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Influence of Climate, Landscape Change and Licenced Water Removal on Flows in the Sturgeon River Basin

Flows in the Sturgeon River have experienced a marked decrease during the past few decades following a rapid expansion of urban areas and changes in land use across the basin. Concern is growing among residents over issues such as declining water levels, summer and winter fish kills and poor water quality in the river. There are many uncertainties with respect to water supply in the Sturgeon River, and long-term water management planning has not been completed for this basin.

Within a context of climate change and continued economic and population growth, it is crucial that we gain an understanding of which drivers are having the most impact on the Sturgeon River. This bulletin provides an overview of the temporal changes in river flows and water supply in the Sturgeon River and analyzes the main drivers causing such changes.

The Sturgeon River Basin

The Sturgeon River is a tributary of the North Saskatchewan River and its basin covers an area of 3,301 km^2. It is a prairie river, fed by the rain and snow that falls throughout the year. It starts near Hoople Lake and flows eastwards through Lake Isle, Lac Ste. Anne, Devil’s Lake and Big Lake before its confluence with the North Saskatchewan across from the City of Fort Saskatchewan (Figure 1).

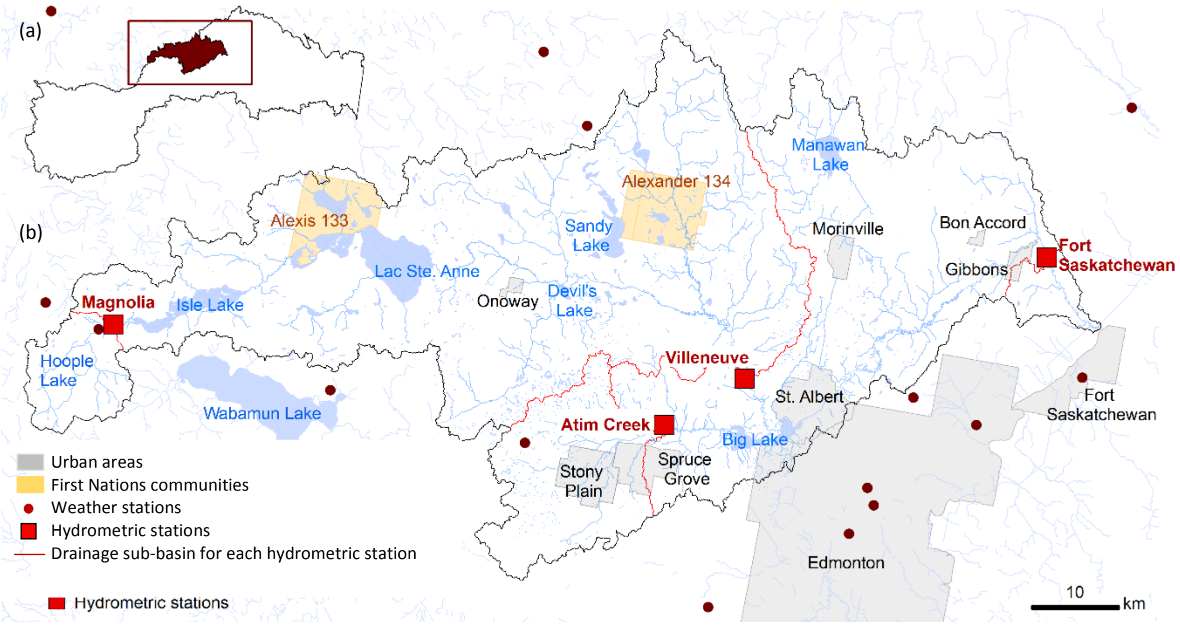

Fig. 1. (a) Location of the Sturgeon River basin within the North Saskatchewan basin; (b) Map showing the Sturgeon River basin and the weather/hydrometric (flow) monitoring stations. Note that the corresponding sub-basin is drawn for each hydrometric station. Larger lakes and communities across the basin are also indicated.

From 1914 to 2015, the average annual temperature in the Sturgeon River region was 2.5°C and average annual precipitation was 457 mm. Most of the precipitation falls in the May-September period (Figure 2).

Average discharge at the river's outlet for the same period 1914-2015 (measured from March to October) was around 4 m^3/s, corresponding to a mean annual value of 83,500 dam^3 (approximately 1% of the annual discharge of the North Saskatchewan at the Alberta/ Saskatchewan boundary).

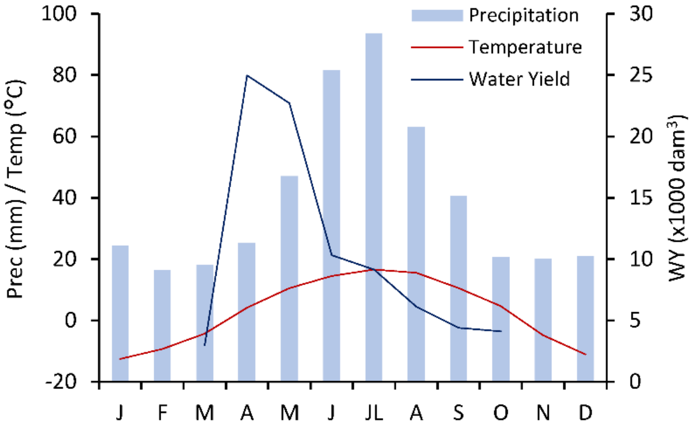

Fig. 2. Average monthly values of precipitation (Prec, blue bars, in mm), temperature (Temp, red line, in °C), and water yield (WY, blue line). Note that flow is measured during the open water season (March to October). 1 $dam^3 = 1000 m^3$

Changes in Flow and Water Supply

Four water monitoring stations maintained by the Water Survey of Canada (WSC) were selected to evaluate historical changes in water yield (WY) and water supply in the Sturgeon River: Magnolia (headwaters), Atim Creek near Century Road, Villeneuve (middle reach) and Fort Saskatchewan (river outlet, Figure 1).

