A SIMULATION GAMING MODEL FOR INTEGRATED RIVER BASIN MANAGEMENT

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Abstract: This paper introduces the Bow River Basin Simulation Gaming Model (BRSGM) as a decision-support tool that can be used to evaluate the effectiveness of various water management strategies. The model, the subject of this paper, contains the main water use sectors in the Bow River Basin – agricultural, municipal, industrial, recreational, and environmental sectors – and water supply, which are connected through water allocations and other water, land, financial management, and technology policies. Model outputs include indicators of basin-scale sustainability that integrate social, economic, and environment components at an annual time step, as well as important output variables for each water use sector, such as crop yields, agricultural profitability, municipal water use, power generation, conventional oil and gas production, mining production, manufacturing value added, water recreational values in a representative reservoir park, and environmental water use. Thus, the model explicitly represents the connection between management strategies and the complex water resources system and provides a comprehensive view of basin-scale sustainability in a social, economic, and environmental context. Finally, the model will be used as a component of a Bow River Basin water management simulation game – currently under development – to identify potential risks of alternative policy selections and improve participants' understanding of the management trade-offs and feedbacks between different water sectors.

1 INTRODUCTION

In many regions of the world, water resources management faces a significant challenge as a result of population and economic growth, uneven resource distribution, and climate change uncertainties (Rijsberman 2006, Wagener et al. 2010). With growing demands and decreasing supply, water shortage may result in a lack of sufficient water to meet regional demands.

A variety of water management models have been developed as decision support tools to balance water supply and demand at the river-basin scale, and can be classified into three types: water supply management, water demand management, and water system management (Singh and Woolhiser 2002, Geerts et al. 2010, Mirchi et al. 2012). The first two types of models have historically focused on a single side of water management, supply or demand, whether related to agriculture, municipalities, or industries. However, the increasing scale of human impacts on water resources is accelerating the rate of change in water systems and requires a management framework that integrates and captures the feedbacks between various sectors: a system approach (GWP & TAC 2011, Simonovic and Fahmy 1999). Thus, an analytical and quantitative framework is needed that can help to achieve collaborative decision-making and consensus-building through improving our understanding of how the different water sectors coexist and interact. A useful framework for improved decision-making in water resources systems is a simulation gaming approach.

Simulation games combine simulation, which simplifies the real world for a better understanding of complex systems, with games, which include players, rules, competition and cooperation (Rusca et al. 2012). By offering immediate, contextualized, and sometimes surprising feedback results in an experimental environment, simulation games can improve players' understanding of the system and trigger their curiosity and imagination (Barreteau et al. 2007, Crookall 2009); they can therefore be a good tool for entertainment, training, motivation, assessment, education and learning, research, and decision support (Mayer and Veeneman 2002). The Bow River Basin Simulation Gaming Model (BRSGM), a component of a proposed Bow River Simulation Game (BRSG), is introduced in this paper as a framework for a simulation-gaming approach to water resources management. Section 2 introduces the Bow River Basin and general features of the proposed BRSG. Section 3 explains the BRSGM structure (3.1) and provides sample simulation results (3.2). The paper ends with conclusions in Section 4.

2 The Context: Bow River Basin Water Management Simulation Game

The Bow River Basin is located in Southern Alberta, and has a drainage area of approximately 25,000 km^2. The main water source (80%) is snowmelt from the Rocky Mountains, with the remainder from rain, groundwater, and glacial melt (BRPRC 2010). The Bow River is highly regulated, with about 68% of the median natural flow allocated to agricultural, municipal, and industrial uses (Alberta Environment 2003). The basin was closed to new water licenses in 2007 (AMEC 2009), which means that new water users can only receive water through conservation efforts and through reallocation from existing users, and climate change and water demand growth increase the likelihood of water scarcity (Martz et al. 2007).

The BRSG is a framework – under development, based on the Invitational Drought Tournament (IDT; Hill et al. 2014) – used to improve both participants' understanding of the Bow River Basin as a system and basin-scale water sustainability. Like the IDT, the BRSG will involve multidisciplinary teams of two to five players. In each of its several rounds, with two years corresponding to a round of the game, teams will choose among a variety of policies in four main categories – water management, financial management, land management, and technological improvements – to improve basin water sustainability in terms of social, economic, and environmental considerations and to reduce the impacts of potential water shortage, based on the current water balance. Results from BRSGM will be used to communicate to the teams the effectiveness of their policy choices and to help them choose options for the next round of the game.

3 MODEL DESCRIPTION

The BRSGM is a simulation gaming model that represents effects of water management actions at an annual scale in the Bow River Basin. Covering the time period from 1996 to 2040, the model simulates possible effects of policy combinations based on current water use conditions and future scenarios involving changing climatic and economic conditions, and population growth. Model outputs are indicators related to basin-scale sustainability as well as important output variables for each water use sector. Model characteristics, structures, variables, and their interactions; water, land, financial, and technical policies; available data; and sample model outputs are discussed in this section.

