CCMN 432 (Sec 310) December 17, 2023

Preventing Floods With Green Roofs

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Toronto and Region Conservation Foundation

Preventing Floods With Green Roofs

EXECUTIVE SUMMARY

Flooding is a common hazard in Canada, often triggered by heavy or prolonged precipitation (Government of Canada [GC], 2021). Toronto experiences flood risks as its urbanization significantly alters natural drainage and increases surface runoff (GC, 2013; Toronto Region Conservation Authority [TRCA], 2023). As a result, this report will examine the possibility of implementing **green roofs (GR)s** while considering the following criteria:

- **Background**: Case studies in the following countries were researched:
  - **Finland:** Finnish cities have scored GRs at 1.3-1.8 through the green factor method mitigate floods and other benefits (City of Helsinki Environment Centre, 2016).
  - **United States:** Impervious surfaces can cost $3,600 more per year for additional area of impervious surfaces (NASEM, 2019)
  - **China:** Urban development in areas near rivers "from 1992-2015" has "increased by 542.21% in China", increasing the risk of floods (Jiang et al., 2023).

- **Similarities:** Similar findings are summarized below:
  - **Reduction Capability:** GRs reduced 10-84% of runoff from storms (Twohig et al., 2022; GSA, 2011; Yan et al., 2022).
  - **Intensive Roof Capability:** Intensive GRs can reduce/absorb "10-15%" or "66%" annual runoff compared to "10-15%" or "40-60%" for "intensive green roofs" (Twohig et al., 2022; Barnhart et al., 2021).
  - **Climate Adaptability:** GRs in the cold climate, similar to Toronto and some US regions, has 30-40% stormwater retention rate compared to 40-70% yearly average (Kuoppamäki, 2021).

- **Differences:** Differences in the case studies were considered:
  - **Climate Qualities:** Evapotranspiration and humidity rates of the region affect retention. Runoff retention rates vary from "28%-84%" in China (Yan et al., 2022).
  - **Rainfall Qualities:** Extreme rainfall conditions decreases runoff reduction rates (Liu & Chui, 2019).
  - **Roof Qualities:** Substrates to be used in GRs are different based on regional availability (Liu, 2019).

There are a number of factors that can decrease the efficiency of stormwater reduction in GRs. Thus, the TRCA offers the following recommendations:

- **Recommendation #1**: *Adjust for Torontonian climate.*
    - **Eliminate Humidity:** Use drainage systems such as shown in **Figure 1** and others to decrease humidity and maximise runoff reduction ('Humidity Control Measures', 2023).
    - **Eliminate Excess Rainfall:** Reduce excess water by adding large pore spaces (Sutton et al., 2014).
    - **Eliminate Winter Challenges:** Using plants that can "withstand extreme weather" such as sedum can improve the use of GRs (Sempergreen, 2021).

- **Recommendation #2:** *Opt for local soil and native plants.*
    - **Use native plants:** Use native plants to improve "structural complexity, and green roof performance" (Cook-Patton & Bauerle, 2012).
    - **Use native soil:** Avoid commercially available substrates without first considering the local environment to prevent TN leaching (Liu, 2019).
    - **Use many native plants:** Improving native plant diversity can improve the performance of green roofs (Kyrö, 2020).

- **Recommendation #3:** *Build more intensive roofs.*
    - **Increase depth:** Increase in depth of substrates can prevent "severe temperature fluctuations" (Getter & Rowe, 2009).
    - **Increase drainage:** Increasing drainage can more effectively drain water (Liu, n.d.).
    - **Decrease use of Geofoam:** Avoid using Geofoam to reduce weight loads as it can be hazardous to the environment (*Intensive green roof*. 2021).

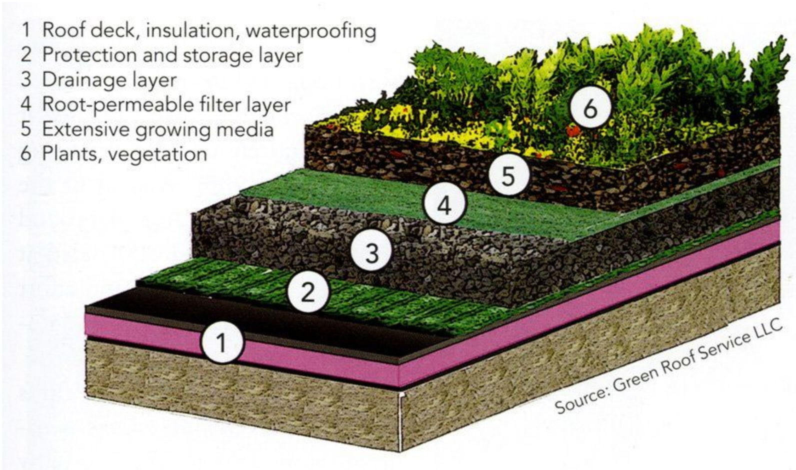

Figure 1: Layers in a GR (The University of Chicago Library, n.d.).