Figure 3 shows the annual values and the temporal trends for each of the four stations. Statistical tests[1] show significant decreasing WY for Magnolia and Villeneuve, whose flow records start in the early 1980s and 70s respectively. WY values at the station near Fort Saskatchewan, located close to the river outlet, do not show a significant decrease when the whole period (since 1914) is considered. However, WY in this station shows a cyclical pattern, and a decreasing trend is indicated since the 1970s.

WY trends in Atim Creek differ from those observed at the other stations. In this sub-basin, the short length of the flow record and the 10-year data gap do not provide enough statistical confidence to draw robust conclusions about the historical trends. Despite this, WY in this station seems to increase during the period from 2005 to 2015.

Decreasing WY values are particularly notable during the summer months, when the flow may even cease in some reaches (Figure 4). It is also during these months when water demand for certain uses, such as irrigation, may be at its highest.

An additional test known as a "breakpoint analysis"[2] was undertaken on the WY data for the three stations with continuous data. This analysis reveals abrupt changes in the data. It identified a breakpoint in the three Sturgeon

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[1] Mann, 1945. Non-parametric tests against trend. Econometrica, 13: 163-171.

[2] Pettitt, 1979. A non-parametric approach to the change-point problem. Appl. Statist., 28, 126-135.

River stations between the years 1990-2000 (Figure 5, vertical lines). From that decade to the present, the WY decline is notable; median WY values for the second (post-change) are between 40 and 60% lower than the median WY before the breakpoint occurs. For example, median annual WY has decreased from 8 to 4 dam^3/yr at Magnolia (headwaters), from 61 to 21 dam^3/yr at Villeneuve, and from 71 to 41 dam^3/yr at Fort Saskatchewan (at the river's outlet).

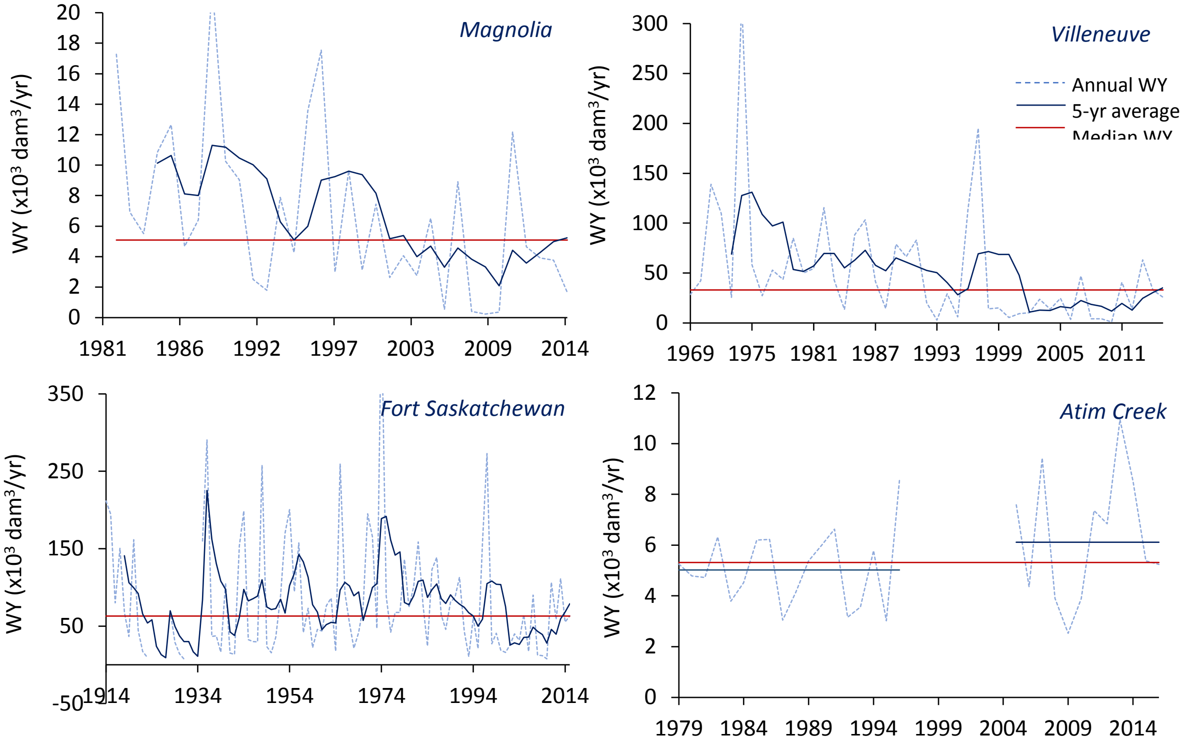

Fig. 3. Annual water yield values (WY, in x10^{3}dam^3/yr) for the hydrometric stations on the Sturgeon River. Dotted lines show the actual WY annual values, while dark lines show the 5-year running average. Red lines indicate the long term median annual WY. Note that the length of the flow record differs in each station. Flow measurements in Atim Creek were discontinued from 1996 to 2005. Only the open water season (from March to October) is considered since most of the stations only measure flow during this period.