The BRSGM was developed using the system dynamics methodology (Forrester 1961, Sterman 2000), which has been used widely to model complex systems. System dynamics produces “causal-descriptive” models that can be used to project future conditions based on a representation of system structure, and to assess the effectiveness of alternative policies (Barlas 1996). It is often used to promote public education and participation (Williams et al. 2009, Tidwell et al. 2004), and to assess policy options comprehensively and inexpensively through iterative “what if” analyses (Winz et al. 2009).

3.1 Model Structures

The BRSGM contains the main water use sectors in the Bow River Basin – agricultural, municipal, industrial, recreational, and environmental – and water supply, which are connected through water allocations and other water, land, financial management, and technology policies. Figure 1 shows the main model components and their connections. The following sections describe each sector separately.

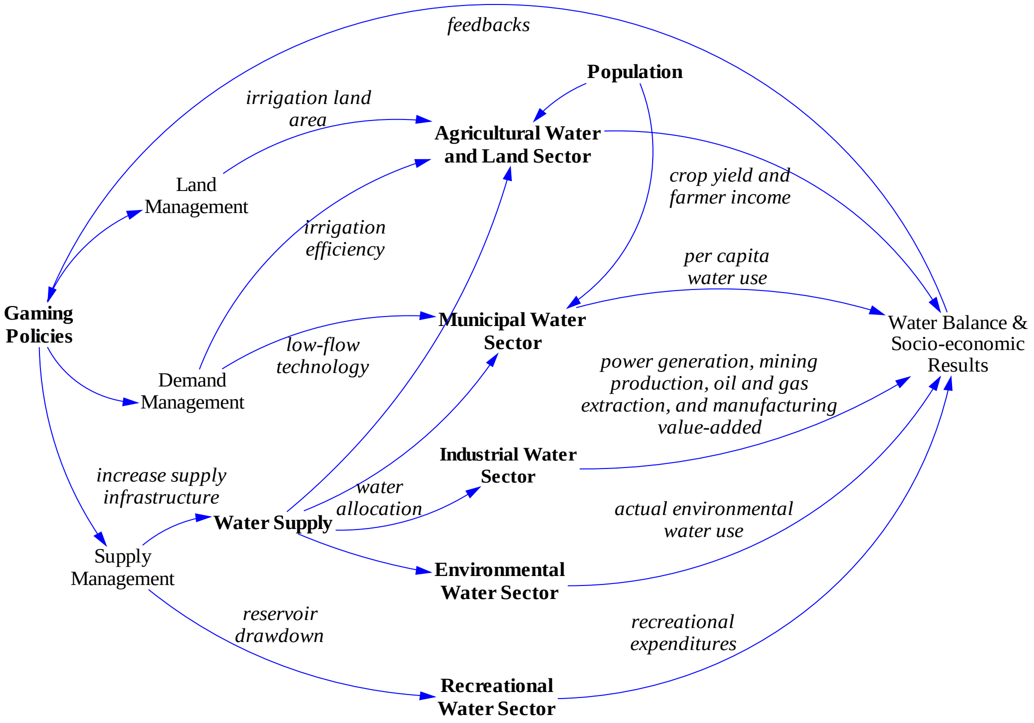

Figure1: Main model structure

3.1.1 Population and Basin Water Supply

The population sector calculates municipal and rural, as well as livestock, populations each year. Births and immigration increase these populations, and deaths and emigration decrease them. A greater population increases water demands, while municipal water conservation and livestock reduction policies reduce demands. Data for this sector come from City of Calgary (2013) and AMEC (2007).

Water supplies in BRSGM are the base river flow, reservoir storage, and water diversion from another basin (a policy option in the game). Reservoir storage, which is used for irrigation, municipal, and hydro-power generation in the basin, is affected by the “reservoir release” policy; the reservoir storage capacity can be affected by the “increase the storage volume” policy. Basin water supply and precipitation are provided by Alberta Environment (2014) and Environment Canada (2014).

3.1.2 Municipal Water Sector

The municipal water sector calculates the annual municipal water use based on interactions between increases in demands with population growth, the available water supply and the effects of conservation policies. Available water conservation policies include adoption of low-flow appliances, grey-water treatment and reuse, investment in water-related research and development, and water rationing. Municipal demand increases with population growth, while the available supply depends on annual flows and water allocations. If demand exceeds supply, the difference is represented as a “municipal water deficit”, which accelerates the adoption of low-flow technologies to decrease municipal water demands in subsequent years. However, the annual water use could still be less than the demand in dry years.

