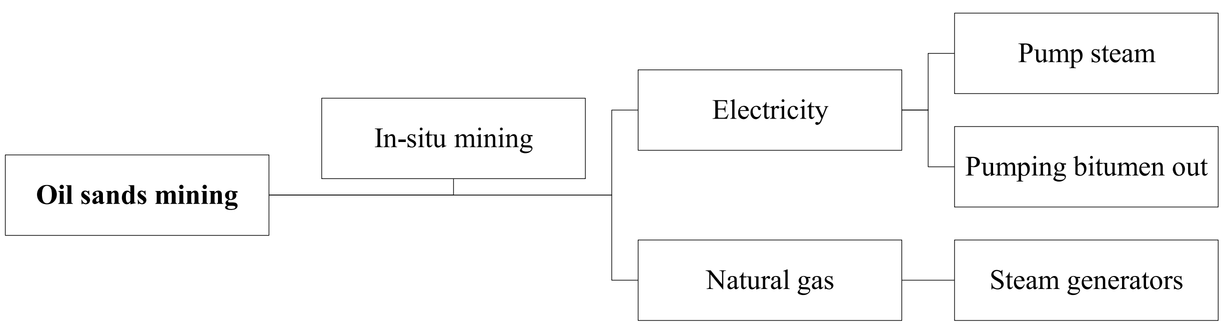

Figure 50: **Energy demand tree for in situ mining in the oil sands sector for Alberta as developed in the LEAP model [154]**

The estimated energy intensities incorporated in the LEAP model are based on data from the plants at various scales and industrial best practice guides [154]. Table 45 shows the input data used for bitumen production. Oil mining includes both conventional and bitumen mining. Conventional mining is not within the scope of this study but has been considered in the demand module in the LEAP model. The input values for the energy intensities of the various fuels used in surface mining are given in Table 46. The energy demand for oil mining rises from 418 PJ to 2048 PJ by 2050 for the reference case as seen in Table 47. The GHG emissions obtained by the LEAP model for bitumen upgrading increase from 12.8 MT to 30 MT for the reference case as shown in Table 48.

Table 45: Reference scenario for bitumen production and upgrading in million barrels as developed by the LEAP model [113, 155]

Demand	2009	2010	2030	2050
Oil mining (total)	704	760	1600	2000
Bitumen mining	549	631	1552	1940
In situ mining	258	300	931	1164
Surface mining	291	331	621	776
Bitumen upgrading	279	292	500	650

Table 46: The energy intensity of the various fuels used in LEAP for oil sands surface mining [156-158]

Activity	End use	Energy intensity of the fuel
Heating	Steam generators	Natural gas (0.25 GJ/barrel)
Non-motive Transport	Pumps to transport steam, slurry, bitumen, and tailings. Conveyor belts for slurry transport	Electricity (4 kWh/barrel) Electricity (0.17 kWh/barrel)
Motive transport	Trucks (front end loaders)	Diesel (3 liters/barrel)
Drilling/digging equipment	Power shovels for ore excavation	Electricity (8 kWh/barrel) Diesel (2 liters/barrel)
Crushing	Crushers	Electricity (0.5 kWh/barrel)
Mixing	Rotary tumblers	Electricity (0.5 kWh/barrel)
Compression	Air compressors	Electricity (0.012 kWh/barrel)
Flotation	Motors	Electricity (0.1 kWh/barrel)

Table 47: Reference scenario for energy demand for Alberta's oil mining and bitumen upgrading as developed by the LEAP model

Energy demand (PJ)	2009	2010	2030	2050
Oil mining	418	452	1638.4	2048
Bitumen upgrading	230	235	413.3	537.2

Table 48: Reference GHG emissions' scenario for Alberta's oil mining and bitumen upgrading as developed by the LEAP model [113, 155]

GHG emissions (MT)	2009	2010	2030	2050
Oil mining	21.46	31	86.6	108.2
Bitumen upgrading	12.87	13.5	23.1	30

To make the LEAP and WEAP integration possible, the relevant demand module in the LEAP model should match the demand sector or sub-sectors in WEAP. For Alberta's LEAP-WEAP model, the energy demand module for the petroleum sector and power generation has the same sub-sectors. The WEAP model is a river-based model. So for bitumen extraction, the Athabasca and Peace river basins are considered. For power generation, more emphasis is placed on the North Saskatchewan River Basin because the main source of power in this area is coal, which contributes significantly to GHG emissions. The Peace and Bow Rivers are discussed in light of natural gas power plants; there is only one coal-fired power plant in Peace region.

4.3.2 LEAP transformation module for Alberta's model

In a transformation analysis, the LEAP model deals with the conversion and transportation of different forms of energy from the point of withdrawal of primary and imported fuels to the point of final fuel consumption. These modules are based on one or more processes that are further classified into input and output processes. These processes represent the individual technologies or a group of technologies that convert one form of energy to another or transmit energy [153]. The technology data such as fuel inputs to each process, capacities, efficiencies, capacity factors, and environmental loadings by linking TED to the process can be defined at this stage [152].

The transformation module for Alberta focuses on power generation, the oil and gas industry, and the coal mining sector. The key transformation modules considered for Alberta's LEAP model are given below [153]:

- Transmission and distribution module
- Electricity generation module
- Natural gas and coal-bed methane module
- Alberta oil refining module

- Crude oil production module
- Synthetic crude oil production module
- Crude bitumen production module
- NGL production module
- Coal mining module

Each process has input for one or more feedstock fuels (e.g., natural gas, coal) with an option to have auxiliary fuels. The auxiliary fuel is the fuel required to produce a secondary fuel (e.g., electricity, diesel). In the LEAP model, all the output fuels generated by the transformation modules are the ones that are needed by the demand sectors after accounting for transmission losses. Hence the final secondary fuel production is controlled by both the final demand set by the demand modules and by the conversion efficiencies of the process in the transformation module. The fuel imported is always subtracted from the total requirement to be produced by the transformation module [153]. Each of the transformation modules is described below:

4.3.2.1 Transmission and distribution module

This module represents the electricity transmission and distribution along with the losses. The pipeline losses in carrying natural gas are also included. The details on the input data and assumptions for this module are given in Subramanyam (2010) [153].

4.3.2.2 Electricity generation module

The electricity generation module is one of the significant transformation modules. Alberta's electricity generation is a mix of coal, natural gas, oil, and renewables. This module is based on the exogenous capacity that is entered by the user and explicitly defines the actual and planned capacities along with the additions or deletions in the regions under consideration. The other input data to this module consists of availability of the plant, historical production, merit order, dispatch rule, system load curve, and process efficiency for each of the selected power generation units. The total production of electricity excludes the MW generated in Alberta's oil sands for bitumen production and upgrading. The detailed input data and assumptions for this module are given in Subramanyam (2010) [153].

4.3.2.3 Natural gas and coal-bed methane module

At present, most natural gas is produced through conventional sources. However, natural gas production from coal-bed methane is growing at a fast pace. In the LEAP model, this transformation module has been modeled by exogenously specifying the input parameters such as the production capacity for Alberta, historical production, and process efficiencies. 5800 million GJ of feedstock is processed including reprocessing and other demands like shrinkage in the oil and gas sector. Natural gas production is expected to decrease over the forecast period in the reference case. The detailed input data and assumptions for this module are given in Subramanyam (2010) [153].

4.3.2.4 Alberta oil refining module

The five refineries in Alberta have been included in the LEAP model. The main driving parameters for crude oil feedstock requirements for these refineries is highly dependent on the local demand of the refined petroleum products, exports to the Western Canadian provinces and the United States, and competition from the other feedstock available. The detailed input data and assumptions for this module are given in Subramanyam (2010) [153].

4.3.2.5 Crude oil production module

Conventional crude oil production in Alberta was around 33.1 million m^3 in 2005. The estimate of the remaining reserves of conventional crude oil by the Electricity and Utility Board (EUB) in Alberta is about 254.8 million m^3 (as of Dec. 31, 2005). The crude oil production rate is expected to decline over the forecast period in the reference case. The detailed input data and assumptions for this module are given in Subramanyam (2010) [153].

4.3.2.6 Synthetic crude oil and crude bitumen production module

Around 228 million barrels of bitumen were extracted by surface mining and 160 million barrels from in situ, totaling 388 million barrels of bitumen extraction in Alberta in 2005. The bitumen produced by surface mining is upgraded to synthetic crude oil (SCO), whereas the bitumen from in situ production is marketed as non-upgraded crude bitumen. The contribution of bitumen to Alberta's oil production has increased, unlike conventional oil. The percentage share of non-upgraded bitumen and SCO production in Alberta's crude oil and supply is expected to increase from 58% in 2005 to 85% by 2015. The detailed input data and assumptions for this module are given in Subramanyam (2010) [153].

4.3.2.7 NGL production module

NGL is a blend of liquid hydrocarbon products that are extracted from the natural gas stream. This blend can be separated into useful products such as ethane, propane, or butane. Crude oil refining and upgrading processes are also sources of propane and butane. The products from these processes are usually referred to as liquefied petroleum gases. It is estimated that around 87% of propane and 69% of butane came from natural gas production in 2006. The NGL processing capacity in Alberta was 600 GJ in 2005. There is no major change considered in NGL production for the reference case. The detailed input data and assumptions for this module are given in Subramanyam (2010) [153].

4.3.2.8 Coal mining module

Sub-bituminous, metallurgical bituminous, and thermal bituminous are the three types of marketable coal produced in Alberta. The coal extracted from mining is called raw coal. The coal marketed after processing is known as clean coal. The remaining established reserves for all types of coal in Alberta were 33.5 gigatonnes as estimated by EUB on Dec. 31, 2005. The detailed input data and assumptions for this module are given in Subramanyam (2010) [153].

4.3.3 LEAP resource module for Alberta's model

The resource sector consists of primary and secondary resources and has been briefly described below. The detailed input data and assumptions for this module are given in Subramanyam (2010).

4.3.3.1 Primary resources

The input data for primary resources consists of reserves for the base year, resource imports, and exports for natural gas, coal, bitumen, crude oil, NGL, and pentanes [153].

4.3.3.2 Secondary resources

The secondary resources include the fuels produced as a result of transformation modules and as demanded by the demand sectors. In LEAP's Alberta model, the secondary fuels are comprised of electricity, steam, and refinery finished products [153].

4.3.3 LEAP Technology and Environment Database (TED) for Alberta's model

Environmental data for different kinds of pollutants (e.g., CO_2 biogenic, methane NO_x, CO_2 equivalent, particulates, and SO_x) are built into the LEAP model. The corresponding global warming effects are also listed in the environmental database. The detailed emissions per unit of fuel consumed with respect to the technology considered have been used for the demand sectors. The Intergovernmental Panel on Climate Change (IPCC) Tier 1 and Tier 2 emission factors for coal, natural gas, biomass, and wood are also specified in TED [153].

For the transformation and resource modules, the TED database has emissions data available for different conversion processes such as oil refining, biomass conversion, natural gas processing, coal processing, and electricity. The emissions factor is developed for Canadian refineries by considering earlier studies that calculate the emissions factor for Alberta refineries [153]. All the transformation and resource sectors have been developed according to Alberta's resource development and are associated with the corresponding emissions. Further details on this module are given in Subramanyam (2010) [153].

4.4 LEAP-WEAP integration

The modeling methodology and framework development of the LEAP model have been described in the previous section. The developed LEAP-WEAP model was used to study three integrated energy scenarios. The water-demand and GHG emissions were estimated for these three scenarios. The following guidelines were adopted for successful integration of the LEAP and WEAP models [48]:

- Both LEAP and WEAP areas must have the same base and end years.
- Both LEAP and WEAP must have the same set of time steps.

Table 49 below shows a summary of the scenarios developed in LEAP-WEAP integrated model.

Table 49: Input parameters and assumptions for development of LEAP-WEAP integrated model scenarios

Sr. #	LEAP-WEAP scenarios	WEAP model input parameters and assumptions	Water demand (MCM) by 2030	GHG emissions (MT) by 2030	Water demand (MCM) by 2050	GHG emissions (MT) by 2050
1	Integrated LEAP-WEAP power generation scenario	The subcritical power plants (Battle River 3/4/5, and Sundance 1/2/3/4/5/6) are expected to retire by the end of 2020 whereas Genesee 1/2 may operate till 2029. Keephills1/2 may operate till 2024. The electricity generation capacity projections by AESO include 4.2% annual growth from 2012-2017 and 3.6% from 2018 to 2050.	32.13	5.36	39.37	7.40
2	Integrated LEAP-WEAP petroleum sector scenario	ERCB's projections for bitumen extraction and considering 57% and 53% improvement in water coefficients for surface mining and in situ by 2035 and 33% and 19% further reduction by 2050.	Surface mining 114.74 In situ 29.20	Surface mining 13.84 In situ 72.61	Surface mining 78.65 In situ 22.20	Surface mining 17.30 In situ 90.76
3	Integrated LEAP-WEAP in situ dominant bitumen extraction scenario	The share of bitumen extraction through in situ increases to 84% by the end of 2050, leaving surface mining with a share of only 16%. Also taking into account 57% and 53% improvement in water coefficients for surface mining and in situ by 2035 and 33% and 19% further reduction by 2050.	Surface mining 93.96 In situ 32.66	Surface mining 10.57 In situ 84.05	Surface mining 31.46 In situ 31.09	Surface mining 6.92 In situ 127.07

4.4.1 Power generation sector

4.4.1.1 Integrated LEAP-WEAP reference scenario for power sector

The assumptions and projections for the power sector reference scenario have been explained in detail in Section 3.2.3 of Chapter 3. It is also assumed that the new natural gas power plants are installed in the same region as the coal-fired power plants, i.e., the North Saskatchewan River Basin.