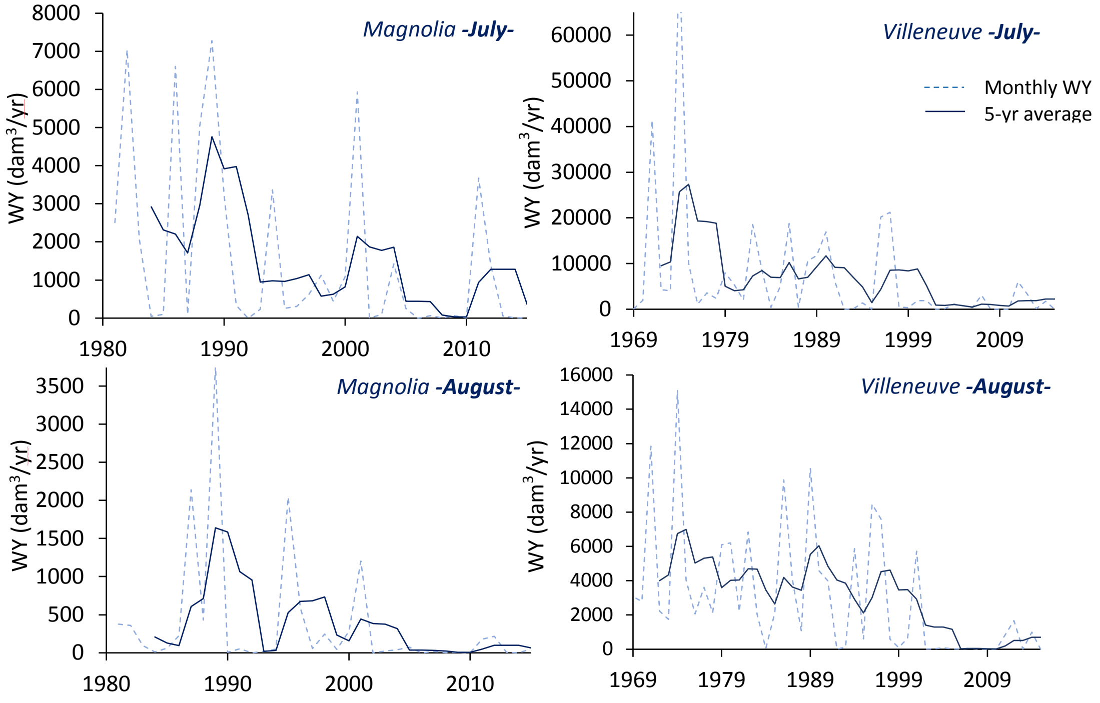

Fig. 4. Example of water yield (WY) trends during July and August at two hydrometric stations. Dotted lines show the flow for the month considered, while the dark blue line shows the 5-year running average.

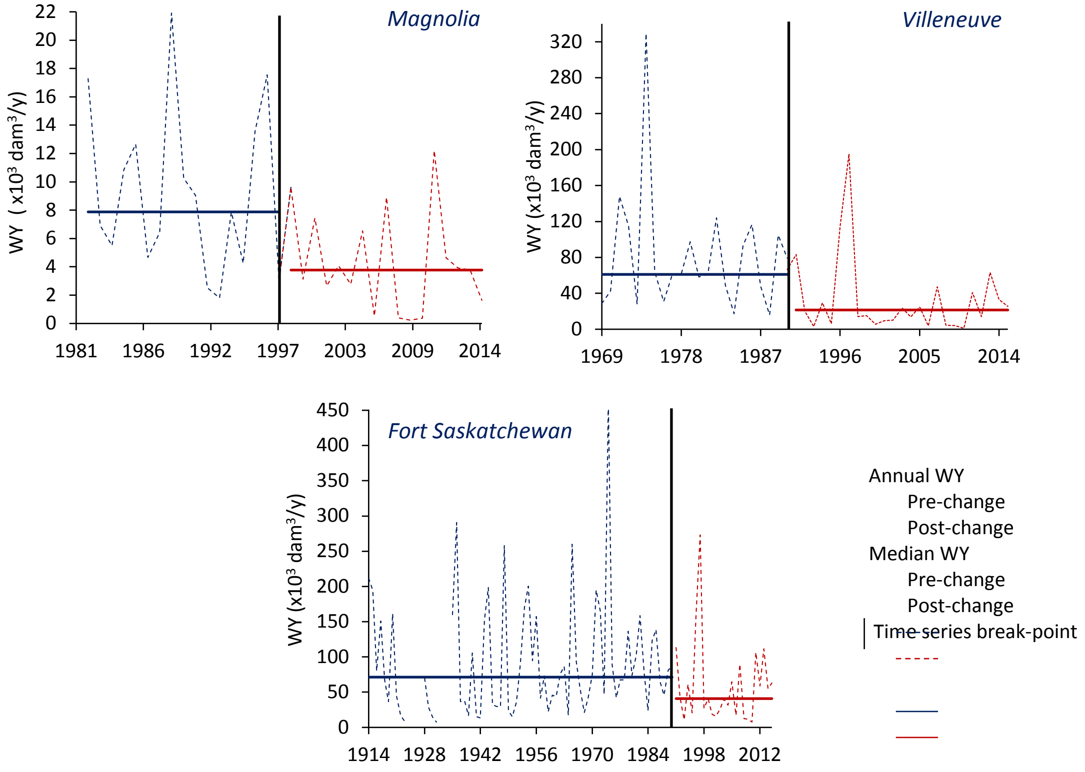

Fig. 5. Pre-and post-change water yield (WY) values for the water monitoring stations. A definite change, or break (black line), is seen in the data for all stations starting in the mid to late 1990s.