The basic structure of the municipal water sector comes from Ahmad and Prashar (2010): indoor use, in the four categories of kitchen, toilet, bathing and laundry uses; outdoor use; and non-domestic water use. The indoor water use categories are each simulated separately because water conservation efforts target specific domestic water uses. Water use reductions with low-flow appliance adoptions are represented as changes in the percentage of households equipped with a particular category of low-flow fixture or appliance. For example, the “municipal water deficit” as well as water conservation policies may increase the adoption of low-flow fixtures and appliances such as toilets, showerheads and front-load washers. Equation 1 represents the municipal water demand, MWD, in million cubic meters (MCM) per year as,

$$[1] \quad \mathrm{MWD} = [\mathrm{p_l} * (1 - \mathrm{f_l}) * \mathrm{k} + (1 - \mathrm{p_l}) * \mathrm{k} - \mathrm{R} + \mathrm{W_{non}}] * \mathrm{P} * 365/10^9$$

where p_l is the percentage of households with each type of low-flow fixture or appliance (%), f_l is the corresponding fractional reduction in water use (dimensionless), k is the base domestic water use per capita for the specific water use category (L/capita/day), R is the water reduction from the (optional) grey water treatment policy (L/capita/day), W_{non} is the non-domestic (commercial, industrial, and public) water demand (L/capita/day) supplied by the municipal system and P is the municipal population (people). The Calgary water demand by user category is shown in Figure 2, with residential demand accounting for the majority of the total; these values are used to represent Bow River Basin communities in general.

The maximum municipal water allocation – the licensed volume – is set in the model; available municipal water supply can be reduced through the “water rationing” policy. To represent impacts of water shortage on municipal water use, where water demand may exceed the licensed or rationed volume, the model allocates the available supply to each the six water use categories based on their relative importance, or “priority”. High priority uses, like kitchen water use, receive water in preference to lower-priority categories, such as outdoor water use; low-priority uses typically receive a smaller fraction of their demand, but not zero water. Typical household water use is shown in Figure 3. Historical per capita water demands are provided by Headwater Communications (2007) and are used to initialize this sector.

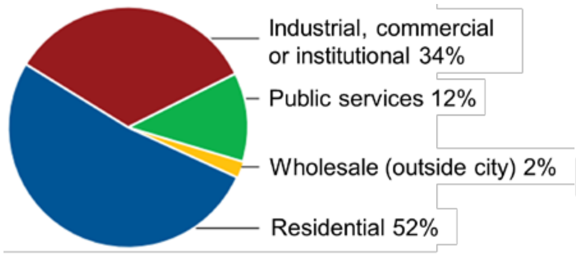

Figure 2: Calgary water demand by sector

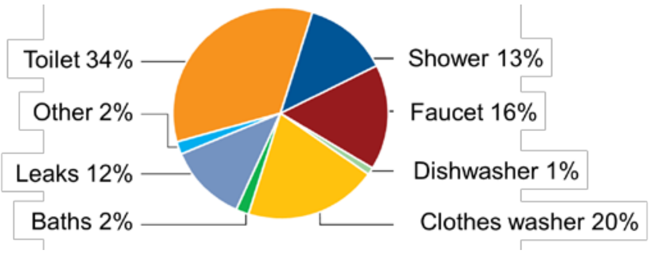

Figure 3: Typical residential water use

3.1.3 Agriculture Water and Land Sector

This sector includes both rain-fed and irrigated agriculture, with irrigation in the Bow River (BRID), Western (WID), and Eastern (EID) irrigation districts. These districts have licensed allocations of 1.69 x 10^6 dam^3 per year (AMEC 2007). The model simulates irrigation requirement, soil-water balance, crop mix, and water allocations and applications in the irrigation districts, as well as crop yields for both irrigated and rain-fed land. Model outputs are crop areas, water requirements, crop yields on both irrigated and rain-fed land, and agricultural net benefit. The main crops in the basin include generic cereals, forages, oilseeds, and specialty crops, based on IDT crop categories (Hill et al. 2014). Five land use types in the model include irrigated, rain-fed, fallow, non-producing land under “green cover”, and range land.

Policies that can affect the agricultural sector are land management policies that affect crop areas or alter their management (for example, promote green cover, promote winter cropping, promote stocking rate reductions, promote diversification of pasture species composition, and promote beneficial management practices); water management policies, including water rationing, reservoir releases, enhancement of irrigation efficiency and rehabilitation of infrastructure; economic policies, such as relief payouts to farmers and agricultural insurance; and general technological policies like investment in agricultural or water research and development, and soil water conservation. Most policies are intended to mitigate the impacts of water shortage; additional policies will be included in the next version of the model.

Soil moisture storage is the water source for crop growth; its value is used to determine irrigation requirements and is the basis of crop yields. Irrigation (for irrigated agriculture) and precipitation (for both irrigated and rain-fed crops) increase soil moisture, while evapotranspiration (ET) decreases it. In terms of crop yield, BRSGM uses linear ET-yield relationships developed for the Canadian Prairies by Bennett and Harms (2011). In addition to soil moisture, yields can also be affected by management policies, such as investment in "agriculture-related research and development". The model can be applied to other regions by adjusting the ET-yield equation parameters to match local figures.