The GHG emissions and water demand for the power sector as calculated by LEAP-WEAP model in the reference scenario are shown in Table 50. Around 4750 MW of subcritical coal power generation capacity will be retired by 2030 (Appendix A: Table A-1). Thus, GHG emissions for the LEAP power supply sector decrease from 10.82 to 5.36 million tonnes (MT) by 2030. Water demand declines from 88.18 to 32.13 MCM by the end of 2030. GHG emissions and water demand decrease by around 50% and 65%, respectively, in 2030 in the reference scenario, as shown in Figure 51. This is mainly because of the coal power plants' retirement and commissioning of new natural gas power plants as the substitution. Since the total power production is increasing, GHG emissions and water demand show an increasing trend for the forecast period after 2030 to keep up with the increase in electricity production requirements.

It should also be noted here that the water demand increases by 4% from 2009 to 2020 (before subcritical power plants' retirement) and 20% from 2030 to 2040 (after subcritical power plants retirement). Although the water demand increase in the years 2009-2020 is lower than in the years 2030-2040, the decrease in overall water demand is greater (65% from 2020-2030) due to the coal power plants' retirement. The water demand from 2040 to 2050 rises by only 2%. The main reason for the small increase in water demand is the retirement of Genesee supercritical coal power unit 3 in 2046 and the increase in power production by gas power plants (that have low water coefficients). Thus, it can be concluded that the reduction in water demand achieved by retiring and substituting coal by natural gas power plants is greater than the increase in water demand with the growth in power production.

Table 50: **GHG emissions and water demand as estimated by the LEAP-WEAP integrated model for power sector in the reference scenario**

Parameters	2009	2020	2030	2040	2050
GHG emissions (MT)	10.82	12.60	5.36	6.75	7.40
Water demand (MCM)	88.18	91.59	32.13	38.58	39.37

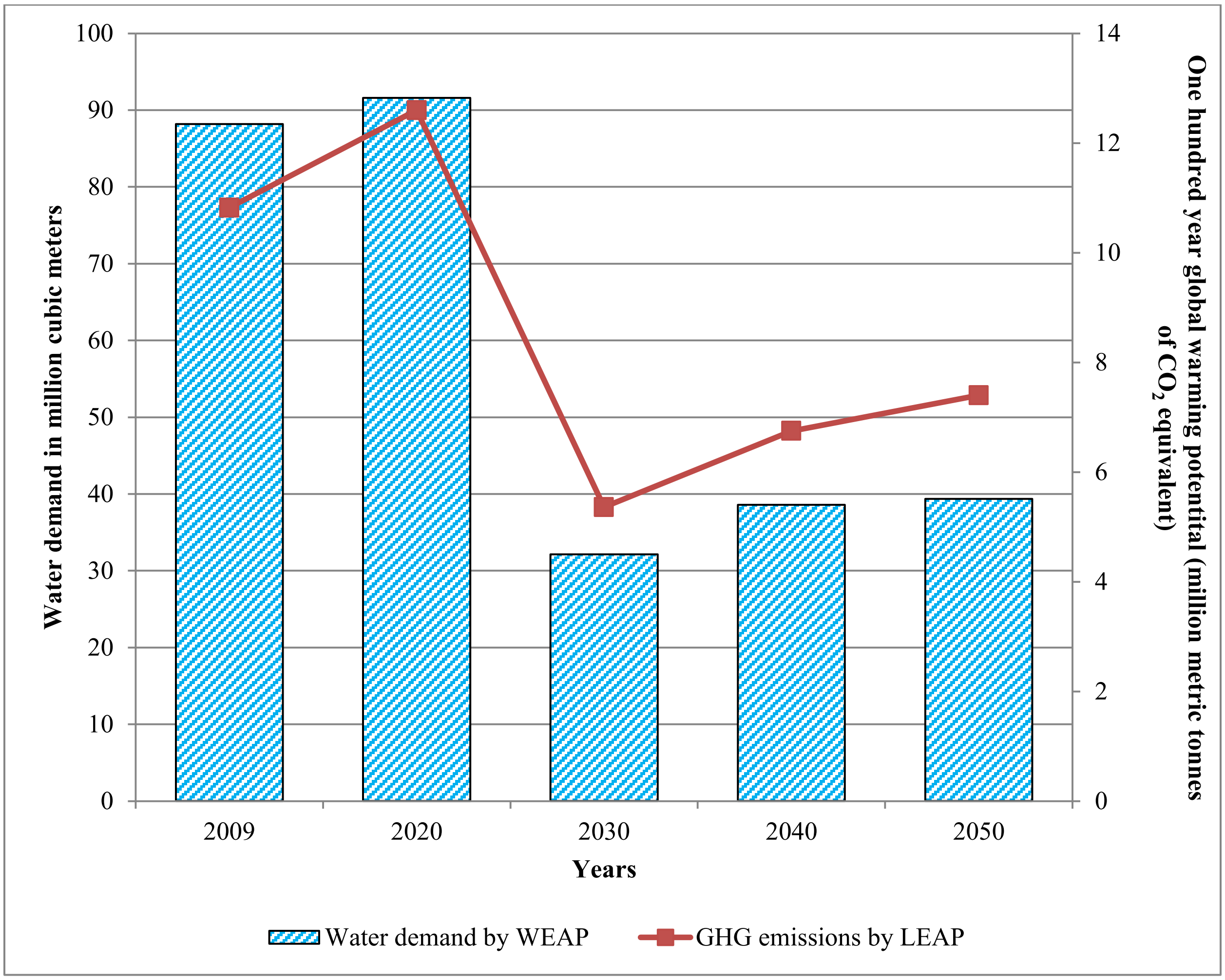

Figure 51: **GHG emissions and water demand for the power sector for the reference scenario based on integrated LEAP-WEAP model**

4.4.2 Petroleum sector

4.4.2.1 Integrated LEAP-WEAP reference scenario for petroleum sector

For the petroleum sector, the data input to the LEAP and WEAP models for the integrated reference scenario for bitumen extraction through surface mining and in situ as per ERCB's projections are given in Table 51. The oil mining includes conventional and bitumen mining. The focus in energy scenario is on the bitumen mining however both bitumen and conventional mining are part of the demand module in the base case as developed in the LEAP model.

Table 51: Reference scenario for bitumen production in million barrels for the integrated LEAP-WEAP model [113, 155]

Demand	2009	2010	2030	2050
Oil mining (total)	704	760	1600	2000
Bitumen mining	549	631	1552	1940
In situ mining	258	300	931	1164
Surface mining	291	331	621	776

The projections shown in Table 52 indicate that the percentage of bitumen extracted through in situ mining increases with time, thereby reducing the amount of bitumen extracted by surface mining. The GHG emissions for the study period in the reference case are shown in Table 52. Under this scenario, the GHG emissions from surface mining grow from 6.49 MT for 291 million barrels of bitumen extracted to 17.30 MT for 776 million barrels of bitumen over the study period. The in situ shows a rise in GHG emissions from 20.12 MT for 258 million barrels of bitumen to 90.76 MT for 1164 million barrels of bitumen. The overall increase in GHG emissions is more than twofold and fourfold over the forecast period by surface mining and in situ, respectively.

Table 52: GHG emissions as estimated by the LEAP model in the reference scenario for bitumen extraction from surface mining and in situ

Sectors	2009	2010	2020	2030	2040	2050
Surface mining (MT)	6.49	7.38	11.38	13.84	15.57	17.30
In situ mining (MT)	20.12	23.36	59.69	72.61	81.69	90.76

In Figure 52, the water demand is dominant for the Athabasca River Basin because of its highest in situ mining activities over the forecast period. For the purpose of simplicity of the model, Cold Lake's in situ activities have been included in the Athabasca River Basin. The water demand for in situ mining decreases because of the improvement in water coefficient over the forecast period. Some projects of in situ mining are completely dependent on saline ground water whereas many use 95% of the recycled water and need only 5% fresh water for extraction processes [123].

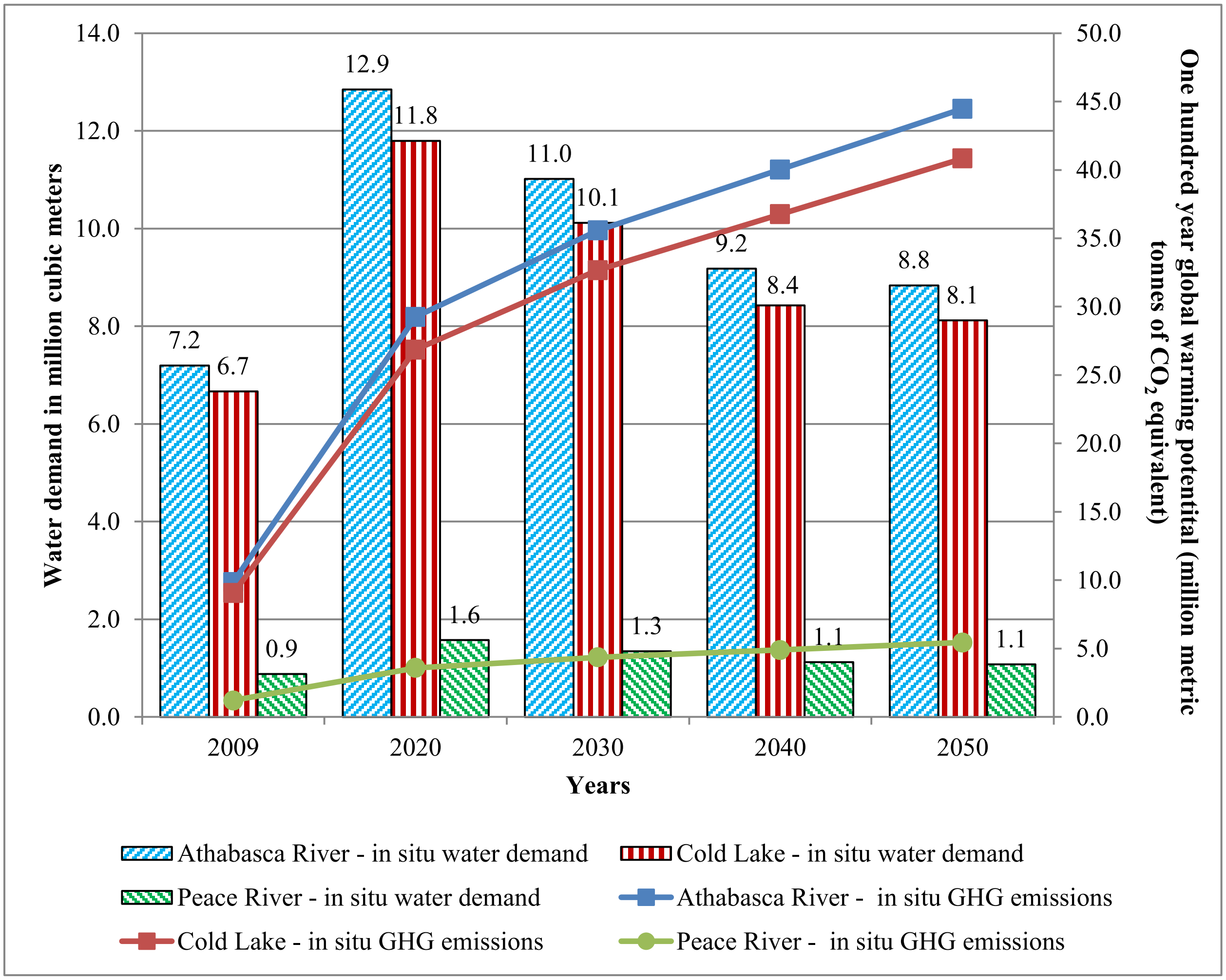

Figure 52: The water demand and GHG emissions for in situ mining on the basis of river basins for the reference scenario as estimated by the integrated LEAP-WEAP model

Water demand for surface mining, as shown in Figure 53, increases from 93.36 to 126.28 MCM in 2020 and then decreases to 89.77 MCM by 2050. For in situ, water demand rises from 14.8 to

29.2 MCM by 2030 and then decreases to 18.04 MCM by 2050. It can be concluded from the results of GHG emissions and water requirements for this scenario that in situ is a less water-intensive but more emissions-intensive method of bitumen recovery compared to surface mining.

