Rainwater Harvesting for Outdoor Gardening: A Brief Literature Review

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Introduction

Due to the growing climate change crisis, weather and precipitation patterns continue to change. Rainwater harvesting is one of many potential actions encouraged by climate action groups. It provides a water supply for lawns & gardens, reduces stress on municipal wastewater systems, and helps control flooding. However, climate change does not affect all areas equally or in the same manner. The purpose of this research is twofold. First, we aim to determine if changing climate patterns would necessitate the addition of rainwater harvesting in Greater Sudbury, Ontario. And secondly, we will examine whether the decreased usage of municipal wastewater systems creates enough monetary savings to reimburse homeowners for the increased costs of implementing these systems. By analyzing these two aspects, this research aims to determine if homeowners in Greater Sudbury, Ontario, should invest in rainwater harvesting systems to ensure an independent & continuous water supply for outdoor gardening, given contemporary climate change modeling.

Examining Secondary Sources

I conducted a brief literature review to provide an overview & create familiarity with the research available. This review includes two secondary sources, published in 2016, that evaluate climate models for Greater Sudbury. An additional three sources examine the effects of rainwater harvesting systems, including a review of quantities harvested, effects on municipal wastewater systems, and requirements for vegetable gardens.

Source Overview

Climate Models

Raphael Abrahão determined there was insufficient prior research & modeling on the effects of climate change on precipitation. As a result, he chose to utilize cluster analysis, "group comparison and trend analysis, to expand knowledge about climate change on local and regional scales from historical precipitation data" (Abrahão, 2016, p. 78). Abrahão specifically utilized precipitation data gathered at Sudbury Airport over 55 years, with seasonal variation, to determine whether precipitation changed over time (Abrahão, 2016, pp. 78-79). Fundamental trend analysis revealed a 12% increase in annual rainfall over the measured period (Abrahão, 2016, p. 79), while snowfall remained statistically neutral. Additionally, there were changes in the "distribution of rainfall throughout the year" (Abrahão, 2016, p. 81), and significant changes in snowfall distribution, with December decreasing by 13%, while January snowfall increased by 38% and February snowfall increasing 113% (Abrahão, 2016, p. 84). Abrahão was able to conclude that utilizing cluster analysis could significantly aid in determining "seasonal and monthly climate changes" (Abrahão, 2016, p. 85).

The second paper on climate modeling "aims to develop high-resolution precipitation projections for the Province of Ontario" (Huang, Liu, & Wang, 2016, p. 3980). They utilized a combination of historical data from a variety of municipalities, combined with a variety of modeling data to simulate potential changes in “PRECIS, a regional climate modeling system developed at the UK Met Office Hadley Centre” (Huang, Liu, & Wang, 2016, pp. 3980-3981). Data was examined both on an annual & seasonal basis, with probability results for 2030, 2050, and 2080 graphed for each city/region studied. The researchers validated PRECIS modeling predictions using historically known periods (Huang, Liu, & Wang, 2016, pp. 3983-3984). Despite finding the accuracy of PRECIS modeling for the Spring precipitation to be “relatively poor” (Huang, Liu, & Wang, 2016, p. 3894), the researchers were able to conclude that most of the cities included in the study projected increases in annual precipitation. Their modeling predicted an overall increase in precipitation “by 7.0% in 2030 s, 9.5% in 2050 s, and 12.5% in 2080 s)” (Huang, Liu, & Wang, 2016, p. 3999).

Rainwater Harvesting

Liu & Sample’s research was focused on water supply and runoff capture and performed a cost-benefit analysis of various simulations regarding rainwater harvesting systems. They utilized mathematical formulas & standard measures to determine the runoff water for different building types & population density, analyzed weather patterns on an hourly scale, and determined storage & overflow (Liu & Sample, 2018, pp. 176-178). Liu & Sample concluded that achieving “high water supply reliability” was completed at most sites; however, the effects of runoff capture were minimal. As a result, no simulations reached a break-even point (Liu & Sample, 2018).

Similarly, Stec researched the impact of rainwater harvesting systems on stormwater runoff and drainage networks. Stec utilized a similar methodology, finding an average size of residential property in Przemysl, Poland, and calculating the average size of rooftops to determine potential runoff into rain barrels (2018, p. 90). The researchers input the Storm Water Management Model data, which calculated the effects of typical rainfall on surfaces of different materials, such as rooftops, green areas, and other impervious & semi-impervious surfaces (Stec, 2018, p. 92). The study also concluded that the use of rain barrels had a negligible effect on pressure flows caused by storms but noted the advantage of reduced reliance on municipal tap water for non-potable purposes (Stec, 2018, p. 95).

