Glacial Shrinkage in Western Canada Threatens Freshwater Availability

The climate-change induced shrinkage of glaciers around the world threatens the human population because glacial meltwater accounts for a large portion of global freshwater. Projections indicate that by 2100, the volume of glacier ice in western Canada will shrink by 70 ± 10% relative to 2005 (Clarke et al., 2015). This is detrimental because as glaciers lose mass, they produce an initial increase in runoff water until they reach a turning point called "peak water," after which the discharge declines as the volume of glacial ice decreases (Chesnokova et al., 2020). Since western Canada is a highly glacierized region, glacial meltwater is a primary source of freshwater. Correspondingly, I argue in this paper that climate change driven deglaciation in western Canada will significantly reduce the availability of freshwater by the end of the twenty-first century. This argument is supported by the fact that glacial discharge decreases after peak water, the reduction in glacial mass exacerbates seasonal freshwater shortages, and increased glacial shrinkage results in higher concentrations of organochlorine contaminants in freshwater.

Evidence shows that once glaciers reach peak water, they no longer have a sufficient mass to supply water. In turn, this causes the discharge from glacier-fed rivers to significantly decrease as glaciers continue to retreat, resulting in a long term reduction in freshwater availability. This poses harmful consequences for the ecosystems and human populations in western Canada because this region relies heavily on glacial meltwater for freshwater. To illustrate this, in 2020, Chesnokova et al. analyzed eight watersheds in southwestern Yukon using a dual approach consisting of trend detection in historical discharge variables and a model-based peak water analysis. This study showed that two watersheds with 30% glacierized area have not yet reached peak water and will still experience discharge of 1.5 to 2 fold. The peak water analysis predicted that watersheds with more than 9% of currently glacierized area will show significant changes after peak water, with discharge potentially decreasing by a factor of 3-5 (Chesnokova et al., 2020). This research indicates that it takes longer for watersheds with higher glacierized areas to reach peak water than lower glacierized areas. Evidently, several watersheds in the study with smaller glacierized portions have already passed peak water, and the discharge will continue to decrease. These findings can better direct resource allocation towards the preservation of watersheds with larger glacierized areas because larger glaciers are more reliable sources of freshwater than smaller glaciers. Similarly, by understanding which glaciers will exhibit decreasing meltwater earlier, more resources can be devoted to supporting the river ecosystems at risk of freshwater withdrawal. Ultimately, this research means that throughout the 21st century in western Canada, there will be fewer and fewer glaciers influencing the watershed, proving that glacier shrinkage reduces freshwater availability.

Additionally, the reduction in glacier mass and meltwater will exacerbate seasonal droughts, particularly in summer when glaciers are no longer able to provide consistent freshwater flow to rivers and streams during dry periods. When there is not enough precipitation for freshwater in dry seasons, glacial meltwater often compensates for this shortage. If the flow of meltwater in the summer is decreased, many issues arise for the infrastructure for water management. To provide context, glacial water storage-release is explained by summer decreases in glacier mass-balance due to higher air temperature, and winter increases in mass-balance as a result of greater snowfall (Milner et al., 2008). However, a 2007 study by Josberger et al. computationally analyzed over 40 years of net and seasonal mass-balance measurements by the

United States Geological Survey of three glaciers in Washington and Alaska. They found that as a result of global warming, glaciers that had seasonally fluctuating positive and negative net balances prior to 1989 experienced exclusively negative net balances from 1989 to 2004. This is because higher temperatures cause more winter precipitation to fall as rain, resulting in winter precipitation being released as streamflow in the winter rather than later being released as snowmelt (Milner et al., 2008). So, not only are glaciers losing mass year-round rather than accumulating snow in the winter, but winter flows will increase and summer flows will decrease (Josberger et al., 2007). This poses a significant threat to communities in western Canada who are dependent on glacial meltwater as a primary freshwater supply in hot and dry summers (Milner et al., 2008). Thus, freshwater shortages in western Canada are predicted to occur in hot and dry summer months due to glacial shrinkage, and are projected to worsen throughout the 21st century as climate change progresses.

In addition, the continued retreat of glaciers may lead to an altered flow regime which can increase the concentration of organochlorine contaminants in glacial meltwater. Organochlorine contaminants are highly toxic pesticides that are often transported long distances through the atmosphere and are deposited in cold and remote locations such as glaciers (Lafrenière et al., 2006). A surplus of organochlorine contaminants in western Canada's glacial runoff will result in less availability of quality freshwater due to the significant implications this pesticide has on human health, ecosystems, agriculture, and the food chain (Jayaraj et al., 2016). To illustrate this, recall that after glaciers reach peak water, stream flow decreases. As a consequence, river basins may shift from an energy supply (meltwater) to a precipitation supply dominated hydrology which alters flow regime (Milner et al., 2008). To investigate this, a 2006 study conducted by Lafrenière et al. examined the concentrations of organochlorine contaminants in glacier fed streams in Bow Lake, Alberta, particularly in one year with less glacial shrinkage (1997) and another year with more glacial shrinkage (1998). Significantly higher concentrations of organochlorine contaminants were found in 1998 versus 1997. Thus, it was concluded that greater glacial mass loss may yield greater concentrations of organochlorine contaminants. Global warming results in glacial shrinkage, so evidently it is also responsible for higher concentrations of organochlorine contaminants (Lafrenière et al., 2006). Therefore, as a result of climate change, not only will communities in western Canada have less freshwater due to a decrease in glacial meltwater, but a greater portion of freshwater may be contaminated with toxic pesticides.