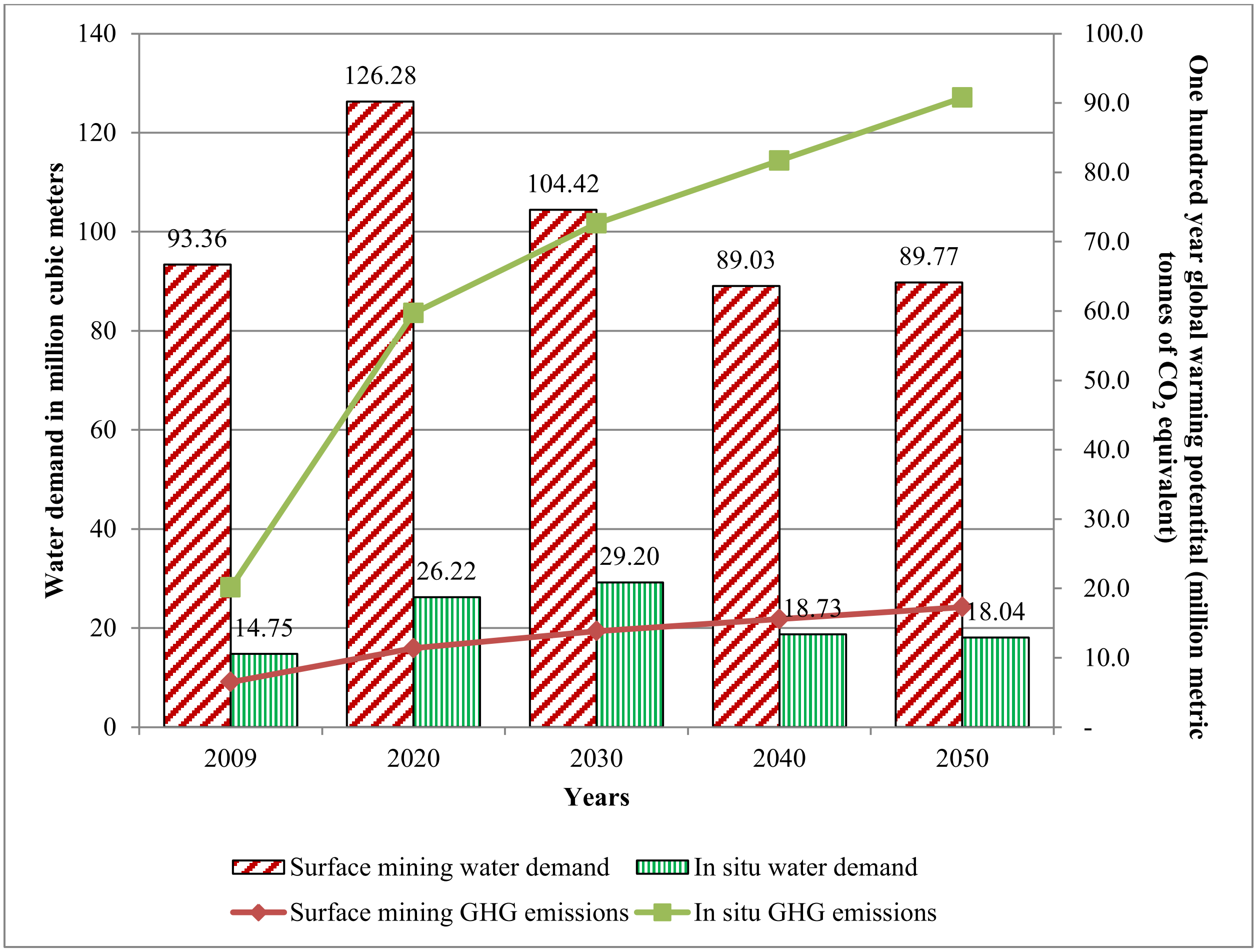

Figure 53: Integrated LEAP-WEAP results for overall water demand and GHG emissions for in situ and surface mining for the reference scenario

4.4.2.2 Scenario P1: In situ dominant bitumen extraction scenario

In the in situ dominant bitumen extraction scenario, rather than following ERCB's projections it has been assumed that the share of bitumen extraction through in situ will increase to 84% by the end of 2050, leaving surface mining with a share of only 16%. This percentage share of in situ and surface mining has been extrapolated from the data available for the last 14 years (2000-2013) from Alberta Energy Reserves and Demand/Supply Outlook Reports (Appendix A: Table

A-2). The contribution of bitumen extraction in oil mining will become 97% from 78% by 2023, whereas conventional oil mining will reduce to 3% [33, 38].

The GHG emissions by surface mining, as estimated by the integrated LEAP-WEAP model, increase by 66% by 2020 from 6.49 to 10.76 MT and then decrease by 36%, i.e., to 6.92 MT in 2050 as shown in Table 53. For in situ, the GHG emissions increase from 20.12 to 127.07 MT, i.e., more than six fold rise, till 2050. This scenario again confirms the conclusion that in situ emits more GHGs and needs less water than does surface mining.

Table 53: The GHG emissions as estimated by the integrated LEAP-WEAP model in situ dominant bitumen extraction scenario

Sectors	2009	2010	2020	2030	2040	2050
Surface mining (MT)	6.49	7.38	10.76	10.57	9.06	6.92
In situ mining (MT)	20.12	23.36	61.86	84.05	104.46	127.07

The water demand for in situ increases from 14.83 to 25.26 MCM over the study period. Water demand for surface mining will increase to 123.6 MCM till 2020 because of the increase in overall bitumen extraction. After 2020, the demand of water starts to decrease for surface mining as the in situ activities start to dominate. Water demand for surface mining decreases by 78% to 27.76 MCM till 2050. The same trend is evident for GHG emissions for surface mining (see Figure 54).

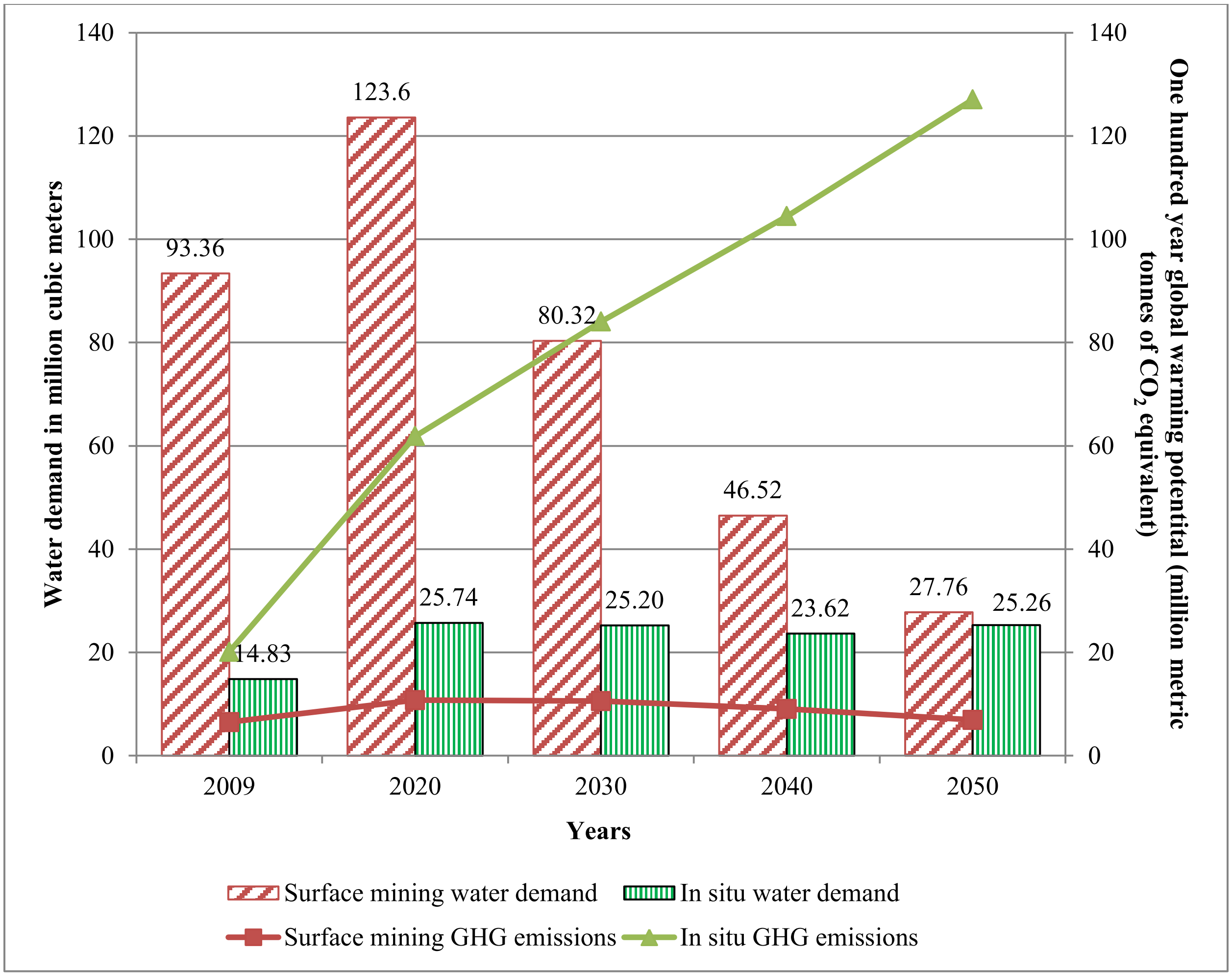

Figure 54: **Results for GHG emissions and water demand for surface mining for in situ dominant scenario as estimated by the LEAP-WEAP model**

The GHG emissions from bitumen extraction through surface mining in 2050 are 17.30 MT in the reference case and 6.92 MT under the in situ dominant scenario. Thus, the GHG emissions decrease by up to 60% by 2050 for surface mining compared to the reference case as shown in Figure 55. The GHG emissions show a decreasing pattern for surface mining under the in situ dominant scenario as the percentage of bitumen extraction from this method declines to 16% over the study period.

For in situ, the GHG emissions in 2050 are 90.76 and 127.06 MT for reference and the in situ dominant scenarios, respectively. Therefore, the GHG emissions increase by 40% by 2050 in comparison to the reference scenario as shown in Figure 55. The GHG emissions from in situ show an increasing trend under this scenario as the percentage of bitumen extraction from this method increases to 84% over the planning horizon.

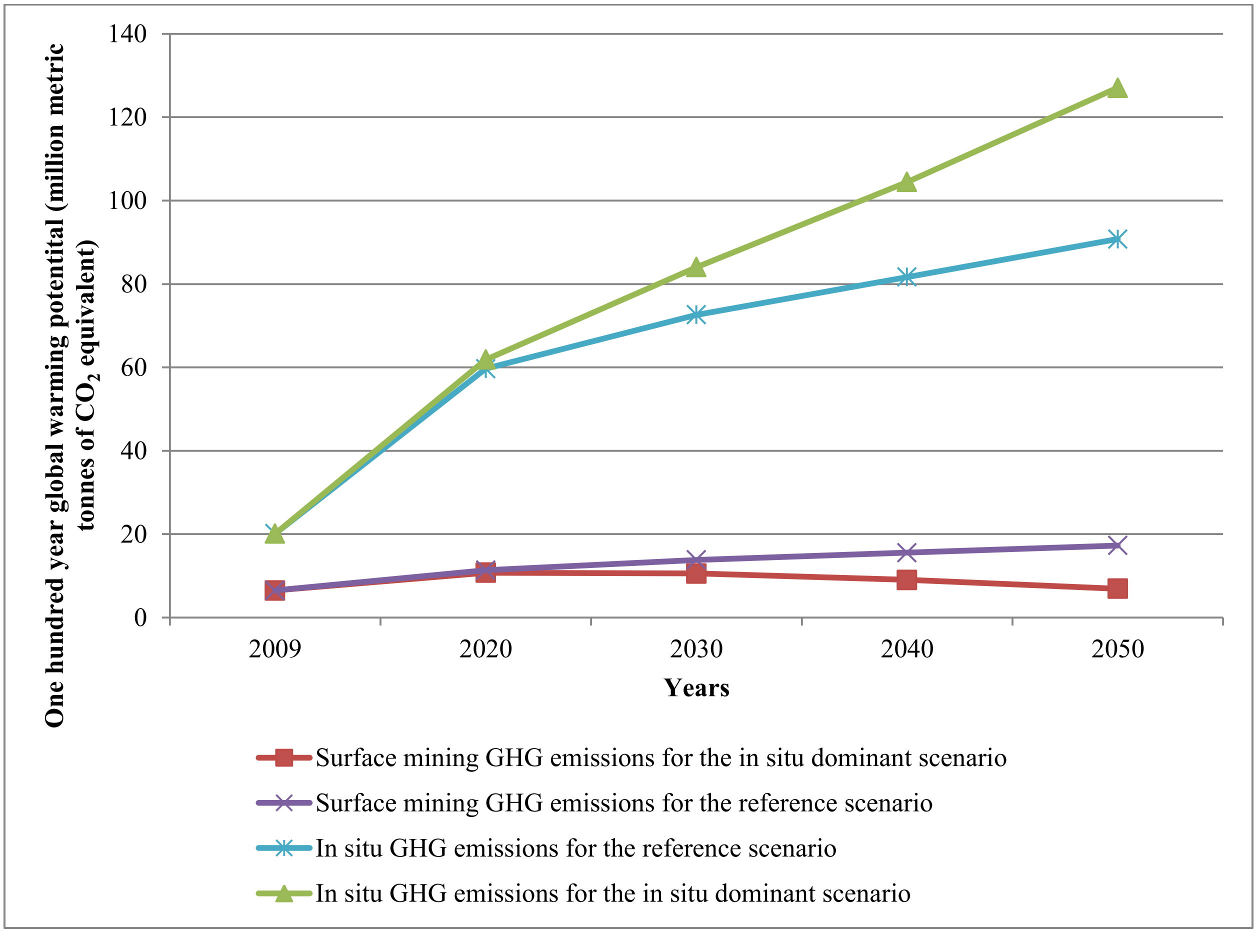

Figure 55: **Results for GHG emissions for the reference case and in situ dominant scenario as estimated by the integrated LEAP-WEAP model**

The water demands for in situ increases from 14.8 to 18.04 MCM in the reference scenario, whereas it rises from 14.8 to 25.26 MCM under the in situ dominant scenario as represented by Figure 56. Thus, the water requirement is 1.2 and 1.7 times greater under the reference scenario and the in situ dominant scenario in 2050 compared to 2009, respectively. The water demand by in situ shows an increasing trend under the in situ scenario, mainly because the percentage of bitumen extraction from this method increases to 84% over the considered time frame.