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1.0 Introduction

Flooding is a common hazard in Canada, often triggered by heavy or prolonged precipitation (GOC, 2021). Toronto, in particular, experiences flood risks due to its urbanization which alters natural drainage and increases surface runoff (GOC, 2013; TRCA, 2023). Forty-percent of rainfall can be converted to direct surface runoff (Li. et al., 2018). A notable problem for the city is basement flooding (Tudhope, 2020). Substantial floods in 2013 left 7,000 basements flooded, 90,000 households without power, and insured damage of $1 billion (Office of the Auditor General of Ontario, 2022). In general, flooding in Canada causes substantial and human impacts (Brown et al., 2021; Moudrak & Feltmate, 2019). **The concerns regarding floods in Toronto are shown below:**

- **Municipal Impact**: 2013 Floods in Toronto have resulted in ~$1bn in damages (Environment and Climate Change Canada, 2017). Additionally, they elevate the risk of pollution. In 6 cities in the US, 560,000 residents at are at risk of industrial pollution by of 6000+ industrial sites at risk of floods (Marlow et al., 2022).

- **Physiological Impact:** vehicle accidents during evacuation cause 60% of all flood-related fatalities in the US (Burton et al., 2016). Water contamination due to floods can also lead to health risks (Department of Ecology, n.d.).

- **Psychological Impact:** The 2017 Burlington floods caused "anxiety, depression, and PTSD," impacting 46% of residents as shown in **Figure 1** (Moudrak & Feltmate, 2018). Property damage and financial burdens are examples of stress causes (Glenn & Myre, 2022).

Thus, the purpose of this report is to mitigate the effects of flooding in Toronto by presenting solutions to make the city more resilient to floods.

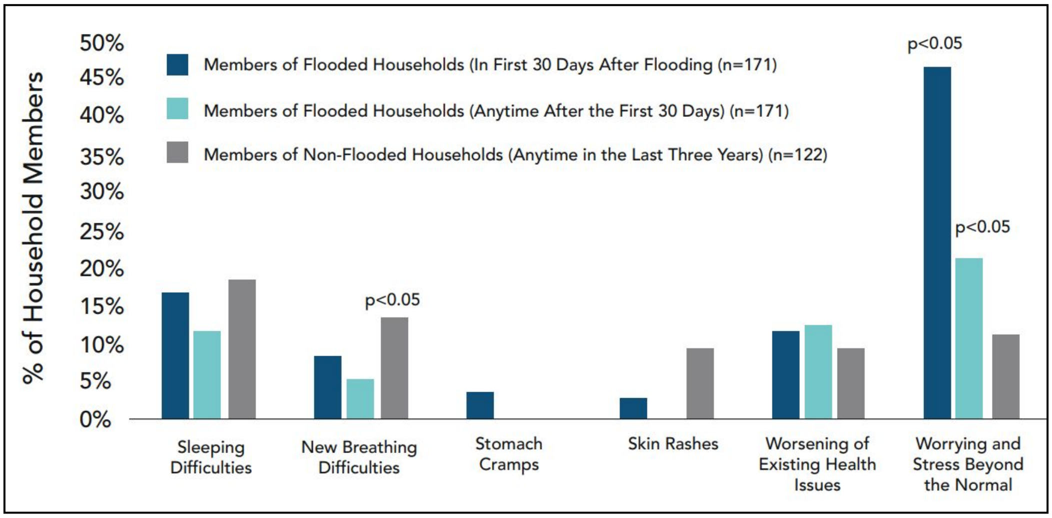

Figure 1: Health Impacts after the floods of 2017 (Moudrak & Feltmate, 2018).