Effects of Climate Patterns

A common concern about climate change is the intensification of the hydrologic cycle, resulting in changes in streamflow and drought severity. However, climate is known to vary naturally over seasons and years. “Climate variability” refers to the way climate fluctuates above or below a long-term average temperature or precipitation value. Common drivers of this natural variability in the region are the *El Niño Southern Oscillation (ENSO)* and the *Pacific Decadal Oscillation (PDO)*. Both patterns are similar in character; they consist of a warm and cool phase that modifies upper level atmospheric winds, resulting in changes in global climate (temperature patterns, droughts, flooding etc.). Despite the similar effect on the global climate system, they act over different time scales; while ENSO typically lasts for 6 to 18 months, the PDO can remain the same for 20 to 30 years. “Climate change” refers to a long-term continuous change (increase or decrease) to average weather conditions, or the magnitude and frequency of the events (for example, extreme storms or droughts).

In western North America, the PDO is the main mode of variability influencing climate and hydrology. Figure 6 shows the natural oscillations of climate variables as well as the fluctuations of the PDO Index. Fluctuations of all variables below and above the long-term normal value are evident. Despite this natural decadal variability influenced by the PDO, climate and flows seem to follow a continuous trend approximately since the 1970s: temperature values have been above the long-term normal, and precipitation and flows show a steady decline. There is evidence of significant changes in climate which cannot be described solely by large-scale circulation patterns. Such changes can be mainly attributed to global warming, which is superimposed on this natural variability (Nazemi et al., 2016[3]).

How natural cycles interact with human interventions in the global climate system is still poorly understood. Despite the uncertainty, it is likely that climate variability will increase in the future, which will ultimately result in an increased variability and uncertainty in stream flows and water resources availability. This is particularly relevant in regions such as the Prairies, where extreme dry periods and natural hydro-climatic variability are inherent to their climate characteristics (Bonsal et al., 2017[4]). Such potential for increased variability and extreme weather conditions poses a challenge for adaptation and water resources management.

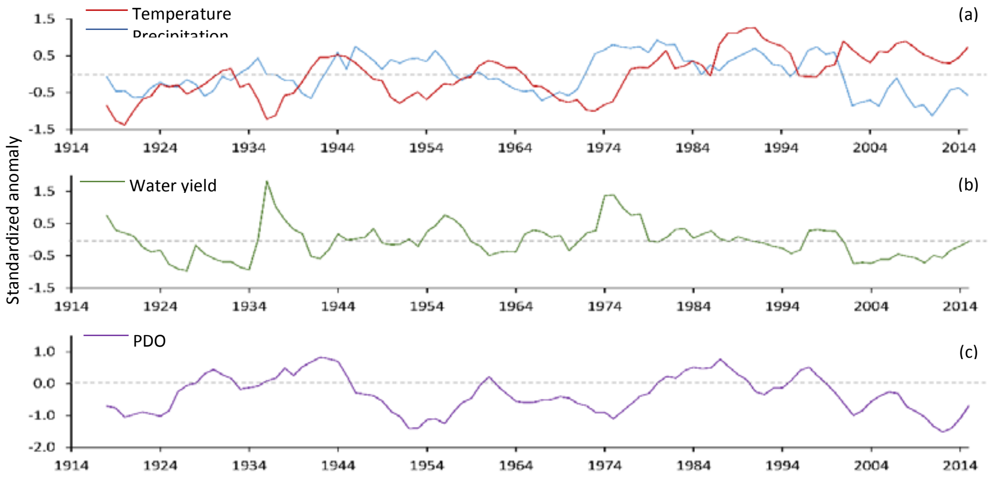

Fig. 6. Deviation from normal in (a) annual temperature and precipitation; (b) annual water yield at the basin outlet; and (c) Pacific Decadal Oscillation Index for the period 1914-2015. Values are represented as standardized anomalies (calculated by dividing each anomaly -or difference between each value and the long-term mean- by the long-term standard deviation. Lines show the 5-year running mean for each variable.

[3] Nazemi et al., 2016. Forms and drivers of annual streamflow variability in the headwaters of Canadian Prairies during the 20th century. *Hydrological Processes*, 31: 221-239.

[4] Bonsal, B., Cuell, C., Wheaton, E., Sauchyn, D.J., Barrow, E., 2017. An assessment of historical and projected future hydro-climatic variability and extremes over southern watersheds in the Canadian Prairies. International Journal of Climatology. Doi: 10.1002/joc.4967

Effects of Land Cover Changes

River basins are complex systems that not only respond to global climate conditions; there are multiple socio-economic and physical processes acting at the basin scale that will ultimately affect water availability. Land clearing, urbanization, wetland drainage, industrial and agricultural activities and domestic uses affect the water cycle, and they in turn depend on an adequate supply of good quality surface water.