For irrigated agriculture, crop water demands (ET) are satisfied by initial soil moisture, precipitation, and irrigation applications. Each year, the model automatically allocates the available water, which can be affected by management policies such as "reservoir drawdown" and "water rationing", to each type of irrigated crop. Irrigators are assumed to irrigate to the initial soil moisture conditions for the next year after satisfying the maximum evapotranspiration (ET_m, mm) water demands in the current year, with the desired net irrigation application ($\mathrm{DNIA_t}$, mm) for year *t* calculated as shown in Equation 2,

$$[2] \quad \mathrm{DNIA_t} = \begin{cases} \mathrm{ET_{m_0}} - \mathrm{P_0} - \mathrm{ISM_0} & \mathrm{t} = 0 \\ \mathrm{ET_{m_t}} - \mathrm{P_t} - \mathrm{SMB_t} & \mathrm{t} > 0 \end{cases}$$

where P_t is precipitation (mm) in year t, ISM_0 is the initial soil moisture (mm) at the start of the game and SMB_t is soil moisture at the beginning of year t (mm). Incorporation of irrigation losses related to evaporation from canals and crops, canal seepage, root-zone deep-percolation and application efficiency produces the desired gross irrigation diversion.

When water is plentiful, crops typically receive the desired irrigation application and achieve near-optimal yields; however, under drought conditions, the gross irrigation application may be less than the desired value. In this case, the BRSGM automatically allocates the available irrigation water to the crops with higher priorities based on their "crop water value" (CWV, $\$/m^3$), as calculated in Equation 3,

$$[3] \quad \mathrm{CWV} = \mathrm{CP} * \mathrm{CWP}$$

where CP is the crop price ($/kg), and CWP is crop water productivity (kg/m^3). Data used to initialize this sector is from Bennett and Harms (2011), Allen et al. (1998), Siebert and Doell (2010), Agricultural Statistics Yearbooks (ARD 2014), and Bob Winter (personal communication, June, 2014).

3.1.4 Industrial Water Sector

Industrial water uses in the Bow River Basin include power generation (hydro and thermal), mining, conventional oil and gas extraction, and manufacturing (Martz et al. 2007). BRSGM estimates industrial water demand, allocations, and actual use for these components. Outputs are power generation, mining production and profit, oil and gas production, and manufacturing value-added. The model policies that can affect this sector are "water rationing", "reservoir releases", "hydraulic fracking oil production changes", and "alternative water source utilization".

The model representations of power generation and mining are adopted from the Invitational Drought Tournament (IDT) Model (Wang and Davies, under review), and the BRSGM adds two new subsectors: oil and gas extraction and manufacturing. The first subsector simulates annual conventional and hydraulic fracking oil and gas production, water allocation, and water demand and use. Production is subdivided into extraction by conventional methods and fracking – which can extract tight oil and gas but requires more water – due to their different water-use efficiencies. Two policies, “hydraulic fracking oil production changes” and “alternative water source utilization”, affect this sector. Oil and gas production are calculated based on the structure developed by Naill (1992), and the incorporation of water use efficiencies produces the total water demand. The calculation for conventional oil water demand (COWD) is shown in Equation 4,

$$[4]\quad \mathrm{COWD} = \mathrm{CME} * \mathrm{WUE}_{\mathrm{cm}} + \mathrm{HFE} * \mathrm{WUE}_{\mathrm{hf}}$$

where CME and HFE are oil extraction by conventional means and by fracking, and $\mathrm{WUE}_{\mathrm{cm}}$ and $\mathrm{WUE}_{\mathrm{hf}}$ are water-use efficiencies of conventional and fracking methods. The “hydraulic fracking oil production changes” policy can change the fracking production and thus water demands. Use of alternative water sources (saline water and municipal/industrial effluents) also affects the water demand by reducing both conventional and fracking requirements. Actual water use is the minimum of the water demand and the available supply, which is determined by water allocations. Under normal condition, demands can be satisfied, while under water shortage conditions, available water (as a component of total industrial water supply) is allocated to oil and gas extractions by their extraction water values ($\$/m^3$ water withdrawal). The relevant data come from the Alberta Energy Regulator (2014) and CAPP & OSDG (2011).

The second subsector calculates manufacturing revenue, and water demand, allocation, and use. BRSGM divides manufacturing into high (printing and publishing, furniture and fixtures, electrical and electronic products, transportation equipment, machinery, plastics, fabricated metal product, and wood product manufacturing), medium (food and beverage manufacturing), and low (chemical, primary metal, and paper manufacturing) value-added groups based on their different water value-added ratios ($\$/m^3$ water intake), which is used to represent the revenue lost by a group if water access is reduced (Martz et al. 2007). The water rationing policy affects this sector.

