Implications of increasing demand for freshwater use from the water footprint of irrigated potato production in Alberta

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ABSTRACT

Rising food demand, rapid urbanization, industrial development and climate change all lead to pressure on freshwater resources. Agriculture is one of the largest users of global freshwater resources, accounting for about 70% of freshwater withdrawals for irrigation. Irrigation accounts for 84% of the total surface water use in the South Saskatchewan River Basin (SSRB) in Alberta. A projection of 53% increase in freshwater use in the SSRB by 2030 could lead to additional pressure on freshwater resources in the region. This study assesses the impact of current and future freshwater use on regional water deprivation impact potential. The result suggests that the water stress index (WSI) and the blue water footprints for a future freshwater use scenario were three times higher than those for the current freshwater use scenario. A combination of increasing irrigation efficiency and improving crop water use efficiency will be an effective way to mitigate pressures of water stress.

Keywords: Water footprint, Water deprivation potential, Freshwater, Irrigated potato, Alberta

1. Introduction

Freshwater use has become a major social and environmental concern in the last two decades. This is due to rising food demand, rapid urbanization, industrial development and climate change which are significantly increasing pressure on freshwater resources (Ridoutt and Pfister 2010; Gheewala et al. 2013). Agriculture is one of the largest users of freshwater resources globally, accounting for about 70% of freshwater withdrawals for irrigation. Alberta has approximately 70% of the irrigated land in Canada. Alberta sources all of its irrigation water from rivers and reservoirs which accounts for 84% of the total freshwater use in the South Saskatchewan River Basin (SSRB) in Alberta (AMEC 2009). Irrigation water use is competing with other demands for freshwater such as urban and industrial consumption.

Global scenarios for future water demand and supply have identified major drivers of change in water demand in order to understand possible changes in the water footprint of production and consumption and to formulate alternative strategies for meeting increased demand for water (de Fraiture and Wichelns 2010; Ercin and Hoekstra 2014). The results of the scenario analyses suggested that future demand for freshwater use would increase significantly and it could exacerbate freshwater scarcity problems unless appropriate action was taken to improve irrigation efficiency and water use efficiency.

Similar to the global scenario analyses, a study of current and future water use in Alberta was conducted to establish a baseline assessment of current water use, to project future water use and to identify potential improvement strategies to meet future freshwater demand. A projection of water supply for the SSRB in Alberta forecasts that water use in the basin will increase 53% from the current 1.98 km^3 to about 3.04 km^3 by 2030 mainly due to expansion of irrigation districts (AMEC 2009). The water demand and supply study did not address a question of how future increased freshwater demand will impact the water footprint of primary agricultural production in Alberta. Therefore, this study assesses the impact of future freshwater use on the water footprint of irrigated potato production in Alberta and identifies potential mitigation strategies to alleviate future water deprivation potential. Potato production is chosen for the study because it is a high value crop, one of the major irrigated speciality crops in southern Alberta and processed potatoes are primarily dependent on irrigation water.

2. Methods

2.1. Water stress index

The water stress index (WSI) developed by Pfister et al. (2009) was used to calculate regional water stress characterization factor relevant to the SSRB in Alberta where most of the irrigated potato production exits. WSI is adjusted to a logistic function ranging from 0.01 to 1 (0.01=low water scarcity, 1= high stress) using a ratio of total annual freshwater withdrawal to hydrological availability (WTA) with modifications to account for monthly and annual variability of precipitation and corrections to account for watersheds with strongly regulated flows (Ridoutt and Pfister 2010).

AMEC (2009) assessed current and future water supply and demand in the SSRB with the Water Resource Management Model (WRMM). The model considered water supplies, natural water flows, precipitation, configuration of streams, canals and water management infrastructure, consumptive and in stream demands, water license priorities, water management policies and operating plans. The SSRB is comprised of four sub-basins: Red Deer, Bow, Oldman and South Saskatchewan. For future water use in 2030, it was assumed that there would be a 32% expansion of irrigation district areas in the Bow sub-basin and a 19% expansion in the Oldman sub-basin. Current water availability, current water use and future water use of the SSRB were taken from AMEC's Water Resource Management Model to calculate the withdrawals to hydrological availability (WTA).