Esterer-Vogel & Smith examined whether rainwater harvesting could supply sufficient water to irrigate gardens and if it would be affordable for homeowners in northern California (2009, pp. 1-2). The researchers chose "typical" garden vegetables and calculated the watering requirements for those vegetables at various points in their development cycle using "using guidelines from the Food and Agricultural Organization of the United Nations" (Esterer-Vogel & Smith, 2009, p. 2). With four different case study homes, they were able to calculate storage requirements at each site. The researchers obtained water supply data based on "the wettest and driest years on record" (Esterer-Vogel & Smith, 2009, p. 4), and calculated water demand for the vegetables to grow & mature. They concluded that, in general, capturing a sufficient water supply was possible at all four sites. However, the cost of installing a fully functional & potable rainwater system was more than $1,400 US, not including "installation of new gutters, downspouts, leaf screens and a first-flush diverter" (Esterer-Vogel & Smith, 2009, p. 21). They also noted that sufficient space for water storage was necessary, as storage amounts in California would need to be between 1,000 – 2,500 gallons (Esterer-Vogel & Smith, 2009, p. 31).

Comparing & Contrasting Climate Models

The two Climate Models have different goals. Abrahão sought to determine if we can use historical data to assess changes in precipitation patterns over time (Abrahão, 2016, p. 78). In contrast, the article by Huang, Liu, and Wang sought to model future precipitation patterns based upon historical data & climate modeling sets (Huang, Liu, & Wang, 2016, p. 3980). In essence, Abrahão's work increases the validity of the data sources used by Wang, Huang, & Liu, as his work demonstrates that you can utilize cluster, group, and trends analysis to show the effects of climate change on precipitation.

Interestingly, the probabilistic modeling predicts a short-term decrease in participation for the Sudbury region, with the 2030s & 2050s decreasing to 802 mm & 801 mm respectively, before ballooning by 12% to 919 mm in the 2080s (Huang, Liu, & Wang, 2016, p. 3988). Of the regions examined, only Sudbury & Owen Sound experienced this temporary decrease in precipitation. This temporary decrease runs counter to the trends found in Abrahão's work, which denoted a 12% increase in rainfall over the 55 years examined (Abrahão, 2016, p. 79).

I believe this discrepancy is partly due to the differing datasets utilized to conduct research. Abrahão used data gathered by Environment Canada at the Sudbury airport from January 1956 – December 2010 (Abrahão, 2016, p. 78). In contrast, Wang, Huang, & Liu used data from the National Land and Water Information Service (NLWIS), cross-referenced with Environment Canada weather station data. The NLWSI data was only available from 1961-2003, and they chose to utilize the period of 1961-1990 as their baseline data in PRECIS (Huang, Liu, & Wang, 2016, p. 3981). As a result, there is a seven-year gap between data used as part of the validation of PRECIS modeling and the measurements in Abrahão's trends analysis.

Additionally, the work of Huang, Wang, & Liu measures all precipitation in mm, while Abrahão measures rainfall in mm and snowfall separately in cm. The difference between precipitation and snowfall volume is significant. By measuring the number of centimetres of snowfall, Abrahão has not measured the precipitation for the winter, as snow can have different levels of water content. To correctly measure the precipitation in the winter, the snow must be caught in a rain gauge and then allowed to melt before measurement. Due to this discrepancy, the overall annual growth in precipitation is indeterminate, making it difficult to compare to the predictions of Huang, Wang, & Liu. This discrepancy is curious as Abrahão utilized data from Environment Canada, which includes both Snowfall (cm) and Total Precipitation (mm) through the periods analyzed (Government of Canada, 1954 - 2013).

Despite this discrepancy, vegetables do not grow well in the winter months. As a result, we can disregard the snowfall patterns for Abrahão and subtract the winter-portion of Huang, Liu, & Wang's probabilistic models. However, once this is complete, we note the PRECIS modeling indicates precipitation growth will be more considerable in the winter months than the remainder of the year, with precipitation decreasing in the summer & autumn for the 2030s & 2050s (Huang, Liu, & Wang, 2016, pp. 3993-3994).