Annual manufacturing revenue is driven Calgary’s manufacturing GDP ($), as forecast by City of Calgary (2012) from 2015 to 2040. Incorporation of the water value-added ratio – $\$422/m^3$ for furniture and fixture industries, and $\$9.8/m^3$ for chemical manufacturing, for example (Martz et al. 2007) – then permits calculation of the annual water demand (m^3). Water use is the minimum of the water demand and supply, as affected by allocations. Further, if available water (as a component of total industrial water supply) is less than the demand, it is allocated to high, medium, and low value-added sectors based on their water value-added ratios, with high value-added industries receiving most of their demands, and low value-added industries receiving less. Note that, reduction of manufacturing revenue due to water shortages triggers a gradual conversion from lower to higher water value-added groups. Data for this subsector come from Statistics Canada (2014a and 2014b), Calgary Economic Development (2009), City of Calgary (2012), Chukwudi Osuji (personal communication, January, 2015), and Martz et al. (2007).

3.1.5 Recreational and Environmental Water Sectors

The recreational sector simulates the recreational values of water storage in a representative reservoir, which can be affected by the “release reservoir” and ““increase the storage volume” policies. It illustrates trade-offs between high water levels for recreational activities and reservoir releases for other purposes. The estimated water use coefficient for recreational reservoir use for Alberta, which is 0.0056 dam^3 per $1000 output (Martz et al. 2007), is adopted to calculate the value of recreation.

The environmental sector deals only with water quantity, and not more-complex water quality parameters. The model simulates water availability for the environment at an annual scale by calculating the water volume at the mouth of the basin, compared with the naturalized flows, to represent a simple measure of “water stress”: withdrawal to availability (Rijsberman 2006). The policy that can affect this sector is “environment first”, which allocates additional water to environmental demand over socio-economic demands. Data used to calculate environmental water demands are from Alberta Environment (2006).

3.2 Model Simulation Examples

Three sets of sample results presented below focus on the effects of water management policies and alternative climate scenarios on domestic water use, agricultural production, and oil extraction and water demand. Since the model will be used in the BRSG, which focuses on the relatively near-term, the following examples are simulation results from 2020 to 2030.

3.2.1 Example 1: Municipal Water Use

As a simulation gaming model, BRSGM includes a graphical user interface that helps players visualize and compare the effects of different policy combinations – useful information as they develop their plans for each game year. Figure 4 compares domestic water use, including both indoor and outdoor uses, based on the policy selections of two "teams" – team A and team B – over the course of a hypothetical 2020-2024 drought; the results shown here focus specifically on the drought period. For team A, the water rationing policy causes allocation of available water primarily to indoor uses, so that outdoor use decreases and browning lawns result. Team B also rationed water from 2022 to 2024, but its outdoor water use did not decrease while indoor water use did, since the team reduced its indoor water use by investing in "grey water treatment and reuse" in 2021. The water team B conserved was reallocated to outdoor uses. BRSGM therefore simulates less water use by team B – obeying the rationing policy – but also maintenance of a green lawn even under drought conditions.

