Integrated Water Resources Management and Modeling: A Case Study of Bow River Basin, Canada

Supplementary Material

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Description of model structures and data sources

The Bow River Integrated Model (BRIM) expands on the IDT Model (Wang and Davies, 2015), with new model sectors and adaptation to the Bow River Basin. The industrial sector is described in greater detail below. For the other water use sectors,

- Water supply was modeled as an exogenous variable and future scenarios were based on historical Bow River Basin stream flow data from S. Tanzeeba (hydrologist at Government of Alberta, personal communication in September 2015), and Environment Canada (2015, 2016)
- Population data were from the City of Calgary (2013), and AMEC (2007, 2009)
- Agricultural crop types and municipal water uses were modified to correspond to Bow River Basin conditions and initialized based on AAF (2016), DeOreo et al. (2016), and City of Calgary (2010)
- The environmental sector includes only water quantity: a water conservation objective (45% of the natural flow) and downstream water requirement (50% of the natural flow) were used to represent environmental demands in the Bow River Basin based on Alberta Environment (2006)
- The recreational value of water was from Martz et al. (2007)

Industrial sector structures

The industrial sector includes four water use categories – power generation, mining, oil and gas extraction, and manufacturing sectors – based on twenty-one categories of the NAICS (Statistics Canada 2012). See Table S1. The manufacturing sub-categories are further classified into three groups based on their value-added ratios (\$/m^3 water intake, Statistics Canada, 2014a; Statistics Canada, 2014b; Martz et al., 2007).

Table S1
Industrial sector categories (Statistics Canada, 2012).

Industry categories	Sub-categories of Bow River Basin		NAICS Digits
Power generation	Thermal-power generation Hydro-power generation		221
Mining	Limestone mining and quarrying		212
Oil and gas extraction	Oil extraction Gas extraction		211
Manufacturing	High value-added group	Printing and publishing	323
		Furniture and fixtures	337
		Electrical and electronic products	335
		Transportation equipment	336
		Machinery	333
		Plastics	326
		Fabricated metal product	332
		Wood product	321
		Computers	334
		Textiles, clothing and leather	313
		Miscellaneous	339
	Medium value-added group	Food manufacturing	311
		Beverage manufacturing	312
		Non-metallic minerals	327
	Low value-added group	Chemical manufacturing	325
		Primary metal manufacturing	331
		Paper manufacturing	322
		Petroleum and coal	324

Industrial sector data sources

Basin-scale thermal electricity demands were estimated based on Enmax (2012, 2014), TransCanada (2004-2014), and AESO (2014), while water use efficiencies and system shares of each cooling system shown in

Table S2 were based on Enmax (2008-2012), Innovation Steam Technologies (2015), and Davies et al. (2013).

Table S2
Thermal plant water use data.

Cooling system types	Once-through	Cooling pond	Cooling tower
Withdrawal efficiency, m^3/MWh	107	2	0.9
Consumption efficiency, m^3/MWh	0.86	1.8	0.73
Shares	11%	8%	81%

In terms of hydropower data, the simplified annual hydropower generation to annual streamflow relationship was derived from data provided by TransAlta (2014) and S. Tanzeeba (personal communication in September 2015). Summer and winter power price differences ($/MWh) and hydropower water consumption values were obtained from AESO (2016) and Davies et al. (2013), respectively.

Mineral production data for the Bow River Basin came from Lafarge Inc. (2013) and Graymont (2014). Water use efficiency and limestone weight percentage data were estimated based on Lafarge Inc. (2011, 2014), National Lime Association (2015), Semi-Bulk System (2011), The Science of Concrete (2017), and Business Valuation Resources (2013) – see Table S3.

Table S3
Mining water use data

Limestone-derived products	Cement	Hydrated lime	Pulverised limestone
Production capacity, tons	1300000	85000	470000
Limestone weight percentage	60%	80%	90%

Oil and gas extraction, initial oil reserves, resource discoveries, and average well production including both vertical and horizontal wells in Alberta were all estimated based on AER (2014). A price-to-drilling lookup relationship was developed from data for oil prices and annual numbers of producing wells (CAPP, 2014). The average well retirement rate was determined from the average conventional and fracking well-retirement rates and their relative fractions, according to Encana (2011). The oil price and capacity utilization look-up was developed based on a crude oil supply curve from Energy Matters (2014). Historical price and cost data were from CAPP (2014), AER (2014), and CERI (2013), while water use efficiencies for both conventional (EOR) and hydraulic fracking methods were estimated from CAPP and OSDG (2011), CSUG (2014), USGS (2016), and Gallegos et al. (2015).

The GDP values for all manufacturing categories were provided by C. Osuji (senior corporate economist at City of Calgary, personal communication in 2015) and City of Calgary (2012), and the value-added ratios were estimated from Statistics Canada (2014a, 2014b) and Martz et al. (2007).

Scenario setup data sources

Economic conditions were established according to AAF (2016), AESO (2016), Calgary Economic Development (2015), and CAPP (2014). Historical water management actions in the Bow River Basin were obtained from AAF (2016), AMEC (2007), City of Calgary (2010), CERI (2013), and AER (2014).

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