The calculated WTA was adjusted by variation factors of monthly and annual precipitation of four sub-basins in the SSRB. Monthly and annual precipitation normals (1961-1990) were obtained from the AgroClimatic Information Service (ACIS) of Alberta Agriculture and Rural Development (ARD). Coefficients of variation of monthly and annual precipitation for each water sub-basin were calculated using 1600 township weather data[1]. The variation factor of the SSRB was calculated using a weighted average of variation factors and the mean annual precipitation of four sub-basins.

The water stress indices of the whole sub-basins in the SSRB were calculated for current water use and future water use scenarios by using the WTA for both scenarios and the variation factor. The WSI was used as a midpoint characterization factor to measure the water deprivation impact potential. As this study focuses on freshwater use and its impact on regional freshwater deprivation potential, the water deprivation potential is calculated by multiplying the blue water footprint with the WSI for the current and future use scenarios.

2.2. Water footprint

In terms of virtual water, water consumption is divided into three categories: green, blue and grey (Hoekstra et al. 2011). The green water consumption describes the evapotranspiration of rainwater during plant growth, which is especially relevant for agricultural products. Blue water consumption describes the volume of ground and surface water that evaporates during production, especially important for irrigated agriculture systems (Ridoutt and Pfister 2010). Grey water consumption describes the total amount of water required to dilute the used water until it reaches commonly agreed quality standards. Grey water consumption is excluded from this study because other LCA studies measure the impact of grey water as eutrophication and acidification potential in life cycle impact assessment (LCIA).

Crop water requirements of potato production for six locations from three irrigation districts (2011) were obtained from the Alberta Irrigation Management Model (AIMM, ARD 2014). The AIMM calculates daily evapotranspiration values over a growing season (May 15 to September 30) using daily climate data from the climate information network stations and crop coefficients and reference evapotranspiration of Penman-Monteith equations developed by Allen et al. (1998). Green and blue water footprints were calculated using the water footprint assessment method developed by Hoekstra et al. (2011). Irrigated potato yield for 2011 was obtained from Agriculture Financial Service Corporation (AFSC, 2012).

The US potato production data were adapted from ecoinvent database to estimate indirect blue water consumption for crop inputs and field operations (Nemecek and Kagi 2007). Data on field operations and

[1] Township weather data were calculated using a mathematical data interpolation method that weighted up to the 8 nearest station observations (ACIS 2013).

transportation was used from the US potato production because cultivation methods were similar across the North American commercial potato production system. Fertilizer production was modified using Alberta/Canada electricity grid mix. Fertilizer application rates were used from fertilizer recommendations for irrigated potato by Alberta Agriculture and Rural Development. Pesticide use was calculated from the 2011 Potato Crop Weed and Pest Control Guide, Prince Edward Island Department of Agriculture. Indirect blue water consumption of potato production was calculated by Impact 2002+ version 2.2 method in SimaPro 7.3.3 (Humbert et al. 2012; Goedkoop et al. 2010).

2.3. Sensitivity analysis

Sensitivity analyses of the future blue water footprint were conducted to identify potential mitigation strategies for alleviation of freshwater deprivation potential. Irrigation water conveyance efficiency, application efficiency and water use efficiency were also included in the analysis. The first sensitivity analysis included a combination of 4.3% increase in conveyance efficiency and 15% increase in application efficiency[2]. It is assumed that irrigation efficiency could be increased by improving irrigation infrastructure and adopting more efficient application equipment. The second and third sensitivity analyses included a 10% and 20% increase in potato yield (increased water use efficiency). It is assumed that potato yields could be increased by varietal and agronomic improvements.

3. Results

Water stress indices (WSI) of South Saskatchewan River Basin were 0.2078 for the current water use scenario and 0.5981 for the future water use scenario in 2030. An increase of 53% in future freshwater use could change from the current very mild water deprivation potential to a moderate severe water deprivation potential in the SSRB because a higher level of water withdrawal leads to a higher value of freshwater WTA, resulting in a higher value of WSI. The results of WSI for current and future freshwater use scenarios suggest that an expansion of irrigated areas in the SSRB would necessitate a determination of what is a sustainable level of irrigation withdrawals from the basin.

Irrigation water requirements of potato production ranged from 146 to 353 mm yr^{-1} depending on potato evapotranspiration (mm) and precipitation (mm) (Table 1). Grassy Lake required the lowest level of irrigation water because it had the highest level of precipitation. Conversely, Seven Persons required the highest level of irrigation water because of the lowest level of precipitation in the region. Both Grassy Lake and Seven Persons were located in the South Saskatchewan sub-basin. Total irrigation water requirement of potato production ranged from 179 to 433 mm after conveyance and application water losses were taken into account.