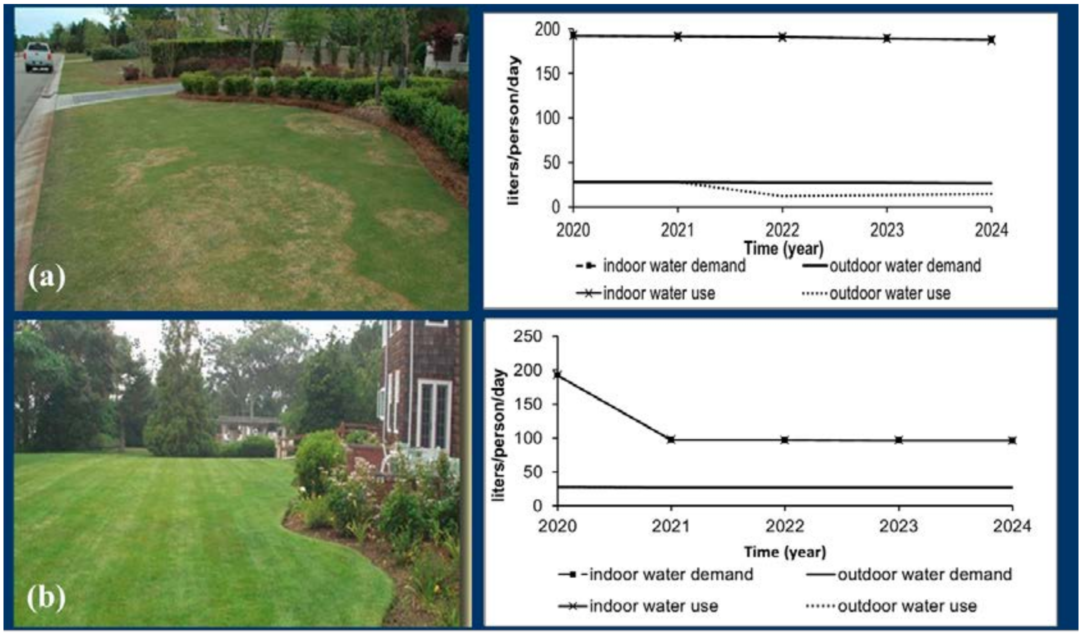

Figure 4: Domestic water use comparison for (a) team A and (b) team B

3.2.2 Example 2: Agricultural Yield

In this section, the results of a set of simulations based on historical climatic conditions in the Bow River Basin are used to represent agricultural sector behaviour. Precipitation values from 2001, 2005, and 2007 (Government of Canada 2014) form the basis of dry, wet, and normal conditions, and are randomly increased or decreased up to 10% for each year from 2020 to 2030 respectively. Based on the assumed precipitation values, the model simulates corresponding irrigation demands, actual water use, and yields. Figure 5 shows the simulated canola (oilseed) yields on both irrigated and rain-fed land for the three climate scenarios. Yields clearly differ for the three climate scenarios on the two land types, with higher yields on the irrigated land under all three climate conditions. Since yields are currently only affected by water availability in the BRSGM – so that factors related to solar radiation, growing season temperatures, soil characteristics, agricultural management, weeds and diseases, and yield increases with research and development (Alston et al. 2009) are neglected – irrigated land yields for both wet and normal scenarios achieve the maximum yield, while irrigated yields under dry conditions are lower because of high crop water demand and lower water availability. Similarly, rain-fed yields are mainly affected by precipitation (Figure 5).

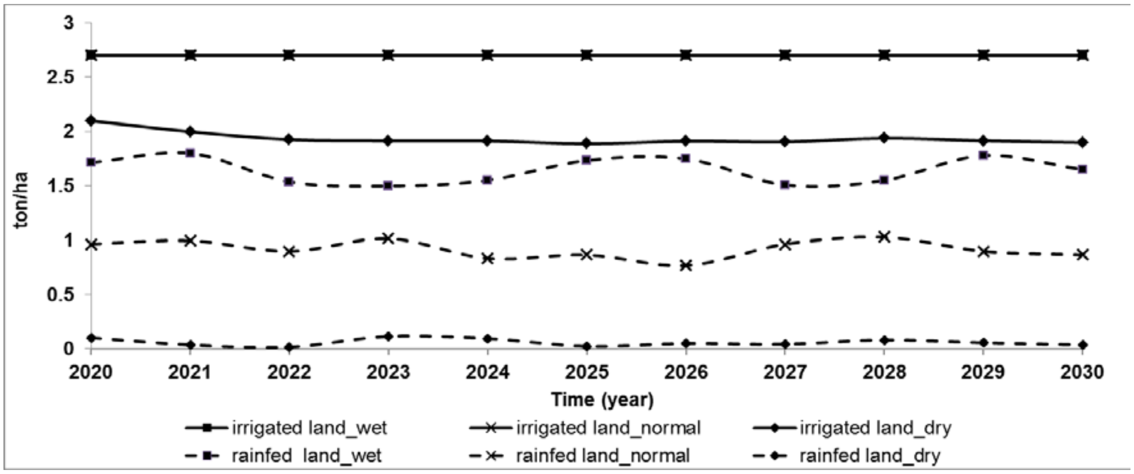

Figure 5: Crop yield comparison for canola

3.2.3 Example 3: Conventional Oil Production and water demand

The third example presents some preliminary results from the oil and gas extraction subsector. Impacts on oil production and water demand of three scenarios – fracking-based production (1) increases, and (2) decreases of 10% in 2022, and (3) the combination of (1) with alternative water sources utilization in 2022 – are compared against the (4) base case simulation (no policy selection). Compared to the base case, scenario (1) and (2) increase or decrease, respectively, the oil production (Figure 6) and water demand (Figure 7). Clearly, there is a trade-off between high water use for oil extraction and water for other water uses under water shortages. However, scenario (3) has an increased oil production with a relatively low water demand – even lower than in the base case – since alternative water sources are not only used for hydraulic fracking but also for water injection for conventional methods (enhanced oil recovery).