In effect, the two sources provide contradictory results. Abrahão denotes increased rainfall during the spring, summer & fall over a historical period until 2010, while Huang, Wang, & Liu's probabilistic model indicates a decrease through the 2030s & 2050s but only utilizes baseline data through 1990.

As data is now available from Environment Canada through December 2020, it may be beneficial to independently repeat Abrahão's analysis, with the appropriate measurements for winter precipitation, to determine how the trend has changed in the 10-years following his study.

Additionally, PRECIS released a new version in 2016, a year after Huang, Liu, & Wang's study. Although it would be valuable to input updated data into the software, PRECIS stopped taking new users in January 2020 (Met Office, 2020).

Comparing & Contrasting Research Papers on Rainwater Harvesting Systems

Regarding rainwater harvesting providing relief for municipal wastewater systems, Stec's research and Liu & Sample's research agreed there is a very minimal effect. The research is consistent, with Liu & Sample's work suggesting higher tariffs on water runoff could allow the costs of rainwater harvesting systems to break even (2018, p. 188).

All three research studies agreed that regardless of location, it was possible to gather a reliable water supply from rainwater harvesting, provided homeowners can safely maintain ample enough storage. Whereas Esterer-Vogel & Smith's research focused on capturing a sufficient water supply for a vegetable garden, the Liu & Sample study focused on other uses for rainwater harvesting, including toilets, laundry, etc. Both of those studies also examined different building types and layouts, albeit to varying degrees.

Much like Liu & Sample, the work of Esterer-Vogel & Smith examined the costs associated with installing a rainwater harvesting system. However, the costs were significantly lower due to lower outdoor gardening costs versus running a dual-piping plumbing system through buildings.

Conclusion

We utilized five secondary sources with the intent of determining:

- how climate change would affect precipitation in Greater Sudbury,
- whether rainwater harvesting systems could provide a reliable water supply for vegetable gardening
- And determine if rainwater harvesting could limit the use of water and wastewater systems enough to recoup their costs.

These three fundamental elements were then to be used to answer the question of whether homeowners in Sudbury *should* install rainwater harvesting systems.

From the sources included in this brief literary review, we can conclude:

- Precipitation in Greater Sudbury over the Spring, Summer, and Fall seasons has increased by 12% from 1956 – 2010.
- Precipitation in Greater Sudbury is likely to increase over time
- The distribution of rainfall in Greater Sudbury throughout the year will likely change.
- Rainwater harvesting systems have a negligible effect on runoff and municipal wastewater systems because of storage overflow & utilization limitations.
- If homeowners correctly calculate needs and match their storage requirements, they can obtain a reliable water supply from rainwater.

At best, this provides a partial answer to our research. Precipitation has increased and will continue to increase; however, given the apparent disagreement between the two climate modeling sources, the degree to which it is likely to increase is not known. Further climate simulations with updated data from Environment Canada are necessary.

Research has indicated there will be no decrease in the utilization of municipal wastewater systems; however, analysis is required on the effects of rainwater harvesting on the decreased utilization of tap water and its potential savings. To make this determination, we will need to examine the Water Rates for the City of Greater Sudbury, the growth rate for water and wastewater pricing, and we will need to determine the amount of tap water replaced by rainwater.

Finally, research indicates that if storage capacity matches gardening needs, there is no issue obtaining a reliable water supply from rainwater.

Additionally, and perhaps most importantly, Esterer-Vogel & Smith's research provides a reliable methodology for calculating water needs based upon the vegetables chosen and provides a way to adjust those needs to match a changing climate. Using the Blaney-Criddle Method for calculating the evapotranspiration factor (Esterer-Vogel & Smith, 2009, p. 7) makes it possible to adjust the monthly average temperature component of the equation to "simulate" climate change's effect on the amount of water needed.

This brief literary review has eliminated an avenue from the study, the effects on wastewater systems, and provided a direction for further exploration. By expanding Abrahão's historical precipitation survey for an additional ten years, additional insight into precipitation trends is generated, creating a more accurate trendline for expected rainfall over the coming years. Esterer-Vogel & Smith have provided the formulas necessary to calculate water needs based upon vegetable crops and a method by which we can adjust those needs to match changing climate temperatures. Combining these new steps with raw data from Environment Canada, water and wastewater rates from the City of Greater Sudbury, and using a series of projected temperature increases, it is possible to find a more definitive answer to whether or not homeowners in Greater Sudbury should invest in rainwater harvesting systems.

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