Most of the Sturgeon basin is under agricultural development, with the highest percentage of agricultural land occurring in the central and eastern portions of the basin (Figure 7). Urban areas have also expanded rapidly during the past few decades. For example, in 1966 urban areas occupied 1% of the total basin area, while they currently take up 13% of the basin.

An extremely high population growth has driven such expansion, particularly in the cities of St. Albert, Spruce Grove and the Town of Stony Plain. Figure 8 shows the population growth in these communities since 1960. During the past 50 years, their population grew from less than 12,000 to over 112,000, an average annual increase of about 2,000 residents. This reflects the ongoing urban development in the basin, and this trend will continue according to the CRB[5] growth projections.

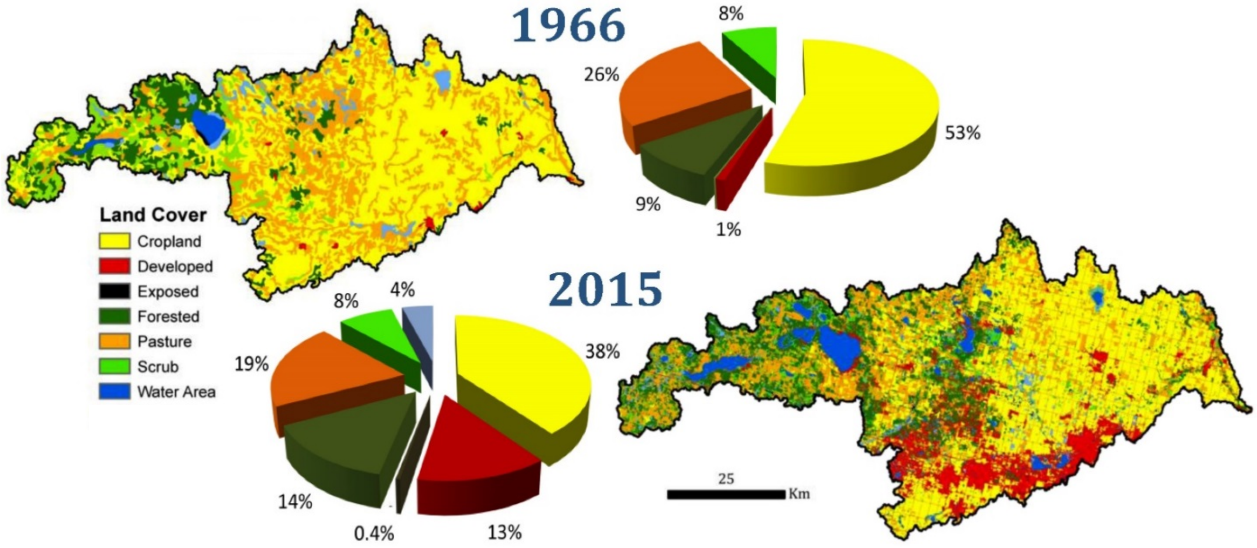

Fig. 7. Land cover changes between 1966 and 2015. Pie charts indicate the percentage of the basin occupied by each land cover type. The expansion of the urban areas (in red) in the southern part of the basin is evident.

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[5] Capital Region Board Growth Plan Update.

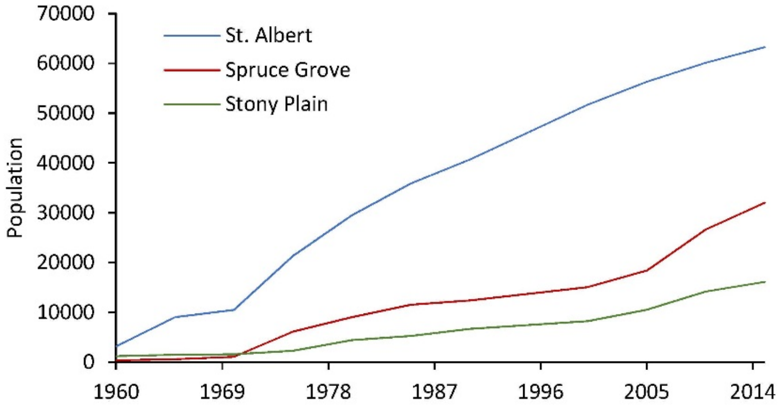

Fig. 8. Population growth for three of the main communities in the Sturgeon River basin. Source: Alberta Municipal Affairs (1960-2015)

Dense urbanization of the land leads to dramatic changes in the timing, quality and amount of water running off the landscape. Such dense urban mosaics could be the main cause driving the divergent flow trends observed in Atim Creek when compared to the overall declining flows across the basin (as shown in Figure 3). The increase in the impervious surface resulting from urban development leads to a decrease in water infiltration rates and an increase in surface water runoff (Figure 9).

The decrease in infiltration from urbanization may also cause profound groundwater changes, as it will affect aquifer recharge areas. Unmanaged storm water flows lead to increased flooding during and shortly after rain episodes; in many instances, it results in lower stream flows during dry weather. Urban development may increase the amount of pollutants carried into streams (e.g. sediment, oils and grease, pesticides and nutrients, bacteria, road salts, heavy metals, thermal pollution, etc.) which, together with a modified hydrological regime, will ultimately affect stream habitat and aquatic ecosystem health.