2.0 Green Roofs

Surface runoff, or precipitation that flows overland, can't get absorbed in cities (Water Science School, 2019). However, GRs are structures that can capture and reduce runoff (U.S. Environmental Protection Agency [EPA], n.d.a). They have vegetation planted on root-repelling, drainage, and filtering systems as layers (City of Toronto, n.d). **Figure 2** demonstrates a sample rainfall management system using GRs. There are two general types of GRs: extensive roofs which require low maintenance and are lightweight from 60-150 kg/m², and intensive roofs which are complex, resemble gardens, and require more maintenance (EPA, n.d.b; Shahmohammad et al, 2022). GRs in Helsinki were over two times more expensive to install (50-60 €/m² or 75-90 CAD$/m²) than bitumen roofs (Nurmi et al., 2013). The average estimated value benefits for GRs in Helsinki for stormwater management was 1.9-3.4 €/m2 (2.84-5.08 CAD$/m2) (Nurmi et al., 2013).

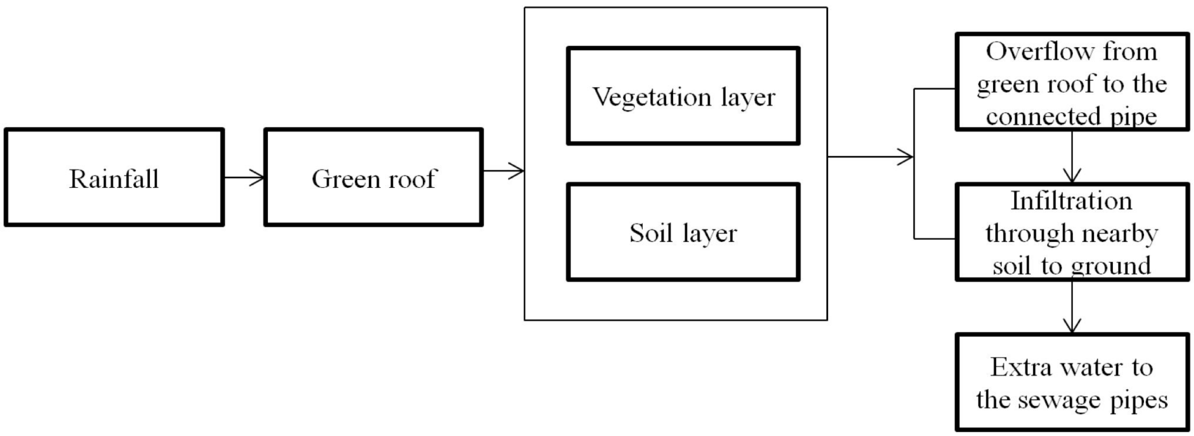

Figure 2: Schematic of a system of flow from rainfall to a green roof (Shafique et al., 2018a).

Thus, the Toronto And Region Conservation Authority has researched investigated the possibility of implementing GRs while considering the following **criteria**:

2.1: Background

2.2: Similarities

2.3: Differences

2.1 Criteria #1: Background

The implementation of GRs has grown in popularity internationally to reduce runoff to address urban floods (Shafique et al., 2018b; Suszanowicz & Więcek, 2019).

Table 1: Summary of Flood History for Finland, U.S., and China

Country	Continent	Flood History
Finland	Europe	Finnish cities in 1986 and 2005 experienced sea floods, influencing projects undertaken by the Finnish Environment Institute (SYKE) (Amani et al., 2023). GRs in Finland, with City of Helsinki green factor method scores averaging 1.3-1.8, are a seen as a possible solution (City of Helsinki Environment Centre, 2016).
United States	North America	In Texas, each extra square metre of "impervious surface" increased flood damage by "$3,600 per year" before 2008 (National Academies of Sciences, Engineering, and Medicine [NASEM], 2019). To address this, programs such as the "Pre-Disaster Mitigation (PDM)" allocate funding, with 12% allocated to measures such as GRs for flood control (Kousky & Golnaraghi, 2020).
China	Asia	Urban development in areas near rivers "from 1992-2015" has "increased by 542.21% in China", increasing the risk of floods (Jiang et al., 2023). Impervious surfaces caused by these developments prevent absorption of runoff and cause "inundated extents," as illustrated in **Figure 3.**