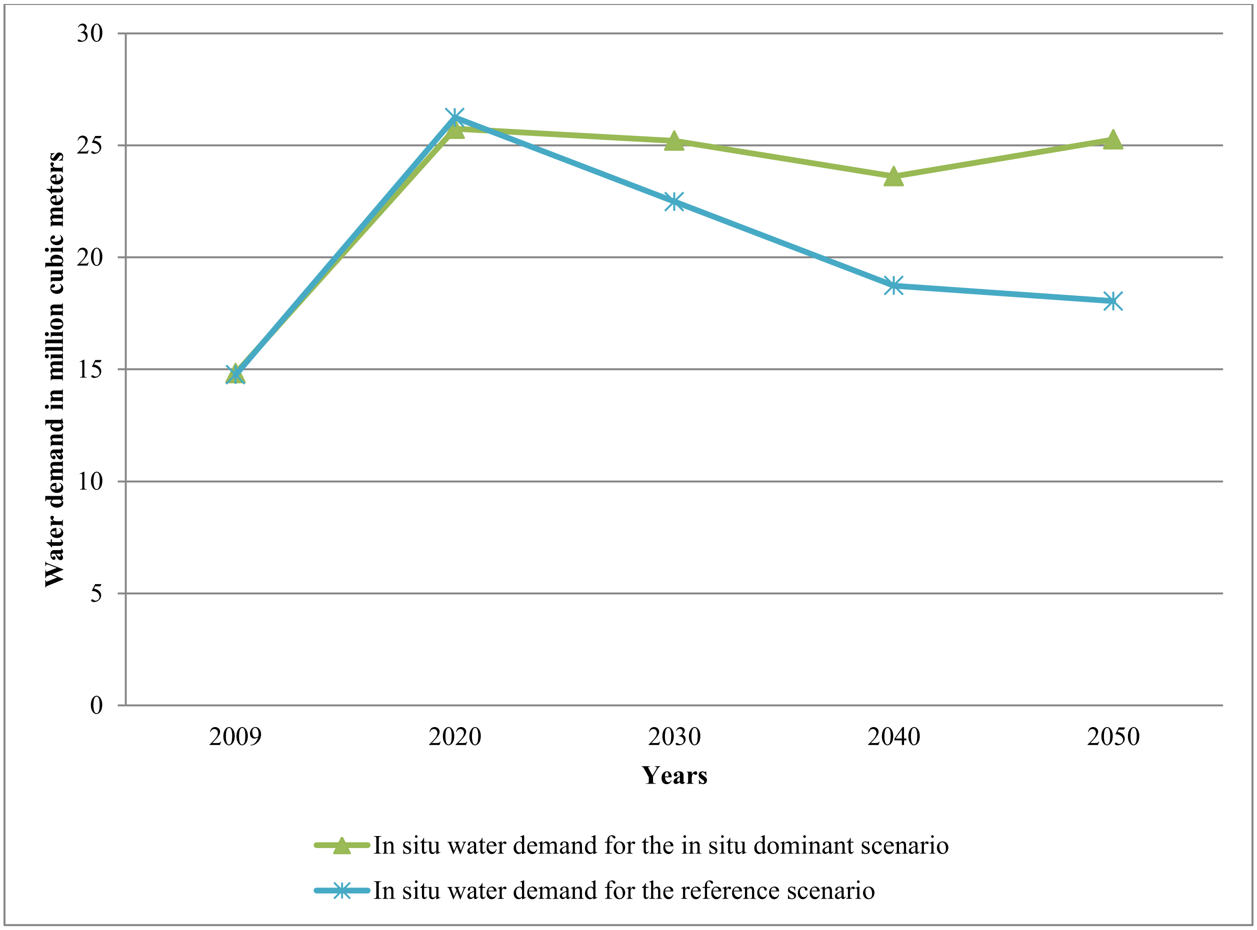

Figure 56: **Results for water demand for in situ for the reference case and in situ dominant scenario as estimated by the integrated LEAP-WEAP model**

The water demand for bitumen extraction from surface mining increases from 93.39 to 126.28 MCM by 2020 in the reference scenario whereas it decreases from 93.39 to 27.76 MCM by 2050 under in situ dominant scenario as represented by Figure 57. The water requirement decreases by 29% from 2020-2050 under reference scenario and decreases by 77% under in situ dominant scenario. Water demand from surface mining shows a declining trend after 2020 under the in situ scenario because the percentage of bitumen extraction from this method decreases to 16% over the study period.

Hence it can be concluded that an increase in bitumen recovery by in situ produces more GHG emissions but requires less water than surface mining, which generates fewer GHG emissions but needs more water. Since the selection of bitumen extraction method is a trade-off between GHG emissions and water use, an optimized point is required where both of these factors can be lessened.

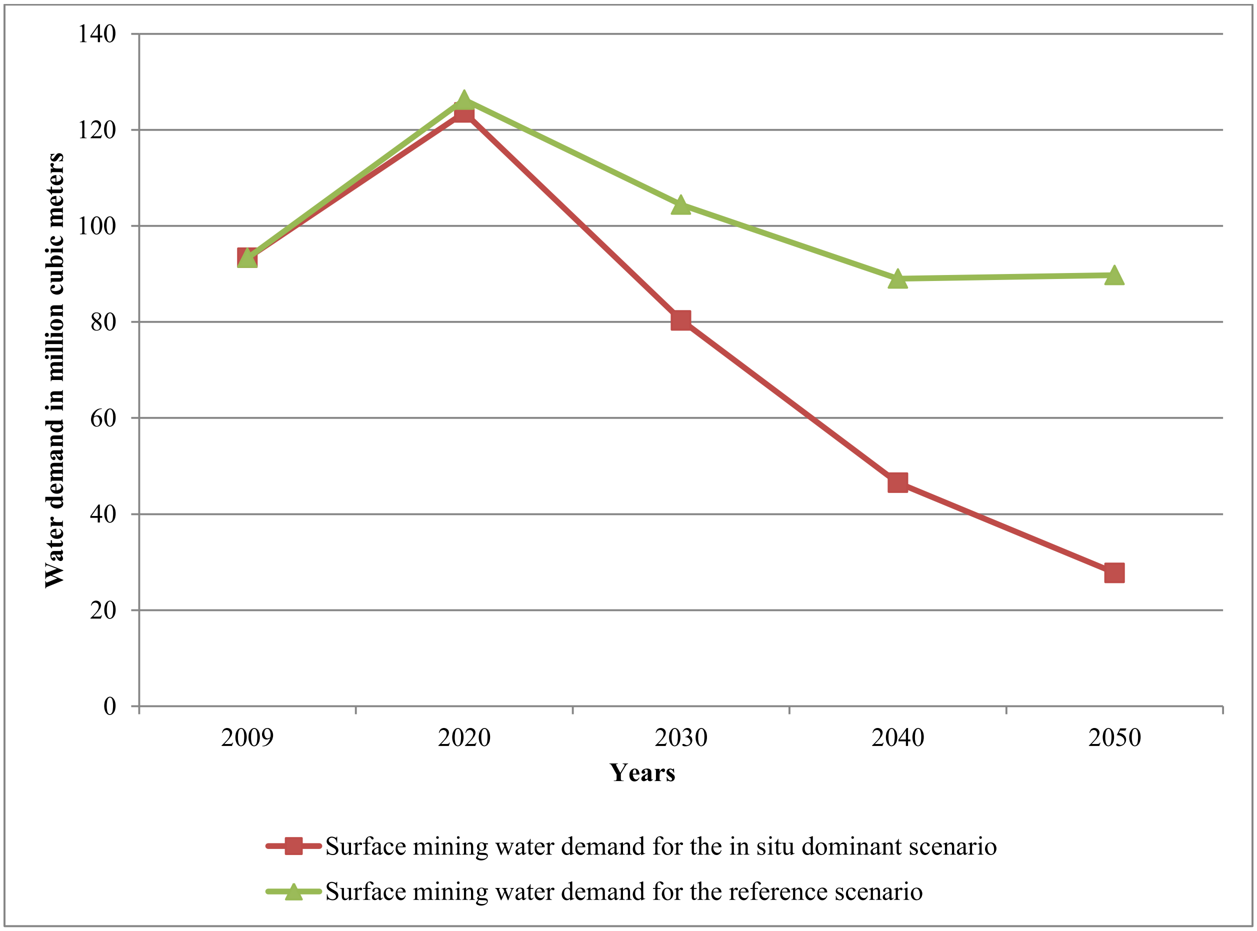

Figure 57: **Results for water demand for surface mining for the reference case and the in situ dominant scenario as estimated by the integrated LEAP-WEAP model**

It can be summarized that GHG emissions and water demand decrease by around 50% and 65%, respectively, in 2030 due to the retirement of subcritical coal power plants. As estimated by the integrated LEAP-WEAP model, the results for the petroleum sector under ERCB's projections indicate that the GHG emissions by surface mining are more than doubled by 2050. For in situ, the GHG emissions increase four folds till 2050 under reference scenario. The demand site coverage for all the sectors of all the river basins under study is 100% in WEAP model.

In this chapter, the developed methodology and the results achieved for the integrated WEAP and the LEAP scenarios were discussed. An integrated water-energy model developed for two demand sectors of Alberta provides a customized water-energy analysis on the basis of river basins. For the same input data of the annual activity of the oil sands and power sectors, the two integrated models provide the water demand results along with the variations in energy demand and GHG emissions under the scenarios considered.

From the results of the integrated LEAP-WEAP scenarios, it can be concluded that in situ needs less water but emits more GHGs than bitumen extraction from surface mining. For the power sector, coal power plants are more GHG and water intensive than natural gas power plants. Since the coverage is 100%, it can be deduced that the rivers have enough water to fulfil the needs under different growth scenarios, if they continue till 2050 with the flows they had in previous ten years.

Chapter 5: Conclusions and recommendations

5.1 Conclusions

Alberta is the fourth largest province of Canada. The growing oil and gas industry has made Alberta's economy one of the most influential in Canada. Alberta is also considered to be the highest consumer of energy per capita in Canada. For Alberta, the energy sector plays an important role by contributing to the GDP, income, employment, and total revenue of the province. Alberta not only consumes more energy than elsewhere in Canada, it emits more GHGs than any other province. Alberta's energy sector includes the oil sands. Of 173 billion barrels of oil reserves in Canada, 170 are found in Alberta and around 168 of these are extracted from bitumen. The water diversions are also expected to increase in the future to meet the needs of this growing economy. When assessing potential environmental concerns, the ultimate objective is to develop the strategies to reduce the vulnerabilities around water and energy, and to mitigate the corresponding GHG emissions. With increasing economic development in Alberta, there is a considerable pressure for the province to reduce its carbon and water footprint by developing environment friendly energy production pathways.

The WEAP model is used in this research to understand water use in Alberta's demand sectors with a focus on the province's four main river basins and to develop different water demand scenarios. The demand trees for Alberta' six sectors (municipal, agriculture, industrial, petroleum, commercial, and "other") were established by incorporating water intensities of various demand sectors into the WEAP model. The WEAP methodology for the agriculture sector of the Bow River Basin is shown in Figure 58. Different scenarios were developed in the WEAP model for water demand and supply pattern for Alberta's river basins for a study period of 42 years (from 2009 to 2050). The WEAP model was also integrated to the LEAP model to estimate the water demand and GHG emissions in the petroleum and power sector. Thus, the current research provides a comprehensive analysis of all the water demand sectors as well as the supply resources. The integrated water-energy model developed for Alberta provides a detailed water-energy analysis based on local rivers. Such an integrated study can help the industrial sector and policy makers to fully understand the interconnections between energy and water use, or the water-energy nexus for Alberta.