In order to minimize the increased runoff from impervious surfaces and reduce the risk of flooding, drainage systems and storm water management facilities have been constructed across urban areas. Storm water ponds are an adaptable and effective technique for providing channel protection and pollutant removal for urban streams (Schueller, 2000[6]). Consequently, storm water management guidelines have been developed and implemented in the urban areas within the basin (for example St. Albert, Stony Plain and Spruce Grove) with the objective of maintaining pre-development discharge rates and pollutant loadings to receiving water bodies.

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[6] Schueller, T. 2000. The Environmental Impact of Stormwater Ponds: The Practice of Watershed Protection. Center for Watershed Protection, Ellicott City, MD. Pages 443-452

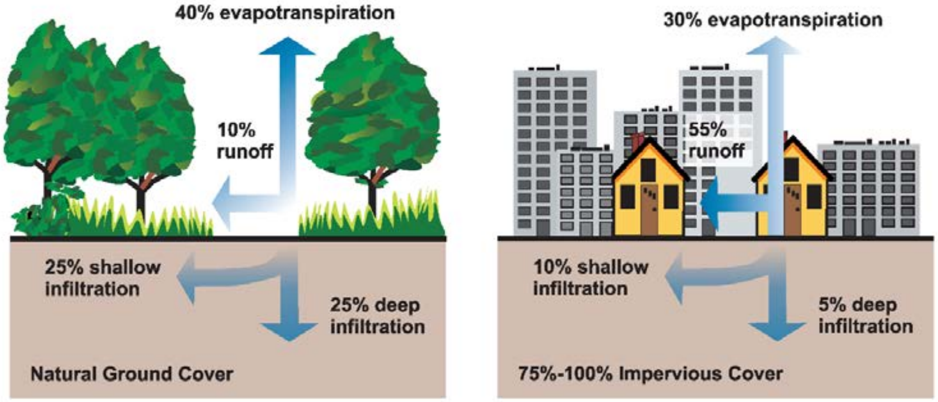

Fig. 9. Relationship between surface runoff and impervious surface in urban areas. As little as 10% impervious cover in a watershed can result in stream degradation. Source: US-EPA (Environmental Protection Agency – EPA 841-F-03-003)

Effects of Water Use

Following the socio-economic development and population growth, the Sturgeon basin has experienced a notable increase in the use of freshwater resources. It has many licenced surface and groundwater water withdrawals for a wide range of purposes, including irrigation, stock watering, municipal, and commercial use. Figure 10 shows the trend over time in the number of surface water licences and the total volume of water allocated. Note that this figure distinguishes between the licenced allocation (blue), which is the maximum volume a licenced user is entitled to take from the river, and the estimated water use (which includes the estimated consumption and the estimated losses). The difference between these two numbers is the amount of water that is unused. Data for the actual water use were not available for the analysis.

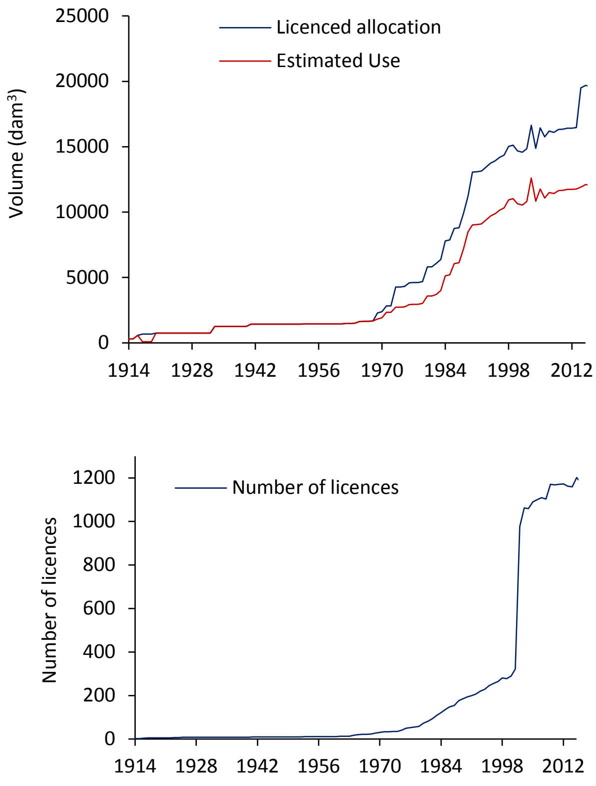

Fig. 10. Licenced allocation and estimated water use (including estimated consumption and estimated losses) from the Sturgeon River basin and number of licences over the period 1914-2015. Source: Alberta Environment and Parks, 2016.

The total volume of surface water allocated in the basin amounts to around 19,600 dam^3, which corresponds to 31% of the long-term median flow in the Sturgeon measured at the outlet (i.e. 63,000 dam^3/yr, flows measured from March to October). However, estimated water use is approximately 12,000 dam^3 (20% of the median flow). Water use is not distributed evenly throughout the year. The report "*Sturgeon River Basin – Current Consumptive Water Use Estimates*" (MPE Engineering, 2004)[7], which examines the actual water use in the basin for the year 2003, indicates that water use is highest during the period from April to August. These five months together account for 95% of the total water use reported in the basin, while water use during the rest of the year is relatively low.