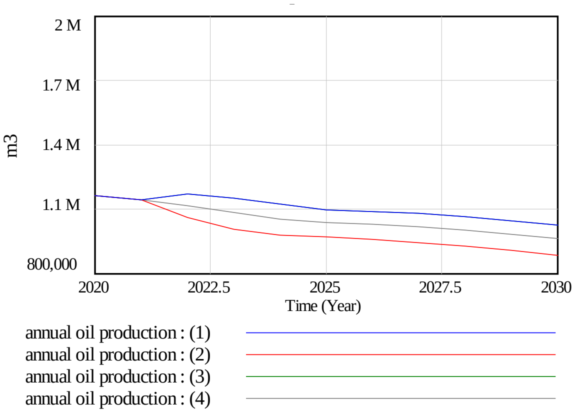

Figure 6: Annual oil production

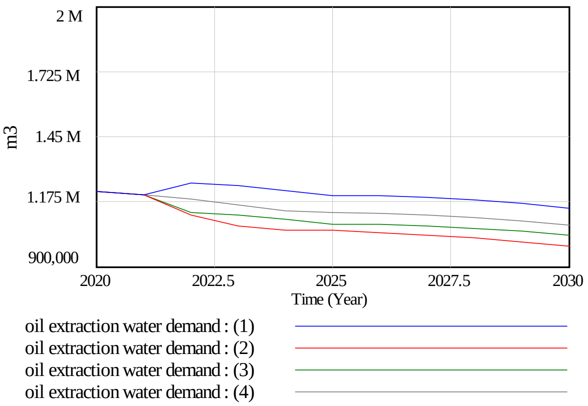

Figure 7: Oil extraction water demand

4 CONCLUSIONS

As a simulation gaming model for water resources management, the BRSGM offers a comprehensive view of river basin-scale sustainability by integrating social, economic, and environmental factors to support multi-dimensional assessment of policy effectiveness and identify potential risks to water-dependent systems. Through alternative scenarios, the model clearly illustrates general effects of policy combinations related to basin-scale water and land uses, and infrastructure and technological developments, for improving basin-scale water sustainability. Results from these scenarios can improve players' understanding of the complexity of water resources systems and the kinds of trade-offs that result from policy selections. In addition, the model elicits and records players' preferences for basin scale water management options, such as water and land allocations, economic and infrastructural priorities and drought mitigation actions.

For water resources management, the model can also be used as an experimental tool to explore various policy combinations and motivate creative thinking, thereby supporting learning – a key objective of both simulation gaming and System Dynamics. For example, the model can illustrate the impacts of population growth and irrigation expansion, and permit the testing of alternative water allocation strategies such as water "shares", prioritize environmental flows, and license transfers. As an educational tool, the model can be used to raise public awareness and improve participatory design for local- and regional-scale water resources management. More generally, the model structure and modeling framework may be applicable to other basins in Canada and internationally.

5 REFERENCES

Ahmad, S. and Prashar, D. 2010. Evaluating Municipal Water Conservation Policies Using a Dynamic Simulation Model. *Water Resources Management*, 24: 3371-3395.

Alberta Agriculture and Rural Development (ARD). 2014. Statistics: Yearbook & Factsheet. Available at: http://www.agric.gov.ab.ca/app21/infopage?cat1=Statistics&cat2=Yearbook%20%26%20Factsheet

Alberta Energy Regulator. 2014. Alberta's Energy Reserves 2013 and Supply/Demand Outlook 2014-2023. Available at: http://www.aer.ca/documents/sts/ST98/ST98-2014.pdf

Alberta Environment. 2003. South Saskatchewan River Basin Water Allocation. Available at: http://www.assembly.ab.ca/lao/library/egovdocs/2005/alen/161171.pdf.

Alberta Environment. 2006. Approved Water Management Plan for the South Saskatchewan River Basin (Alberta). Available at: http://environment.alberta.ca/documents/SSrb_Plan_Phase2.pdf

Alberta Environment. 2014. Available at: http://esrd.alberta.ca/

Allen, R.G., Pereiraa, L.S., Raes, D. and Smith, M. 1998. Crop Evapotranspiration-Guidelines for Computing Crop Water Requriements, FAO Irrigation and Drainage Paper 56. *Food and Agriculture Organization of the United Nations*.

Alston, J.M., Beddow, J.M. and Pardey, P.G. 2009. Agricultural Research, Productivity, and Food Prices in the Long Run. *Science*, 325: 1209-1210.

AMEC Earth & Environmental. 2007. Water for Life, Current and Future Water Use in Alberta. *Alberta Environment*. Available at: http://www.assembly.ab.ca/lao/library/egovdocs/2007/alen/164708.pdf

Barlas, Y. 1996. Formal Aspects of Model Validity and Validation in System Dynamics. *System Dynamics Review,* 12: 183-210.

Barreteau, O., Le Page, C. and Perez, P. 2007. Contribution of Simulation and Gaming to Natural Resource Management Issues: An Introduction. *Simulation & Gaming*, 38: 185-194.

Bennett, D.R. and Harms, T. 2011. Crop Yield and Water Requirement Relationships for Major Irrigated Crops in Southern Alberta. *Canadian Water Resources Journal,* 36: 159-170.

Bow River Project Research Consortium (BRPRC). 2010. Bow River Project Final Report. Available at: http://albertawater.com/work/research-projects/bow-river-project.

Calgary Economic Development. 2009. Calgary: Manufacturing Force. Available at: http://www.calgaryeconomicdevelopment.com/sites/default/files/pdf/sector_profiles/manufacturing_sectorProfile.pdf

CAPP & OSDG. 2011. Water Conservation, Efficiency and Productivity Plan – Upstream Oil and Gas Sector. Available at: http://www.capp.ca/getdoc.aspx?DocID=187709&dt=PDF

City of Calgary. 2012. Calgary and Region Economic Outlook 2012-2017. Available at: http://www.calgary.ca/_layouts/cocis/DirectDownload.aspx?target=http%3a%2f%2fwww.calgary.ca%2fCA%2ffs%2fDocuments%2fCorporate-Economics%2fCalgary-and-Region-Economic-Outlook%2fCalgary-and-Region-Economic-Outlook-2012-Fall.pdf&noredirect=1&sf=1

City of Calgary. 2013. Civic Census Resutls, Calgary, Alberta, Canada. Available at: http://www.calgary.ca/CA/city-clerks/Documents/Election-and-information-services/Census2013/Final%202013%20Census%20Results%20book.pdf.