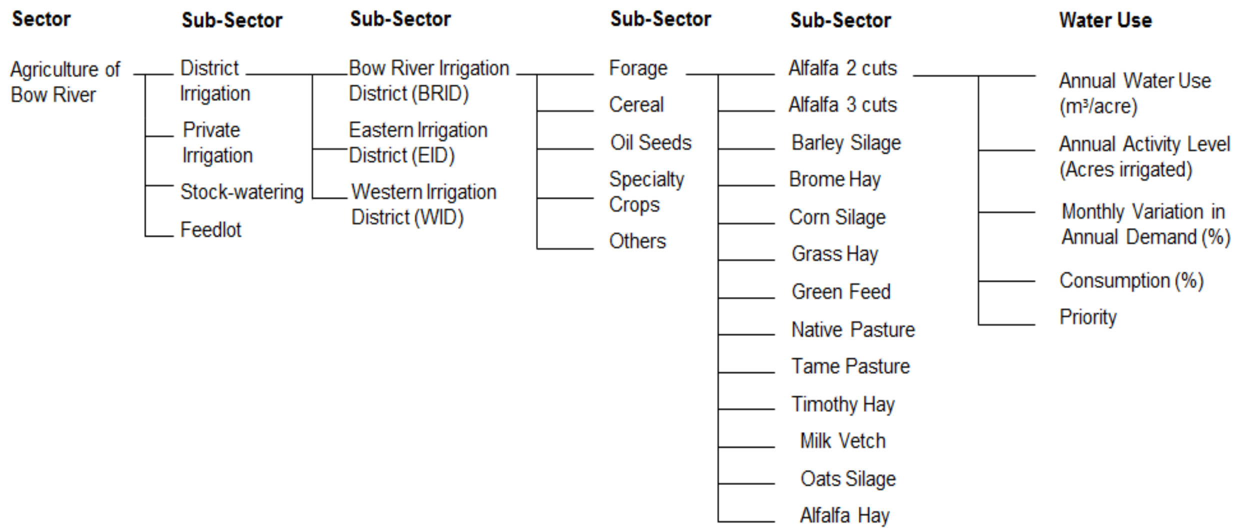

Figure 58: The WEAP methodology for the agriculture sector of the Bow River Basin

The four river basins in Alberta considered for this study are the North Saskatchewan, Bow, Athabasca, and Peace. These river basins are in a critical stage compared to others because of increased water withdrawal requirement to satisfy thriving industry's demand. The soaring oil sands development in Alberta is mostly concentrated in the Athabasca and Peace river basins, the Bow River Basin is capped for further water allocations, and the North Saskatchewan River Basin is threatened by six proposed bitumen upgraders and future industrial expansion.

For municipal, agriculture, commercial and 'other' demand sectors, low and high growth scenarios have been developed in addition to the reference scenario. The growth rate in Alberta is considered to be slow as compared to the previous years for the above mentioned demand sectors under low growth scenario. For the reference scenario, current rate of increase in activity levels is projected for the future. An optimistic level of increase in future is expected in the high growth scenario. Coal power plants' retirement and expected industrial expansion is taken into account for the industrial sector reference scenario whereas the other scenario for industrial sector is based on GDP projections. The reference scenario for the petroleum sector gives the water conserved over the forecast period by the improvement in water coefficients for bitumen production. The in situ dominant scenario estimates the water demand over the study period when bitumen extracted by in situ is 84% of the total bitumen produced whereas surface mining accounts for only 16%. The important results obtained for the scenarios developed in the WEAP model for the different sectors are highlighted in the sections below. In addition to the WEAP model scenarios, three integrated LEAP-WEAP scenarios were also developed for power and petroleum sector. Same time steps, base and end years were used in both LEAP and WEAP for successful integration of the two modeling softwares.

Cumulative water demand for the municipal sector as calculated by the WEAP model declines by 26% in low growth of population and rises by 44% in high growth of population scenarios as compared to the reference scenario. This increase in water demand is directly coupled with population expansion and improving per capita water use. Water demand for the agriculture sector in the Bow River Basin for the low growth, reference and high growth scenarios decreases over the study period because of the increase in precipitation in the future. For high growth scenario, water demand rises by 6% more than that of the reference scenario value in 2050. The overall consumption for the river basins increases up to 191% under the high growth scenario. The cumulative water demand for the reference scenario for municipal and agriculture sector is given in Table 54.

Table 54: The WEAP model cumulative water demand (MCM) for the reference scenario for four major river basins in Alberta

Demand sector	2009	2020	2030	2040	2050
Municipal	538	570	566	576	521
Agriculture	1478.77	1348.77	1370.66	1393.37	1417.69

The water demand for industrial sector reference scenario decreases by 24% over the forecast period, mainly, because of the retirement of most of the coal-fired subcritical power plants by 2020. Moreover, the estimated GHG emissions and water demand by LEAP-WEAP model indicates a decrease of around 50% and 65%, respectively, in 2030 in the reference scenario (Figure 59). Therefore, water savings can be achieved by substituting coal-fired power generation by natural gas power generation. However, other economic aspects need to be considered too. This option seems feasible with respect to low water demand and GHG emissions. Water requirement for industrial growth based on GDP projections rises by 41% in 2050 compared to reference value.

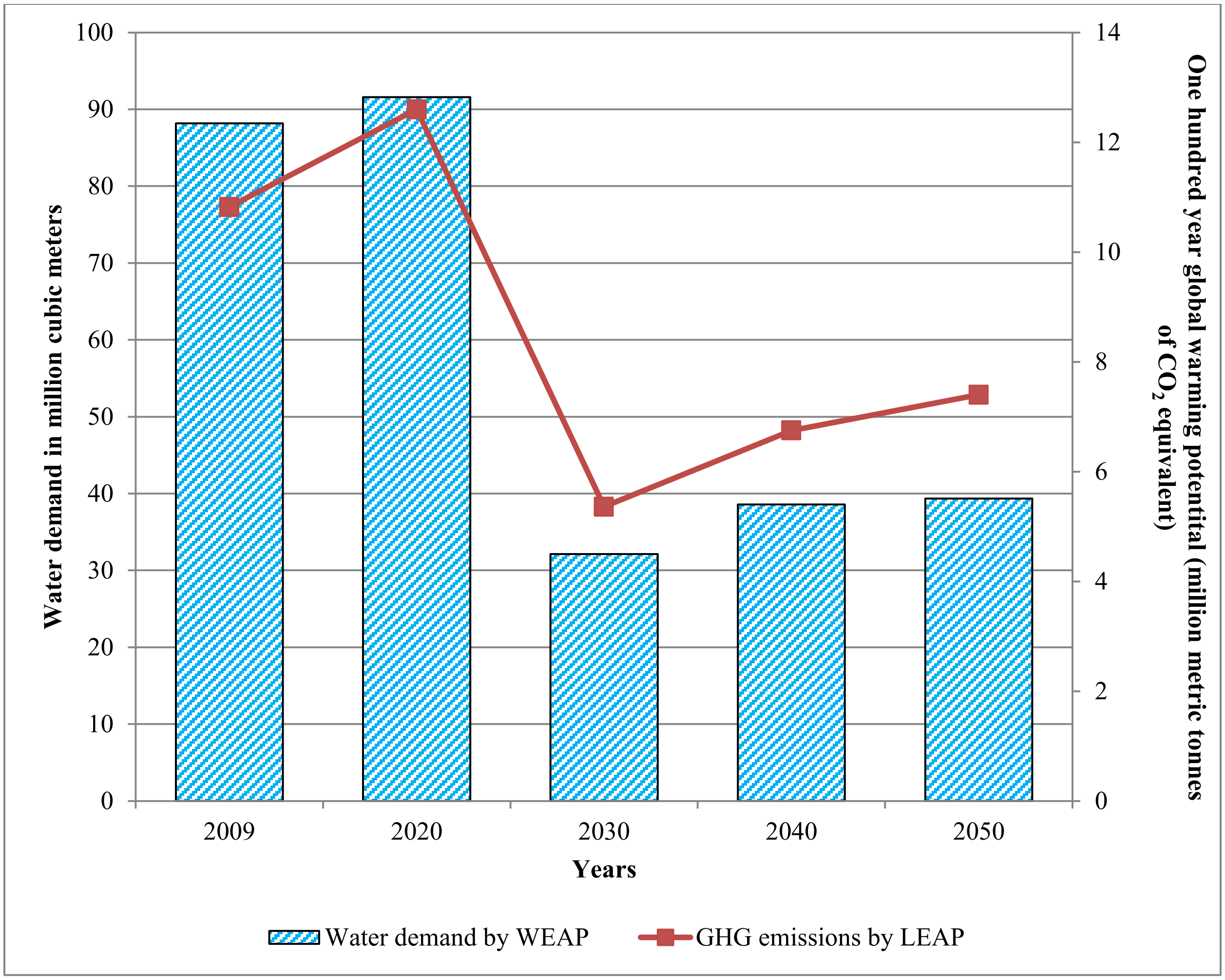

Figure 59: **GHG emissions and water demand for the power sector for the reference scenario based on integrated LEAP-WEAP model**

The cumulative petroleum sector water demand will more than double by 2050 due to expansion in the province in the reference scenario, whereas, the increase in GHG emissions is more than twofold and fourfold over the forecast period by surface mining and in situ, respectively. The integrated LEAP-WEAP results for water demand and GHG emissions for in situ and surface mining are shown in Figure 60.

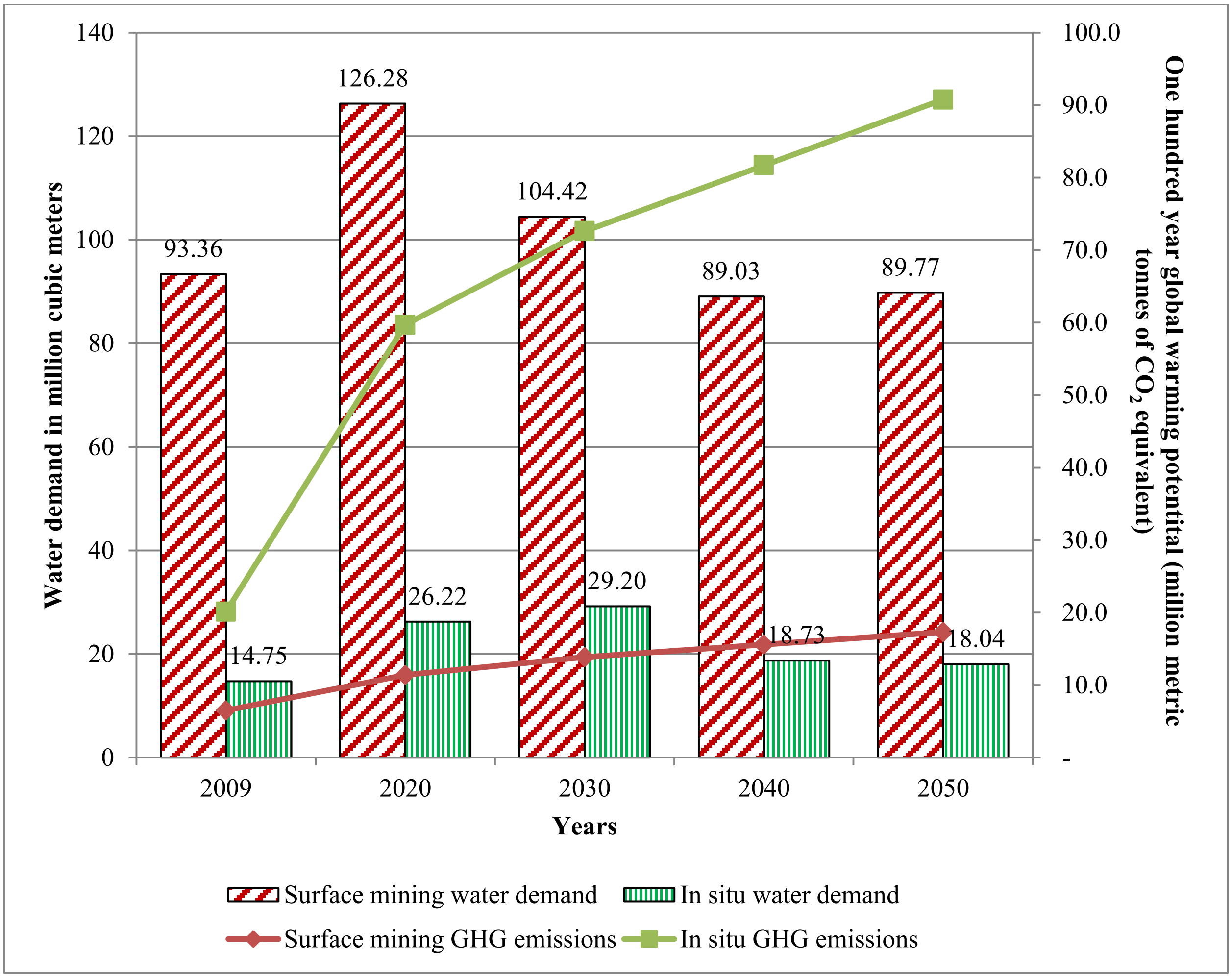

Figure 60: Integrated LEAP-WEAP results for overall water demand and GHG emissions for in situ and surface mining for the reference scenario

For in situ dominant scenario, a reduction of 35% of the water demand can be achieved over the forecast years with an increase of more than six fold in GHG emissions by 2050. Therefore, it can be concluded that in situ is more GHG but less water intensive compared to surface mining.

Compared to the reference scenario of commercial sector, the demands of water are 24% less in the low growth scenario whereas demand increases around threefold for the high growth scenario. For the 'other' sector, the water requirement is about 5.4% less in 2050 in the low growth scenario than the reference case value whereas water demand increases by 11% over the reference scenario in 2050 for the high growth scenario.