Using the monthly distribution of water use indicated in the MPE report and the allocation data provided by Alberta Environment and Parks, we estimated the monthly water use for 2015, the last year for which updated flow data is available. The results are shown in Figure 11, where the estimated use is compared to the median monthly flows in the Sturgeon.

This approximation to the monthly water use in the Sturgeon for 2015 indicates an increased pressure on water resources and the river ecosystem during the summer, particularly July and August, when the estimated use clearly exceeds the monthly flows. In July, estimated use is around 123% of the long-term stream flow median for this month, while this percentage rises to 237% when the period from 2000-2015 is considered.

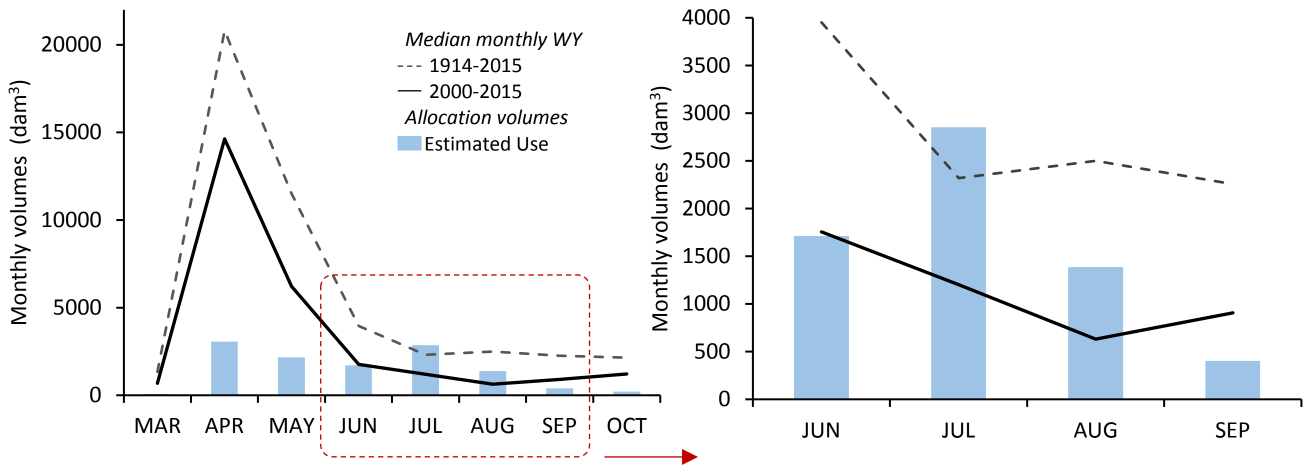

Fig. 11. Monthly distribution of estimated surface water use (estimated consumption + estimated losses) compared to the median monthly water yield (WY) in the Sturgeon. Monthly stream values are reported for the whole flow record (1914-2015) and for the last decade (2000-2015), evidencing the lower current values. Diagram on the right focuses specifically on the summer months (from June to September).

Land cover, Water Use or Climate Effects?

One of the most widely-used techniques to tentatively distinguish the cause of the changes in hydrological conditions is the "Double Mass Curve" method[8], which is used to determine the consistency in the relationship between two variables. The graph of the cumulative data of one variable (precipitation) against the cumulative

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[7] MPE Engineering (2004)- Sturgeon River Basin – Current (2003) Consumptive Water Use Estimates. Final Report 2120-038-000. Prepared for Central Region, Alberta Environment.

[8] Walling and Webb (1996). Erosion and Sediment yield: Global and regional perspectives. IAHS press, Institute of hydrology, Wallington, UK.

data of a related variable (flow) is a straight line, so long as the relation between both variables is a fixed ratio. The hypothesis is that if flows are decreasing mainly due to a decline in precipitation (resulting from climate effects), both variables should change at a similar rate. Diversions from the straight line indicate the influence of an external variable that modifies their relationship. Changes in the landscape and water use will potentially affect the amount of runoff that is generated in a basin given a specific amount of precipitation.

Figure 12 shows the Double Mass Curves for each of the stations in the Sturgeon basin. A linear relationship between both variables is evident, but a change in the line slope can be clearly identified in each of them (indicated by the color change). This break coincides with the breakpoint detected in the breakpoint analysis between 1990 and 2000 (Figure 5). The graphs imply that flows do not change at the same rate as precipitation, with the former increasing at lower rates (as indicated by the more gradual slope observed after the breakpoint). These results could be indicating that, given a specific amount of precipitation, flows are currently lower than they were before the breakpoint.

The exception is Atim Creek, where the change in color on the graph reflects the two periods when flow was measured. In this tributary, there is an increase in the line slope on the graph during the second period, meaning that for the same amount of precipitation, there is an increase in flows compared to the first period. This reversed pattern follows the increased surface runoff that results from the expansion of urban areas and the pumping of groundwater from local subdivisions into the stream. However, trends in this sub-basin should be interpreted with care given the lack of long flow records for this station.