Crookall, D. 2009. Acting, Knowing, Learning, Simulating, Gaming. *Simulation & Gaming*, 40: 8-26.

Environment Canada. 2014. Climate Data. Available at: http://climate.weather.gc.ca/index_e.html

Forrester, J. W. 1961. *Industrial Dynamics*. MIT Press, Cambridge.

Geerts, S., Raes, D. and Garcia, M. 2010. Using Aquacrop to Derive Deficit Irrigation Schedules. *Agricultural Water Management*, 98: 213-216.

Global Water Partnership (GWP) & Technical Advisory Committee (TAC). 2011. Integrated Water Resources Management at a Glance.

Headwater Communications. 2007. Water Efficiency Plan 30-in-30, by 2033. City of Calgary, Water Resources Calgary, Alberta, Canada. Available at: http://www.calgary.ca/UEP/Water/Documents/Water-Documents/water_efficiency_plan.pdf.

Hill, H., Hadarits, M., Rieger, R., Strickert, G., Davies, E., and Strobbe, K.M. 2014. The Invitational Drought Tournament: What Is It and Why Is It a Useful Tool for Drought Preparedness and Adaptation? *Weather and Climate Extremes Journal*, 3: 107-116.

Martz, L., Bruneau, J. and Rolfe, J.T. 2007. Climate Change and Water, SSRB Final Technical Report. Available at: http://www.parc.ca/pdf/research_publications/ssrb-final2007.pdf

Mayer, I. and Veeneman, W. 2002. *Games in A World of Infrastructures: Simulation-games for Research, Learning, and Intervention*. First Ed. Eburon Publishers, Delft.

Mirchi, A., Madani, K., Watkins, D. and Ahmad, S. 2012. Synthesis of System Dynamics Tools for Holistic Conceptualization of Water Resources Problems. *Water Resources Management*, 26: 2421-2442.

Naill, R. 1992. A System Dynamics Model for National Energy Policy Planning. *System Dynamics Review,* 8: 1-19.

Rijsberman, F.R. 2006. Water Scarcity: Fact or Fiction? *Agricultural Water Management,* 80: 5-22.

Rusca, M., Heun, J. and Schwartz, K. 2012. Water Management Simulation Games and the Construction of Knowledge. *Hydrology and Earth System Sciences*, 16: 2749-2757.

Siebert, S. and Döll, P. 2010. Quantifying Blue and Green Virtual Water Contents in Global Crop Production as Well as Potential Production Losses without Irrigation. *Journal of Hydrology,* 384: 198-217.

Simonovic, S.P. and Fahmy, H. 1999. A New Modeling Approach for Water Resources Policy Analysis. *Water Resources Research,* 35: 295-304.

Singh, V.P. and Woolhiser, D.A. 2002. Mathematical Modeling of Watershed Hydrology. *Journal of Hydrologic Engineering*, 7: 270-292.

Statistics Canada. 2014a. Gross Domestic Product (GDP) at Basic Prices, by North American Industry Classification System (NAICS). Available at: http://www5.statcan.gc.ca/cansim/a26

Statistics Canada. 2014b. Water Intake in Manufacturing Industries, by Source and North American Industry Classification System (NAICS). Available at: http://www5.statcan.gc.ca/cansim/a47

Sterman, J.D. 2000. *Business Dynamics, Systems Thinking and Modeling for a Complex World*. McGraw-Hill, Boston.

Tidwell, V.C., Passell, H.D., Conrad, S.H. and Thomas, R.P. 2004. System Dynamics Modeling for Community-Based Water Planning: Application to the Middle Rio Grande. *Aquatic Sciences,* 66: 357-372.

Wagener, T., Sivapalan, M., Troch, P.A., McGlynn, B.L., Harman, C.J., Gupta, H.V., Kumar, P., Rao, P.S.C., Basu, N.B. and Wilson, J.S. 2010. The Future of Hydrology: An Evolving Science for a Changing World. *Water Resources Research,* 46.

Wang, K. and Davies, E.G.R. 2014. A Water Resources Simulation Gaming Model for the Invitational Drought Tournament. Prepare to submit to *Journal of Environmental Management.*

Williams, A., Lansey K. and Washburne, J. 2009. A Dynamic Simulation Based Water Resources Education Tool. *Journal of Environmental Management,* 90: 471-82.

Winz, I., Brierley, G. and Trowsdale, S. 2009. The Use of System Dynamics Simulation in Water Resources Management. *Water Resources Management,* 23: 1301-1323.