The rivers, if they continue with the flows they have had for the past ten years, will have enough water to fulfil the needs of the different growth scenarios considered as the WEAP demand site coverage is 100% for all the sectors of the four river basins. From Figure 61, it can be concluded that the water withdrawn from all the river basin regions, their return flow, and total consumption for the forecast period for all the sectors for the reference scenario based on the WEAP model show an increasing trend. For all the water sources considered in the study, the water remaining in the rivers, as estimated by the WEAP model, decline with the expansion in various demand sectors over time e.g. 9.27% decrease in water of the Athabasca River Basin.

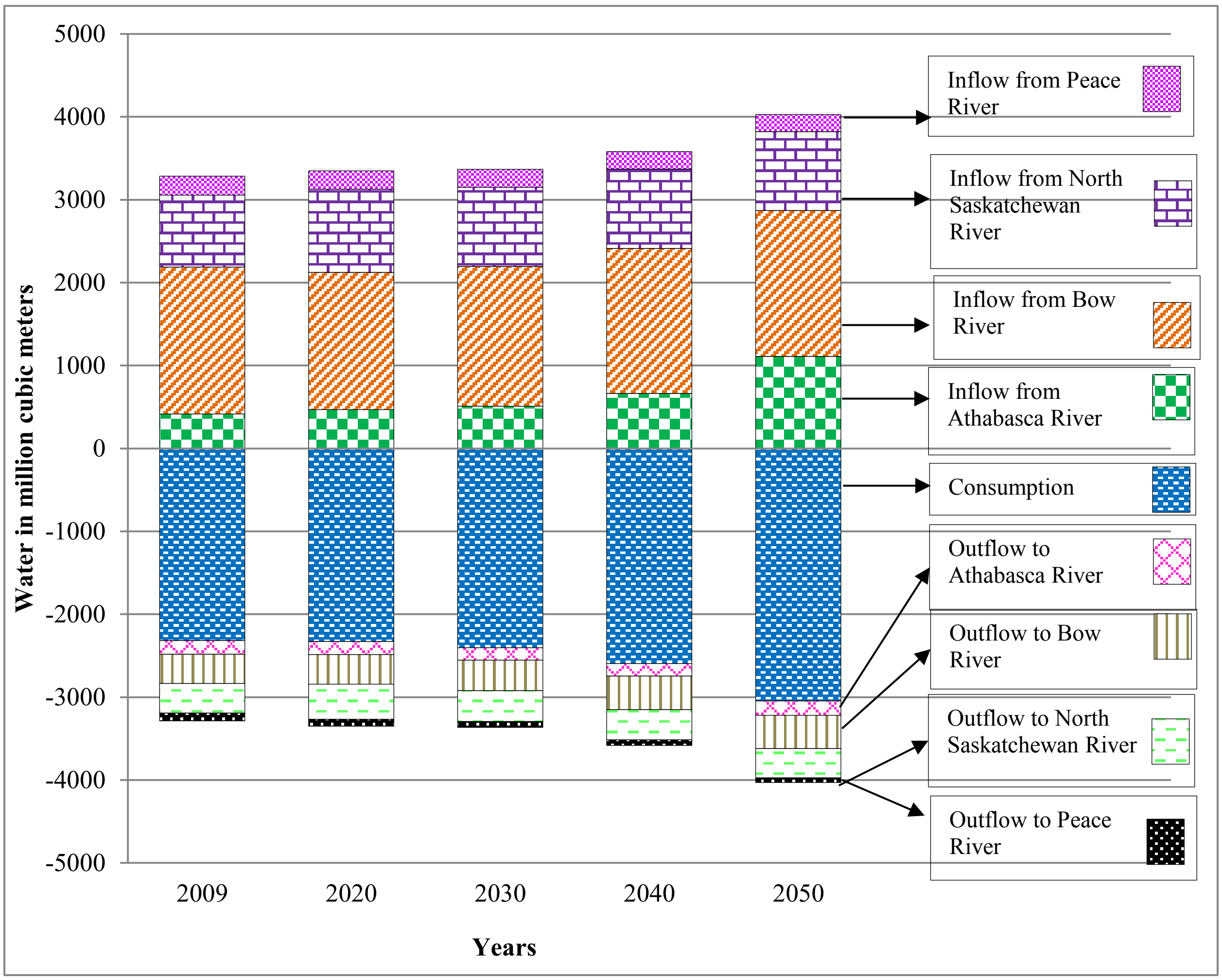

Figure 61: Demand site inflows and outflows for all sectors for the reference case

Thus, the WEAP-Alberta model provides an integrated water-resource system by incorporating supply resources (the four river basins) and demand sectors. The developed WEAP model is used for the evaluation of Alberta's river basins on the basis of water withdrawal, return flow, water consumption, inflows, and outflows for each sector, demand site coverage. The WEAP model also estimates the water demand that is not satisfied by the supply resource, i.e., unmet demand. So, a complete evaluation of water demand-supply is possible with the WEAP-Alberta model. Moreover, it can also be concluded that there is a considerable margin to explore the opportunities available in different demand sectors to reduce water demand. This purpose can be achieved by conservation, recycling, and implementation of water efficient technologies.

5.2 Recommendations for future work

The developed WEAP-Alberta model estimates the water demand from the demand sectors, return flows to the supply resources and overall consumption. The demand site coverage and unmet demand (based on the demand-supply balance) are also provided among many results from the WEAP model. Thus, the model can be used to study the impacts on water demand by various activity levels carried out in different demand sectors, to evaluate the water resource potential to satisfy future population and economy expansion, and to set targets to control water consumption by various sectors and enhance water return.

This research also developed an integrated LEAP-WEAP model for assessing various different scenarios. The integrated model facilitates in presenting the water demand results along with the variations in energy demand and GHG emissions.

Some of the recommendations to expand the current study are:

- The water-energy nexus for power sector (renewable energy resources), pulp mills and chemical sectors can be assessed.
- Water quality has not been considered in this model. This parameter can be coupled to different demand sector activities in the WEAP model to track water pollution and contaminants in WEAP.
- The WEAP-Alberta model does not differentiate between surface and ground water distribution except for the in situ sub-sector of the petroleum demand sector. To enhance the capability of the developed model, water allocations can be separated according to ground water and surface water for all the demand sectors.

- The current study has limited data on the projections of the water intensities/coefficients and consumption for different demand sectors' activities. Different methods can be considered and explored to forecast the water coefficients' future trends. This addition can help achieve more realistic results from the WEAP model.
- WEAP has the ability to incorporate the demand side management savings along with other capital and variable operating costs. Since the cost factor has not been accounted for in the WEAP-Alberta model so the option of water cost savings can be explored.
- Four rivers basins are modelled through WEAP in this study. This work can be continued for the remaining river basins in Alberta to produce an in-depth water model for the whole province. The WEAP model for the entire province can then be integrated with LEAP to obtain a detailed water-energy nexus model. For the integration, both LEAP and WEAP must have the same sectors and sub-sectors and the units of activity levels should match. The integrated LEAP-WEAP model can help identify the water and energy demands and supplies as well as the effects on water quality with increase in the energy demand.
- The demand priorities of the demand sectors were added for a sector as a whole in the WEAP model. To make the WEAP model more realistic and accurate in terms of allocating water to the competing demand sites, individual demand priorities for the sub-sectors of the demand sectors can be considered.
- The WEAP model for Alberta can be improved by incorporating climate variability and considering monthly time steps to evaluate summer and winter water flows.

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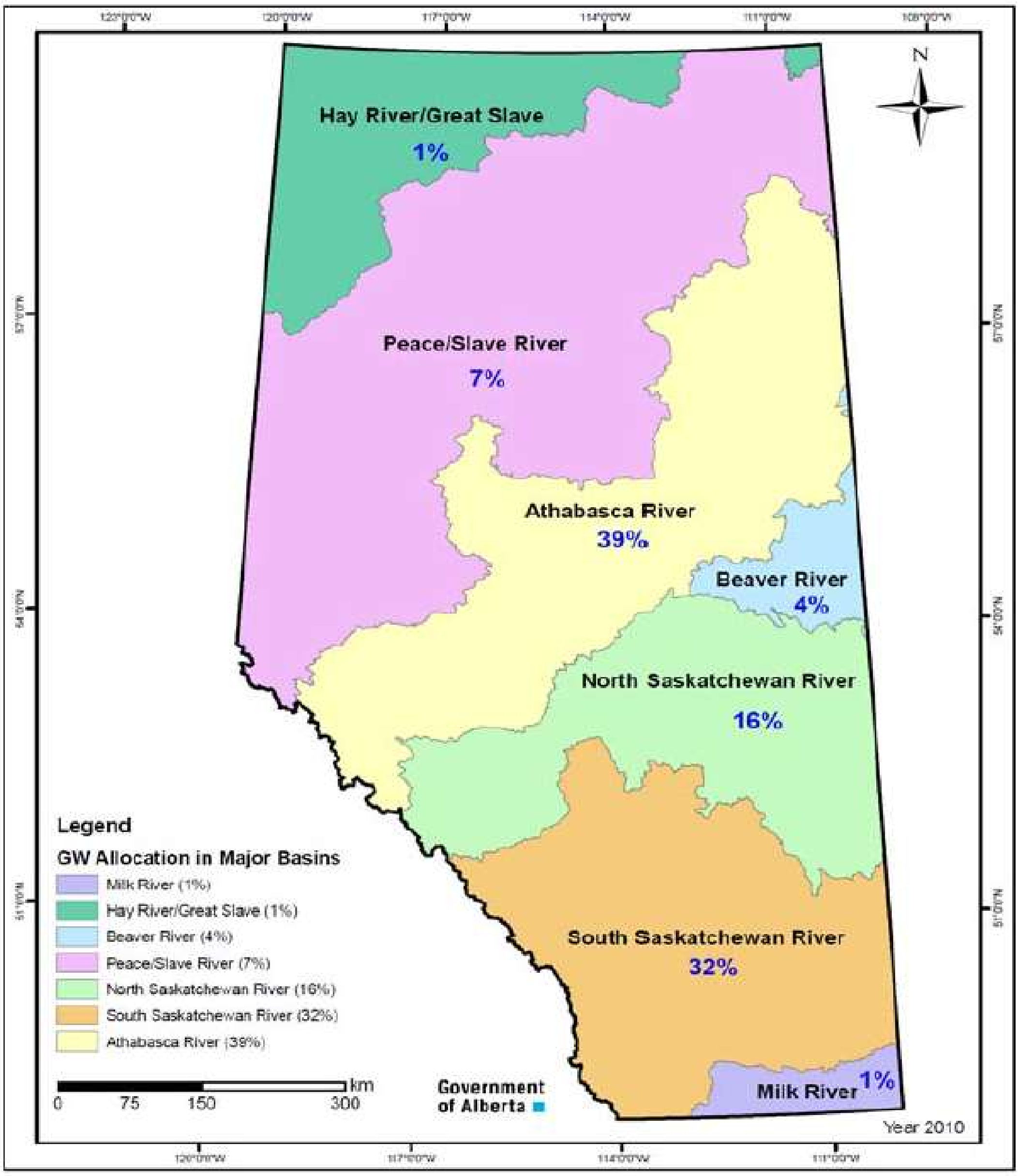
Appendix A

The ground water allocations on the basis of major river basins are shown in Figure A-1. 39% of ground water available in Athabasca River region is allocated to various demand sectors followed by South Saskatchewan River Basin with 32% of ground water allocation.