Although significant research indicates that glacial shrinkage reduces freshwater availability, some researchers suggest that groundwater storage through aquifers could act as an alternative water reservoir to glacial meltwater. Geodetic observations indicated an increase in groundwater storage and a decrease in glacier mass from 2002-2015, demonstrating the potential for large storage accumulations in aquifers (Castellazi et al., 2019).

However, a study conducted by Somers et al. suggests that this solution may not be sustainable in the long term (2019). Field measurements and computer modelling of the Shullcas Watershed in the Peruvian Andes showed that the loss of glacier meltwater was indeed buffered in the short term (~30 years) due to consistent groundwater flow to rivers. Nevertheless, they found that in the long term (>60 years), precipitation is expected to decrease and the rising temperature will cause an increase in both evaporation and water use by plants, which would significantly diminish groundwater reserves (Somers et al., 2019). Therefore, groundwater storage is a temporary fix to glacier shrinkage, and a more sustainable strategy such as addressing global warming should be implemented to protect the availability of freshwater in Canada.

In conclusion, climate-change driven deglaciation in western Canada will significantly reduce freshwater availability by the end of the 21st century, threatening human livelihoods, agriculture, industrial processes, and energy production. This is supported by the fact that glacial discharge decreases after peak water, the reduction in glacial mass heightens seasonal freshwater shortages, and increased glacial shrinkage results in higher concentrations of organochlorine contaminants in freshwater. To mitigate this, policy makers in Western Canada should prioritize water conservation and invest in alternative sources of freshwater. Additionally, in order to slow the rate of glacial shrinkage, it is suggested to integrate man-made dams to slow erosion, artificial icebergs to preserve mass, or wind power to increase thickness of ice.

References

Bonsal, B., Shrestha, R. R., Dibike, Y., Peters, D. L., Spence, C., Mudryk, L., & Yang, D. (2020). Western Canadian Freshwater Availability: Current and future vulnerabilities. *Environmental Reviews*, *28*(4), 528–545. https://doi.org/10.1139/er-2020-0040

Castellazzi, P., Burgess, D., Rivera, A., Huang, J., Longuevergne, L., & Demuth, M. N. (2019). Glacial melt and potential impacts on water resources in the Canadian Rocky Mountains. *Water Resources Research*, *55*(12), 10191–10217. https://doi.org/10.1029/2018wr024295

Chesnokova, A., Baraër, M., Laperrière‐Robillard, T., & Huh, K. (2020). Linking mountain glacier retreat and hydrological changes in southwestern Yukon. *Water Resources Research*, *56*(1). https://doi.org/10.1029/2019wr025706

Clarke, G. K., Jarosch, A. H., Anslow, F. S., Radić, V., & Menounos, B. (2015). Projected deglaciation of Western Canada in the twenty-first century. *Nature Geoscience*, *8*(5), 372–377. https://doi.org/10.1038/ngeo2407

Davies, B. (2024, October 28). *Glaciers as a water resource*. AntarcticGlaciers.org. https://www.antarcticglaciers.org/glaciers-and-climate/glaciers-and-water-resources/glaciers-as-a-water-resource/

Iberdrola. (2021, April 22). *Glaciares, Los Grandes Guardianes de la Estabilidad del Clima del Planeta*. https://www.iberdrola.com/sustainability/melting-glaciers-causes-effects-solutions

Jayaraj, R., Megha, P., & Sreedev, P. (2016). Review article. Organochlorine pesticides, their toxic effects on living organisms and their fate in the environment. *Interdisciplinary Toxicology*, *9*(3–4), 90–100. https://doi.org/10.1515/intox-2016-0012

Josberger, E. G., Bidlake, W. R., March, R. S., & Kennedy, B. W. (2007). Glacier mass-balance fluctuations in the Pacific Northwest and Alaska, USA. *Annals of Glaciology*, *46*, 291–296. https://doi.org/10.3189/172756407782871314

Lafrenière, M. J., Blais, J. M., Sharp, M. J., & Schindler, D. W. (2006). Organochlorine pesticide and polychlorinated biphenyl concentrations in snow, snowmelt, and runoff at Bow Lake, Alberta. *Environmental Science & Technology*, *40*(16), 4909–4915. https://doi.org/10.1021/es060237g

Milner, A. M., Brown, L. E., & Hannah, D. M. (2008). Hydroecological response of river systems to shrinking glaciers. *Hydrological Processes*, *23*(1), 62–77. https://doi.org/10.1002/hyp.7197

Moore, R. D., Fleming, S. W., Menounos, B., Wheate, R., Fountain, A., Stahl, K., Holm, K., & Jakob, M. (2008). Glacier change in western North America: Influences on hydrology, geomorphic hazards and water quality. *Hydrological Processes*, *23*(1), 42–61. https://doi.org/10.1002/hyp.7162

Somers, L. D., McKenzie, J. M., Mark, B. G., Lagos, P., Ng, G. C., Wickert, A. D., Yarleque, C., Baraër, M., & Silva, Y. (2019). Groundwater buffers decreasing glacier melt in an Andean watershed—but not forever. *Geophysical Research Letters*, *46*(22), 13016–13026. https://doi.org/10.1029/2019gl084730

Stadnyk, T., & Déry, S. (2021). Canadian continental-scale hydrology under a changing climate: A Review. *Water*, *13*(7), 906. https://doi.org/10.3390/w13070906

UNU Institute for Environment and Human Security. (n.d.). *5 alarming realities about mountain glaciers melting*. United Nations University. https://unu.edu/ehs/series/5-alarming-realities-about-mountain-glaciers-melting