The total water footprint of potato production ranged from 133 to 158 L/kg (Table 2). As previously mentioned, the study focused on freshwater use and its impact on regional water deprivation potential so the water deprivation impact potential of blue water was calculated multiplying blue water with the water stress index (WSI) of the SSRB. The stress-adjusted blue water footprints are presented in Table 3. The results of the future freshwater use scenario in all regions were about three times greater than the current freshwater use scenario because the value of the WSI for future water use was about three times higher than those of current water use.

[2] Water conveyance efficiency is the ratio between the irrigation water that reaches a farm or field to that diverted from the water source. Water application efficiency is a measure of the fraction of the total volume of water delivered to the farm or field to that which is stored in the root zone to meet the crop evapotranspiration needs (Irmak et al. 2011).

Table 1. Parameters used for calculation of irrigation water requirement for irrigated potato production

Irrigation District	St. Mary	St. Mary	St. Mary	Taber	Taber	Bow River
Location	Seven Persons	Bow Island	Grassy Lake	Fincastle	Barnwell	Enchant
Potato yield (tonne/ha)	41	41	41	41	41	41
Conveyance efficiency (%)	93.7	93.7	93.7	93.7	93.7	93.7
Irrigation application efficiency (%)	80	80	80	80	80	80
Evapotranspiration (mm)	486	435	441	484	478	437
Precipitation (mm)	133	155	295	187	260	172
Irrigation water requirement (mm)	353	283	146	297	218	265
Conveyance loss (mm)	9	7	4	8	6	7
Irrigation application loss (mm)	71	56	29	59	44	53
Total irrigation water requirement (mm)	433	343	179	364	267	325

Table 2. Water footprint of irrigated potato (per hectare and per kg of potato)

Irrigation District	St. Mary	St. Mary	St. Mary	Taber	Taber	Bow River
Location	Seven Persons	Bow Island	Grassy Lake	Fincastle	Barnwell	Enchant
Green WF (m^3/ha)	1330	1550	2950	1870	2600	1720
Direct blue WF (m^3/ha)	4458	3536	1844	3751	2753	3347
Total WF (m^3/ha)	5788	5086	4794	5621	5353	5067
Green WF (L/kg)	33	38	73	46	64	42
Direct blue WF (L/kg)	110	87	45	92	68	82
Indirect blue WF (L/kg)	15	15	15	15	15	15
Total WF (L/kg)	158	140	133	153	147	139

Table 3. Water Stress Index-weighted blue water footprint of irrigated potato (L/kg) for two different water use scenarios

Irrigation District	St. Mary	St. Mary	St. Mary	Taber	Taber	Bow River
Location	Seven Persons	Bow Island	Grassy Lake	Fincastle	Barnwell	Enchant
WSI=0.2078 current water use	26	21	13	22	17	20
WSI=0.5981 future water use	75	61	36	64	50	58

Results of the sensitivity analyses are presented in Table 4. The results confirmed that an increase in irrigation efficiency and water use efficiency could alleviate future freshwater deprivation potential of potato production. Increased irrigation efficiency reduced about 11-13% in the blue water footprint. A 10% potato yield increase reduced the blue water footprint by 6-8%. And a 20% potato yield increase reduced about 22-25% of the blue water footprint.

Table 4. Sensitivity analyses for irrigation efficiency and potato water use efficiency (blue water footprint L/kg)

Irrigation District	St. Mary	St. Mary	St. Mary	Taber	Taber	Bow River
Location	Seven Persons	Bow Island	Grassy Lake	Fincastle	Barnwell	Enchant
Baseline	75	61	36	64	50	58
Increased irrigation efficiency	65	53	32	56	43	51
10% yield increase	69	56	34	59	46	54
20% yield increase	56	46	28	48	38	44

4. Discussion

An increase in irrigation freshwater use could lead to a moderate-severe level of regional freshwater scarcity. A projection of a 53% increase in freshwater demand by 2030 is not sustainable in terms of regional freshwater withdrawals to hydrological availability. However, sensitivity analyses indicate that increased irrigation efficiency and water use efficiency could alleviate the severity of regional freshwater scarcity.