Credit: Alberta Environment

Figure A-1: Allocation of ground water on the basis of major river basins of Alberta [16]

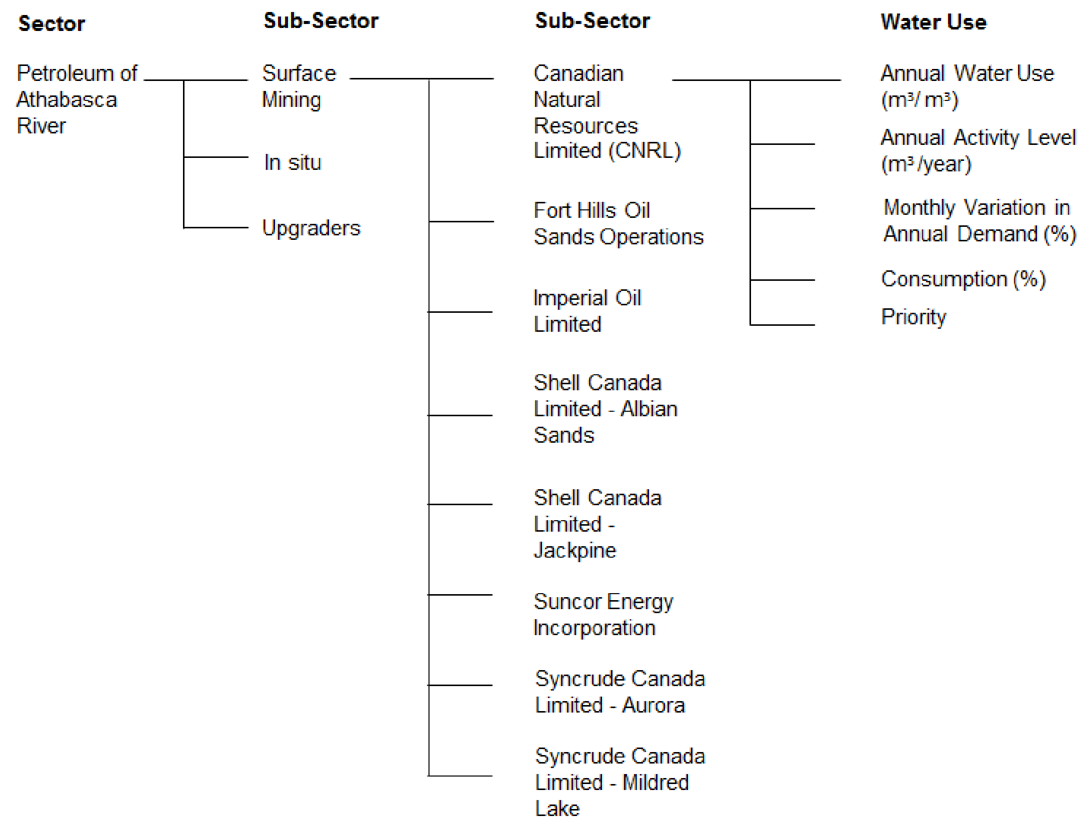


Figure A-2: The WEAP methodology for petroleum sector of the Athabasca River Basin

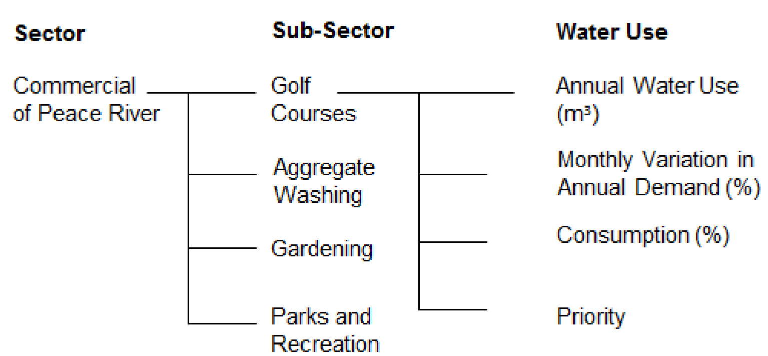


Figure A-3: The WEAP methodology for commercial sector of the Peace River Basin

Table A-1: Coal-fired power plants' retirement schedule

Power plant	Commissioning year	Power purchase agreement (PPA) expiry	End of useful life – Alberta regulation
Battle river 3	1969	31-Dec-2013	31-Dec-2013
Battle river 4	1975	31-Dec-2013	31-Dec-2015
Battle river 5	1981	31-Dec-2020	31-Dec-2021
Genesee 1	1994	31-Dec-2020	31-Dec-2034
Genesee 2	1989	31-Dec-2020	31-Dec-2029
Genesee 3	2005	-------	-------
Keephills 1	1983	31-Dec-2020	31-Dec-2023
Keephills 2	1984	31-Dec-2020	31-Dec-2024
Keephills 3	2011	-------	-------
Sundance 1	1970	31-Dec-2017	31-Dec-2017
Sundance 2	1973	31-Dec-2017	31-Dec-2017
Sundance 3	1976	31-Dec-2020	31-Dec-2020
Sundance 4	1977	31-Dec-2020	31-Dec-2020
Sundance 5	1978	31-Dec-2020	31-Dec-2020
Sundance 6	1980	31-Dec-2020	31-Dec-2020

Table A-2: Percentage share of surface mining and in situ in bitumen extraction

Years	Surface mining	In situ
2000	56	44
2001	58	42
2002	64	36
2003	64	36
2004	65	35
2005	59	41
2006	61	39
2007	59	41
2008	55	45
2009	55	45
2010	53	47
2011	51	49
2012	48	52
2013	47	53

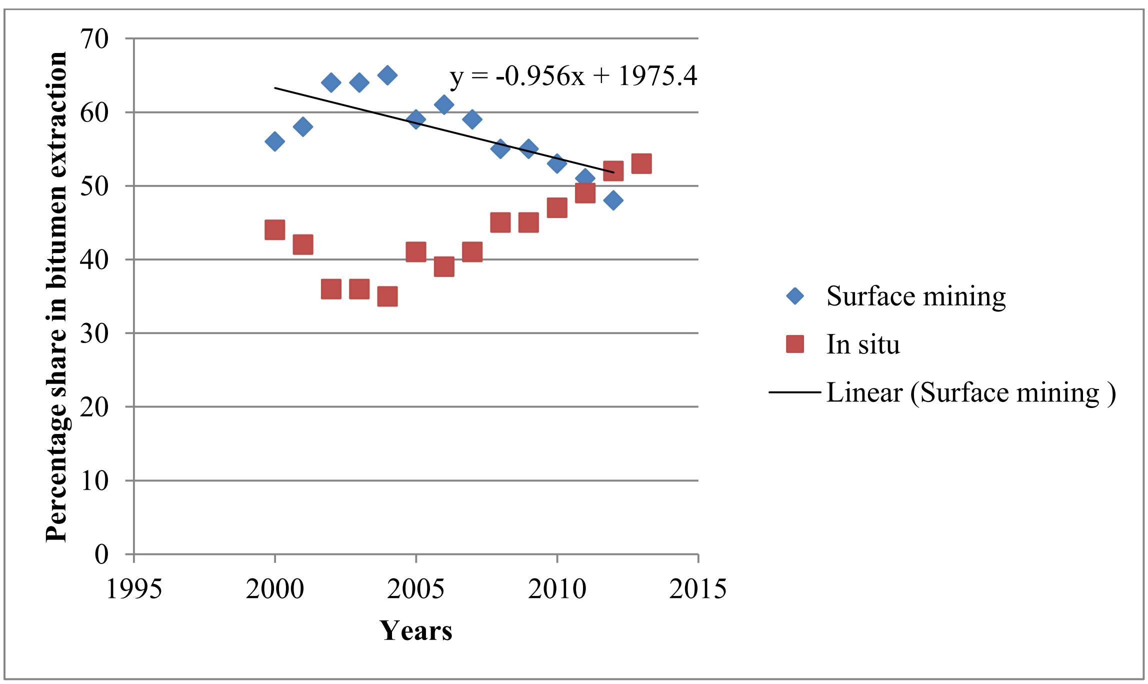


Figure A-4: Percentage share of surface mining and in situ in bitumen extraction

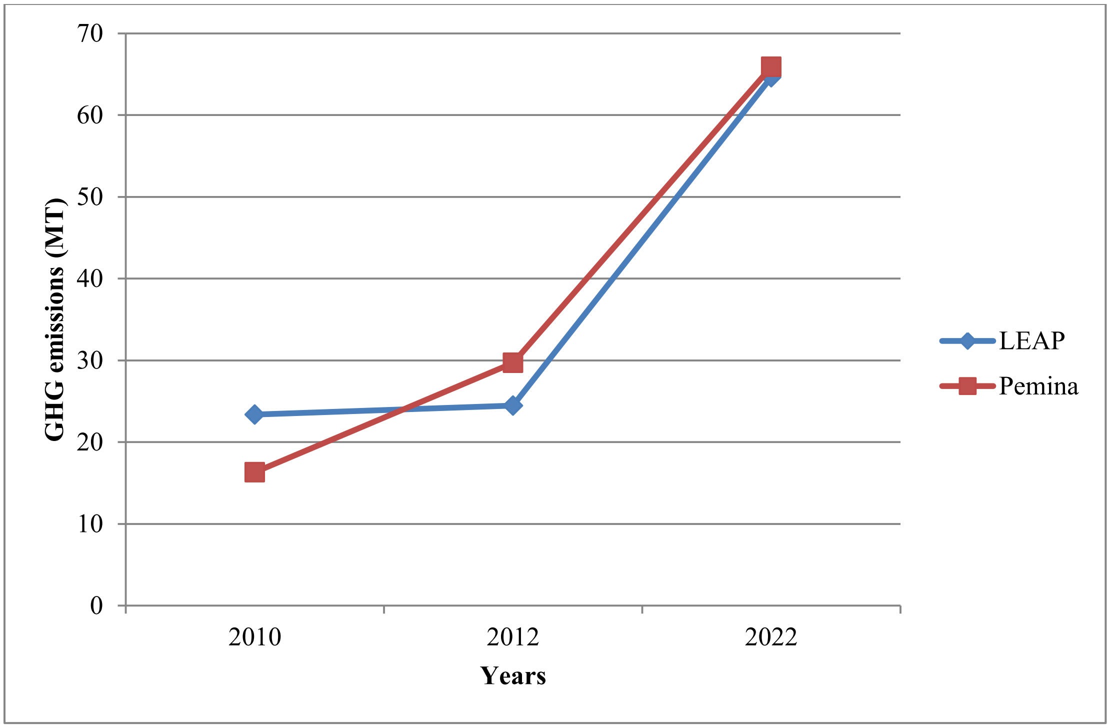


Figure A-5: LEAP-WEAP model validation for in situ GHG emissions

Appendix B

Table B-1: Municipal sector's water demand in million cubic meters for the North Saskatchewan River Basin

Low growth scenario						
Municipal Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Alberta Infrastructure and Transportation	0.13	0.13	0.13	0.13	0.13	0.13
Edmonton Regional Airports Authority	0.23	0.23	0.23	0.23	0.23	0.23
Regional Municipality of Wood Buffalo	0.32	0.32	0.32	0.32	0.32	0.32
Rural Municipality	40.10	40.48	40.98	37.47	32.64	26.61
Urban Municipality	163.73	165.27	167.34	152.58	133.27	108.67
Reference scenario						
Municipal Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Alberta Infrastructure and Transportation	0.13	0.13	0.13	0.13	0.13	0.13
Edmonton Regional Airports Authority	0.23	0.23	0.23	0.23	0.23	0.23
Regional Municipality of Wood Buffalo	0.32	0.32	0.32	0.32	0.32	0.32
Rural Municipality	40.10	40.75	44.12	43.00	40.15	35.00
Urban Municipality	163.73	166.38	180.10	175.55	163.03	142.90
High growth scenario						
Municipal Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Alberta Infrastructure and Transportation	0.13	0.13	0.13	0.13	0.13	0.13
Edmonton Regional Airports Authority	0.23	0.23	0.23	0.23	0.23	0.23
Regional Municipality of Wood Buffalo	0.32	0.32	0.32	0.32	0.32	0.32
Rural Municipality	40.10	41.15	49.19	52.95	54.61	52.57
Urban Municipality	163.73	168.04	200.87	216.23	223.00	214.66

Table B-2: Municipal sector's water demand in million cubic meters for the Bow River Basin

Low growth scenario						
Municipal Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Al Azhar Temple	0.37	0.37	0.37	0.37	0.37	0.37
City of Brooks	4.93	4.93	4.93	4.93	4.93	4.93
Cochrane Lake Properties Ltd.	0.76	0.76	0.76	0.76	0.76	0.76
Corix Utilities	0.61	0.61	0.61	0.61	0.61	0.61
County of Newell No. 4	0.61	0.61	0.61	0.61	0.61	0.61
McGregor Water Users Co-op Ltd.	0.43	0.43	0.43	0.43	0.43	0.43
Rural Municipality	21.00	22.12	20.12	19.13	20.03	17.42
Town of Bassano	0.84	0.84	0.84	0.84	0.84	0.84
Town of Vauxhall	0.74	0.74	0.74	0.74	0.74	0.74
Urban Municipality	215.70	228.35	207.74	197.45	207.00	179.78
Village of Duchess	0.32	0.32	0.32	0.32	0.32	0.32
West Ridge Utilities Inc.	1.31	1.31	1.31	1.31	1.31	1.31
All Others	1.34	1.34	1.34	1.34	1.34	1.34
Reference scenario						
Municipal Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Al Azhar Temple	0.37	0.37	0.37	0.37	0.37	0.37
City of Brooks	4.93	4.93	4.93	4.93	4.93	4.93
Cochrane Lake Properties Ltd.	0.76	0.76	0.76	0.76	0.76	0.76
Corix Utilities	0.61	0.61	0.61	0.61	0.61	0.61
County of Newell No. 4	0.61	0.61	0.61	0.61	0.61	0.61
McGregor Water Users Co-op Ltd.	0.43	0.43	0.43	0.43	0.43	0.43
Rural Municipality	21.00	22.27	21.66	22.01	24.64	22.90
Town of Bassano	0.84	0.84	0.84	0.84	0.84	0.84
Town of Vauxhall	0.74	0.74	0.74	0.74	0.74	0.74
Urban Municipality	215.70	229.88	223.57	227.18	254.35	236.42
Village of Duchess	0.32	0.32	0.32	0.32	0.32	0.32
West Ridge Utilities Inc.	1.31	1.31	1.31	1.31	1.31	1.31
All Others	1.34	1.34	1.34	1.34	1.34	1.34

Table B-2 (continued)