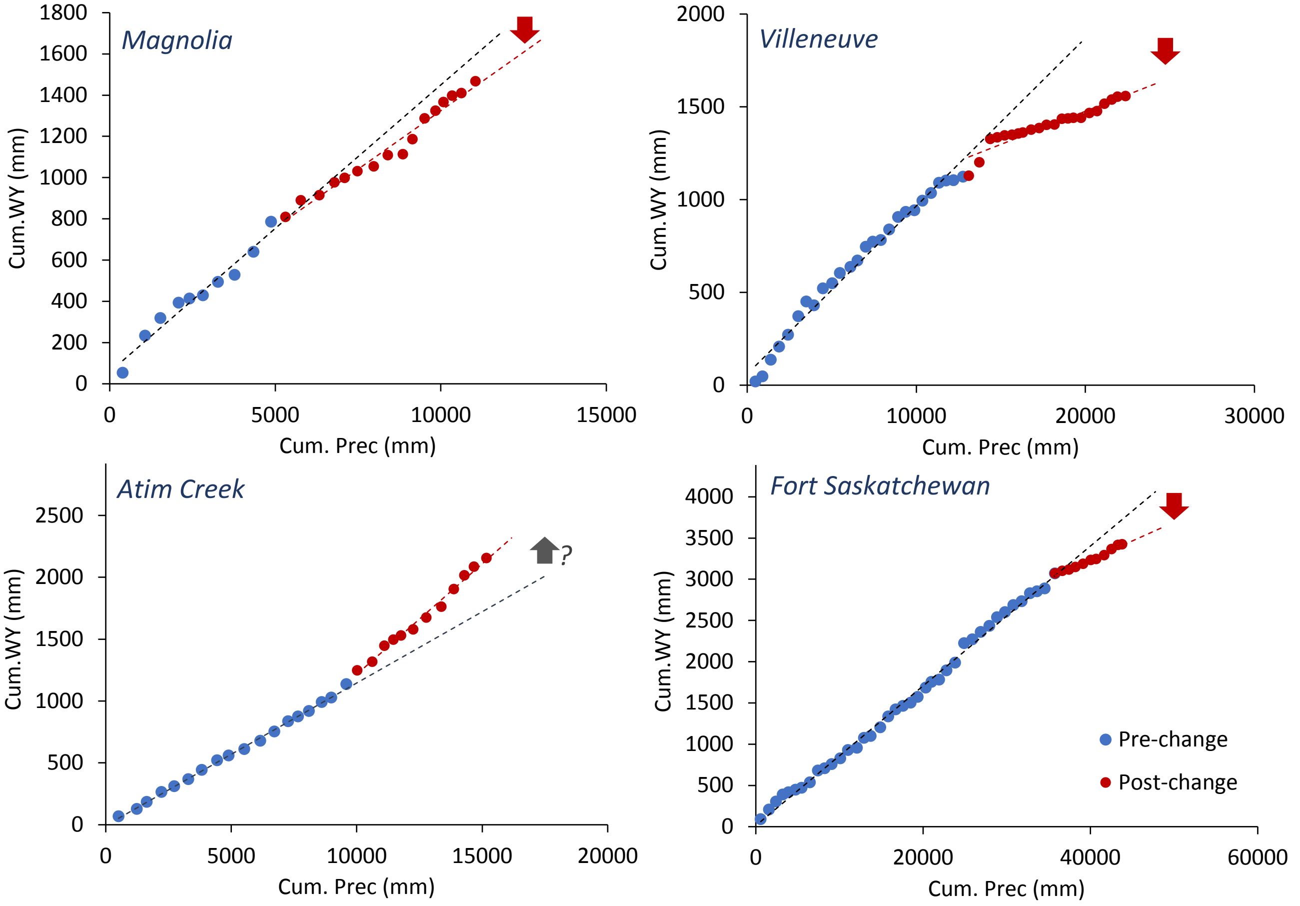

Fig. 12. Double mass curves for the stations in the Sturgeon basin. The relationship shown is between cumulative precipitation (Cum. Prec) and water yield (Cum. WY), both in mm/yr. The change in the line from blue to red indicates a change in this relationship. The timing of this change corresponds with the time breakpoint in Figure 5.

While changes in the flow and water supply in the Sturgeon River are evident, it is difficult to evaluate exhaustively whether the trends observed result from climate variability, or the intense development and water use that has occurred across the basin during the last decades. The Double Mass Curve method only provides a basic approach to this fundamental question. However, results seem to suggest that the effects of human activities on stream flows (through landscape changes and increased water use) might be having more of an effect than climate variability.

Summary

- Despite historical climate oscillations driven mainly by the Pacific Decadal Oscillation, local climate has been warmer and drier, particularly since the 70s, which could be explained by human-induced climate change effects.
- During the past few decades, there has been substantial growth and development in the Sturgeon River basin, which has resulted in an increase in the number and volume of water licences.
- The analysis of annual trends across the basin indicates a decline in flows by 40-60%, particularly from the 1990's to the present. Landscape changes and the increased water use driven by human activities may have influenced the negative trend to an extent larger than the influence of climate forcing. However, it is important to consider local conditions in each sub-basin, as trends might vary depending on the land use, particularly in highly developed urban areas (such as Atim Creek).
- There is a temporal mismatch between water use and stream flows during the summer months: estimated water use is particularly high during summer and clearly exceeds flows during July and August, when the river is at its lowest.
- Given the detrimental effects that human activities and climate change are exerting on freshwaters, and given the statistical evidence of hydrological change in the Sturgeon, it is essential to evaluate instream flow needs to set water conservation objectives and implement water management recommendations in the basin.

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