In order to maintain sustainable consumption of freshwater resources in the region, it is necessary to develop strategies for sustainable freshwater resource management including improvement in irrigation efficiency, increased water use efficiency and the development of new drought resistant and short growing season varieties (Ridoutt and Pfister 2010; Gheewala et al. 2013). Although most potato growers already use efficient irrigation systems (low pressure pivot sprinkler systems) in the SSRB, there is still room for improvement in irrigation efficiency through adoption of new advanced irrigation systems such as LEPA (low energy precise application) sprinkler irrigation systems, variable rate irrigation systems (VRI) and, advanced management such as adequate irrigation scheduling.

Crop water use efficiency plays a major role in alleviating water scarcity because irrigation water requirements of crop production mainly depend on crop evapotranspiration (Gheewala et al. 2013). The development of drought resistant and high-yield crop varieties could potentially minimize the water footprint of crop production. Figure 1 illustrates that the average potato yields have increased by about 25% over the past the two decades due to varietal and agronomic improvements. Improvement in crop yield could lower the water footprint of agricultural products. An integrated management of freshwater resources combining strategies for increasing irrigation efficiency and improving crop water use efficiency will be an effective way of reducing the blue water footprint of irrigated crop production and alleviating the water deprivation potential in the region.

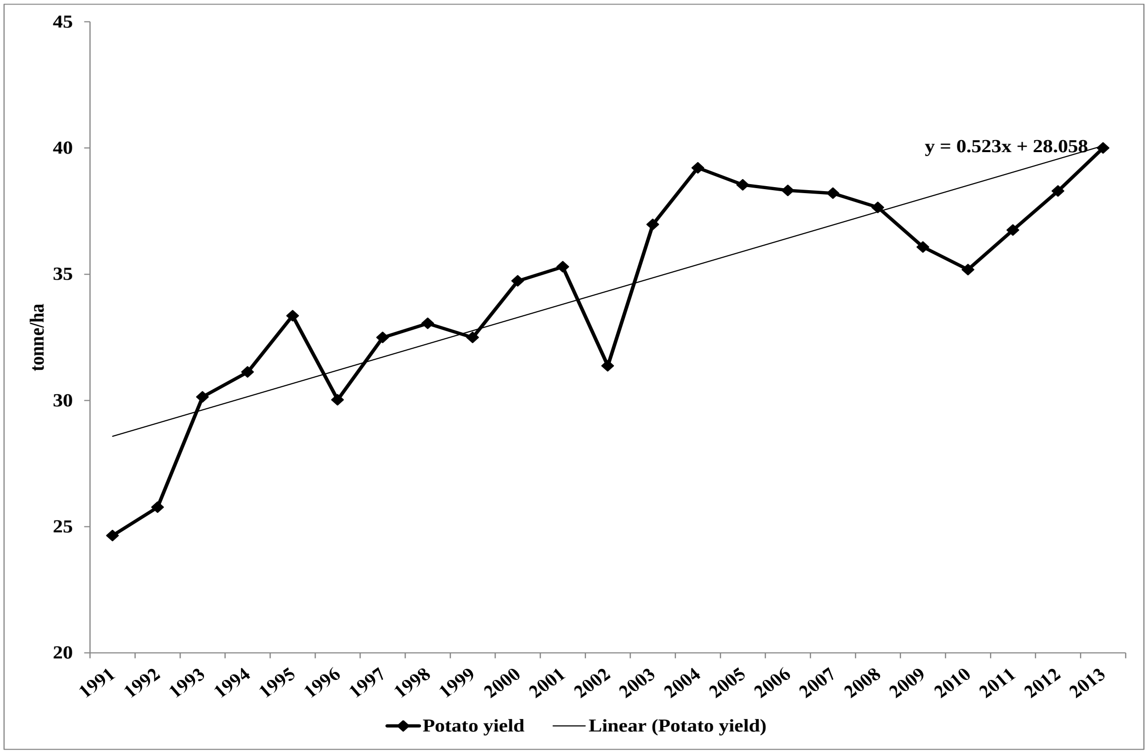

Figure 1. Average potato yield in Alberta (1991-2013)
Source: Statistics Canada, CANSIM Database (1991-2013)

5. Conclusion

Increased water use for irrigation could lead to additional pressure on freshwater resources and in a greater blue water footprint of irrigated potato production. A regional water stress index is a relevant characterization factor to measure local water scarcity in the particular region. Therefore, the WSI can be used to assess the impacts of different scenarios of water use and supply on regional water deprivation potential. A combination of increased irrigation efficiency and an improvement in crop water use efficiency will be essential to mitigate increase pressures of water stress.

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