High growth scenario						
Municipal Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Al Azhar Temple	0.37	0.37	0.37	0.37	0.37	0.37
City of Brooks	4.93	4.93	4.93	4.93	4.93	4.93
Cochrane Lake Properties Ltd.	0.76	0.76	0.76	0.76	0.76	0.76
Corix Utilities	0.61	0.61	0.61	0.61	0.61	0.61
County of Newell No. 4	0.61	0.61	0.61	0.61	0.61	0.61
McGregor Water Users Co-op Ltd.	0.43	0.43	0.43	0.43	0.43	0.43
Rural Municipality	21.00	22.49	24.16	27.12	33.52	34.41
Town of Bassano	0.84	0.84	0.84	0.84	0.84	0.84
Town of Vauxhall	0.74	0.74	0.74	0.74	0.74	0.74
Urban Municipality	215.70	232.17	249.36	279.82	345.97	355.13
Village of Duchess	0.32	0.32	0.32	0.32	0.32	0.32
West Ridge Utilities Inc.	1.31	1.31	1.31	1.31	1.31	1.31
All Others	1.34	1.34	1.34	1.34	1.34	1.34

Table B-3: Municipal sector's water demand in million cubic meters for the Peace River Basin

Low growth scenario						
Municipal Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Alberta Municipal Affairs	0.44	0.44	0.44	0.44	0.44	0.44
Aquatera Utilities Inc.	7.28	7.28	7.28	7.28	7.28	7.28
Rural Municipality	24.11	24.34	23.10	21.04	18.38	15.00
Urban Municipality	12.70	12.82	12.15	11.10	9.67	7.89
Alberta Municipal Affairs	0.44	0.44	0.44	0.44	0.44	0.44
Aquatera Utilities Inc.	7.28	7.28	7.28	7.28	7.28	7.28
Rural Municipality	24.11	24.50	24.83	24.21	22.61	19.71
Urban Municipality	12.70	12.90	13.10	12.75	11.91	10.38
Alberta Municipal Affairs	0.44	0.44	0.44	0.44	0.44	0.44
Aquatera Utilities Inc.	7.28	7.28	7.28	7.28	7.28	7.28
Rural Municipality	24.11	24.74	27.70	29.82	30.75	29.61
Urban Municipality	12.70	13.03	14.60	15.71	16.19	15.59

Table B-4: Municipal sector's water demand in million cubic meters for the Athabasca River Basin

Low growth scenario						
Municipal Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Rural Municipality	31.27	31.56	29.92	27.27	23.82	19.41
Urban Municipality	9.25	9.34	8.85	8.07	7.05	5.75
Aboriginal Settlements	2.70	2.71	2.76	2.52	2.19	1.79
Reference scenario						
Municipal Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Rural Municipality	31.27	31.77	32.19	31.36	29.27	25.51
Urban Municipality	9.25	9.40	9.52	9.28	8.67	7.56
Aboriginal Settlements	2.70	2.71	2.97	2.89	2.70	2.36
High growth scenario						
Municipal Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Rural Municipality	31.27	32.09	35.89	38.61	39.79	38.29
Urban Municipality	9.25	9.49	10.63	11.44	11.79	11.36
Aboriginal Settlements	2.70	2.71	3.31	3.56	3.68	3.54

Table B-5: Agriculture sector's water demand in million cubic meters for the North Saskatchewan River Basin

Low growth scenario						
Agriculture Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Feedlot	0.54	0.54	0.54	0.54	0.54	0.54
Private Irrigation	3.48	3.48	3.48	3.48	3.48	3.48
Registrations	10.98	10.98	10.98	10.98	10.98	10.98
Stock-watering	12.80	12.86	13.52	14.21	14.93	15.70
Reference scenario						
Agriculture Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Feedlot	0.54	0.54	0.54	0.54	0.54	0.54
Private Irrigation	3.48	3.48	3.48	3.48	3.48	3.48
Registrations	10.98	10.98	10.98	10.98	10.98	10.98
Stock-watering	13.16	13.31	15.00	16.90	19.04	21.45
High growth scenario						
Agriculture Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Feedlot	0.54	0.54	0.54	0.54	0.54	0.54
Private Irrigation	3.48	3.48	3.48	3.48	3.48	3.48
Registrations	10.98	10.98	10.98	10.98	10.98	10.98
Stock-watering	13.68	13.98	17.38	21.61	26.86	33.40

Table B-6: Agriculture sector's water demand in million cubic meters for the Bow River Basin

Low growth scenario						
Agriculture Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
District Irrigation	1133.61	199.12	989.76	995.14	1000.11	1005.25
Feedlot	2.69	2.69	2.69	2.69	2.69	2.69
Private Irrigation	276.59	276.59	276.59	276.59	276.59	276.59
Registrations	2.85	2.85	2.85	2.85	2.85	2.85
Stock-watering	7.31	7.40	8.34	9.39	10.58	11.93
Reference scenario						
Agriculture Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
District Irrigation	1133.61	199.12	998.07	1014.05	1029.83	1046.01
Feedlot	2.69	2.69	2.69	2.69	2.69	2.69
Private Irrigation	276.59	276.59	276.59	276.59	276.59	276.59
Registrations	2.85	2.85	2.85	2.85	2.85	2.85
Stock-watering	7.61	7.77	9.66	12.01	14.93	18.56
High growth scenario						
Agriculture Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
District Irrigation	1133.61	199.12	1010.70	1043.15	1076.16	1110.38
Feedlot	2.69	2.69	2.69	2.69	2.69	2.69
Private Irrigation	276.59	276.59	276.59	276.59	276.59	276.59
Registrations	2.85	2.85	2.85	2.85	2.85	2.85
Stock-watering	7.91	8.16	11.18	15.32	21.00	28.77

Table B-7: District Irrigation's water demand in million cubic meters for the Bow River Basin

Low growth scenario						
District Irrigation	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Bow River Irrigation District (BRID)	427.61	78.48	371.48	373.51	375.38	377.32
Eastern Irrigation District (EID)	576.19	101.13	524.07	526.93	529.58	532.31
Western Irrigation District (WID)	129.81	19.51	94.19	94.69	95.14	95.61
Reference scenario						
District Irrigation	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Bow River Irrigation District (BRID)	427.61	78.48	374.61	380.61	386.55	392.63
Eastern Irrigation District (EID)	576.19	101.13	528.48	536.96	545.33	553.91
Western Irrigation District (WID)	129.81	19.51	94.98	96.47	97.95	99.46
High growth scenario						
District Irrigation	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Bow River Irrigation District (BRID)	427.61	78.48	379.35	391.54	403.95	416.81
Eastern Irrigation District (EID)	576.19	101.13	535.17	552.38	569.88	588.03
Western Irrigation District (WID)	129.81	19.51	96.17	99.22	102.32	105.54

Table B-8: Agriculture sector's water demand in million cubic meters for the Peace River Basin

Low growth scenario						
Agriculture Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Feedlot	0.34	0.34	0.34	0.34	0.34	0.34
Private Irrigation	3.36	3.36	3.36	3.36	3.36	3.36
Registrations	3.67	3.67	3.67	3.67	3.67	3.67
Stock-watering	2.90	2.91	3.06	3.22	3.38	3.56
Reference scenario						
Agriculture Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Feedlot	0.34	0.34	0.34	0.34	0.34	0.34
Private Irrigation	3.42	3.44	3.62	3.80	4.00	4.20
Registrations	3.67	3.67	3.67	3.67	3.67	3.67
Stock-watering	2.98	3.02	3.40	3.83	4.31	4.86
Feedlot	0.34	0.34	0.34	0.34	0.34	0.34
Private Irrigation	3.47	3.51	3.88	4.28	4.73	5.23
Registrations	3.67	3.67	3.67	3.67	3.67	3.67
Stock-watering	3.10	3.17	3.94	4.90	6.09	7.57

Table B-9: Agriculture sector's water demand in million cubic meters for the Athabasca River Basin

Low growth scenario						
Agriculture Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Feedlot	0.15	0.15	0.15	0.15	0.15	0.15
Private Irrigation	3.48	3.48	3.48	3.48	3.48	3.48
Registrations	5.92	5.92	5.92	5.92	5.92	5.92
Stock-watering	7.11	7.15	7.51	7.90	8.30	8.73
Reference scenario						
Agriculture Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Feedlot	0.15	0.15	0.15	0.15	0.15	0.15
Private Irrigation	3.48	3.48	3.48	3.48	3.48	3.48
Registrations	5.92	5.92	5.92	5.92	5.92	5.92
Stock-watering	7.31	7.40	8.34	9.39	10.58	11.93
High growth scenario						
Agriculture Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Feedlot	0.15	0.15	0.15	0.15	0.15	0.15
Private Irrigation	3.48	3.48	3.48	3.48	3.48	3.48
Registrations	5.92	5.92	5.92	5.92	5.92	5.92
Stock-watering	7.61	7.77	9.66	12.01	14.93	18.56

Table B-10: The water demand in million cubic meters for Industrial sector for the North Saskatchewan River Basin

Reference scenario						
	2009	**2010**	**2020**	**2030**	**2040**	**2050**
Chemical Plants	25.84	25.84	25.88	25.88	25.88	25.88
Coal Fired Generation	80.15	80.15	80.15	16.93	16.93	8.56
Coal Mining	0.01	0.01	0.01	0.01	0.01	0.01
Fertilizer Plants	5.64	5.64	5.64	5.64	5.64	5.64
Hydro	0.00	0.00	0.00	0.00	0.00	0.00
Manufacturing Plants	46.34	46.34	90.41	90.41	90.41	90.41
Mining other than Coal	5.28	5.28	5.28	5.28	5.28	5.28
Natural Gas Power Plants	3.74	3.74	9.55	12.68	18.06	25.72
Other Industrial	0.06	0.06	0.06	0.06	0.06	0.06
Scenario 2: GDP projections						
	2009	**2010**	**2020**	**2030**	**2040**	**2050**
Chemical Plants	25.84	25.84	31.37	37.13	44.37	53.03
Coal Fired Generation	80.15	80.15	80.15	16.93	16.93	8.56
Coal Mining	0.01	0.01	0.01	0.02	0.02	0.03
Fertilizer Plants	5.64	5.64	6.83	8.09	9.67	11.56
Hydro	0.00	0.00	0.00	0.00	0.00	0.00
Manufacturing Plants	46.34	46.34	102.95	121.51	145.24	173.61
Mining other than Coal	5.28	5.28	6.40	7.58	9.06	10.82
Natural Gas Power Plants	3.74	3.74	9.55	12.68	18.06	25.72
Other Industrial	0.06	0.06	0.07	0.09	0.10	0.12

Table B-11: The water demand in million cubic meters for Petroleum sector for the North Saskatchewan River Basin under reference scenario

Gas or Petrochemical Plants	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Gas Plants	5.79	5.79	8.42	8.42	8.42	8.42
Petrochemical Plants	315.73	315.73	315.73	315.73	315.73	315.73
Proposed Upgraders	0.00	0.00	54.25	58.27	58.27	58.27
Proposed Gas Plants	0.00	0.00	0.02	0.02	0.02	0.02
Refineries	46.71	46.71	46.71	46.71	46.71	46.71
Upgraders	4.02	3.60	7.83	10.56	14.23	19.18
Injection	39.03	39.03	36.80	35.46	35.46	35.46
Other Petroleum Activities	3.03	3.03	3.03	3.03	3.03	3.03

Table B-12: The water demand in million cubic meters for Petroleum sector for the Peace River Basin under reference scenario

Petroleum Sector	**2009**	**2010**	**2020**	**2030**	**2040**	**2050**
Gas or Petrochemical Plants	1.48	1.48	1.48	1.48	1.48	1.48
Other Petroleum	0.06	0.06	0.056	0.06	0.06	0.06
Peace CSS	0.27	0.30	0.40	0.51	0.64	0.80
Peace Enhanced Recovery Schemes	0.003	0.008	0.008	0.010	0.013	0.017
Peace Primary	1.47	1.26	1.92	2.46	3.15	4.03

Table B-13: The water demand in million cubic meters for Petroleum sector for the Athabasca River Basin under reference scenario

Petroleum Sector	2009	2010	2020	2030	2040	2050
Enhanced Recovery Schemes	2.00	1.91	2.67	3.42	4.38	5.61
Experimental	0.00	0.00	0.00	0.00	0.01	0.04
Primary	2.47	2.32	3.45	4.42	5.66	7.24
SAGD	4.52	5.98	22.79	60.57	169.27	553.49
Upgraders	28.75	30.74	31.45	31.45	31.45	31.45
Cold Lake CSS	8.72	9.95	12.96	16.27	20.42	25.64
Cold Lake Primary	3.85	3.86	5.71	7.30	9.35	11.97
Cold Lake SAGD	0.13	0.14	0.72	1.92	5.38	17.60
Gas or Petrochemical Plants	4.30	4.30	4.30	4.30	4.30	4.30
Surface Mining	93.36	90.45	126.29	104.42	89.03	89.77

Table B-14: The water demand in million cubic meters for upgraders for the Athabasca River Basin under reference scenario

Upgraders	2009	2010	2020	2030	2040	2050
CNRL Horizon Upgrader	2.39	4.21	3.86	3.86	3.86	3.86
Opti or Nexen Upgrader	0.23	1.01	1.36	1.36	1.36	1.36
Suncor Upgrader	13.06	11.85	12.92	12.92	12.92	12.92
Syncrude Upgrader	13.06	13.67	13.32	13.32	13.32	13.32