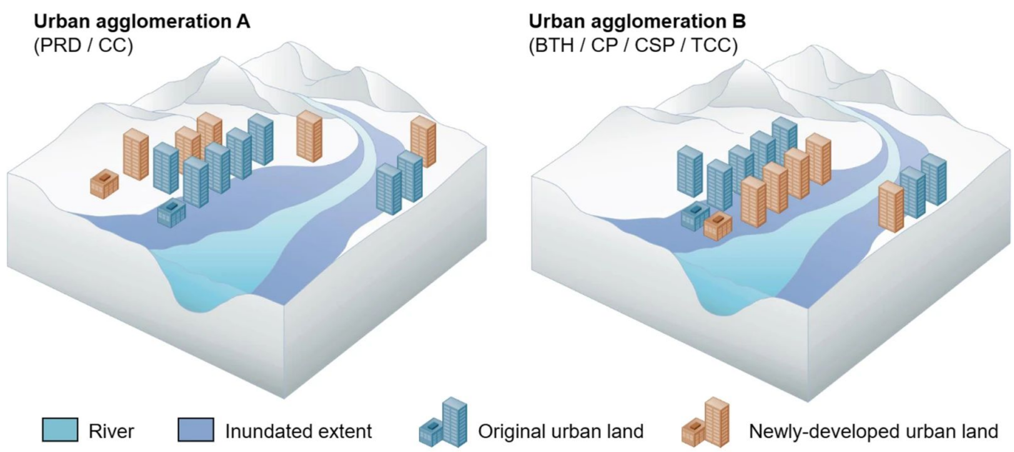

Figure 3: Urban development and its Influence on Floods (Jiang et al., 2023).

2.2 Criteria #2: Similarities

Though investigated in different countries, there are a few similarities in the studies reviewed in Finland, the United States, and China. The similarities are outlined below:

Table 2: The similarities in GR research in three countries.

Reduction Capability	Intensive Roof Ability	Climate Adaptability
GRs reduced 10-84% of runoff from storms (Twohig et al., 2022; GSA, 2011; Yan et al., 2022). They are also able to cool down buildings, with a "92.7 W/m² heat exchange" of a normal roof in the summer compared to a reduced 33.4 W/m² for GRs (EPA, 2018).	Intensive GRs can reduce/absorb "10-15%" or "66%" annual runoff compared to "10-15%" or "40-60%" for "intensive green roofs" (Twohig et al., 2022; Barnhart et al., 2021).	GRs in the cold climate still have retention ability In Helsinki, there is a "30-40% stormwater retention rate" in a cold environment compared to the "40-70% yearly average" (Kuoppamäki, 2021). **Figure 4** shows other cities that have the ability to reduce runoff, winter cities.

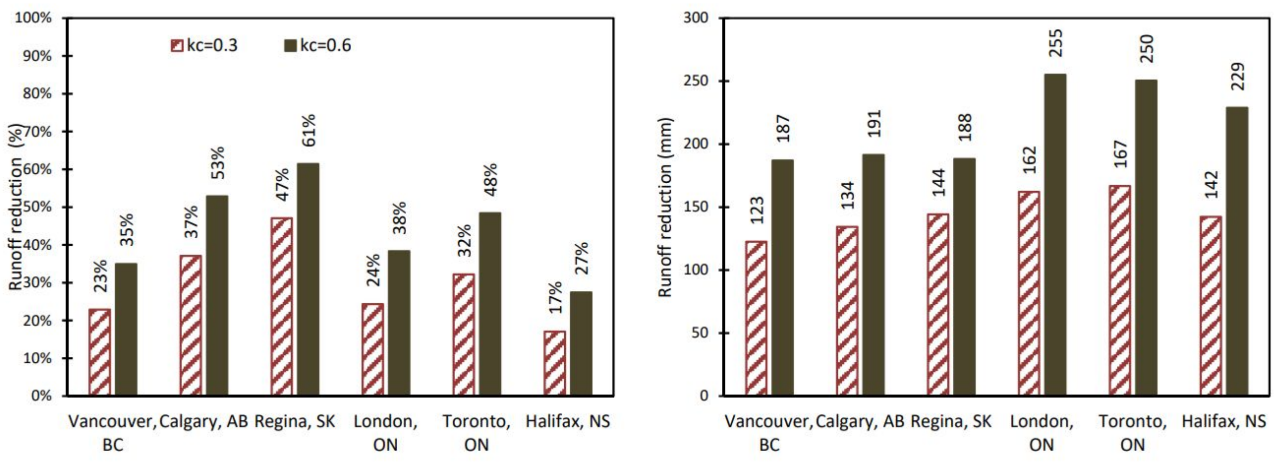

Figure 4: Runoff reduction (%) and (mm) for years 2000-2006 (Talebi, 2018).

GRs used across the world have the ability to reduce stormwater, as shown in **Figure 4**, and provide cooling, even in cold climates, with a preference for intensive roofs.

2.3 Criteria #3: Differences

There are a number of factors that may play into the performance of a GR. These factors are found as differences between the different countries, shown in the list below:

- **Climate Qualities**: The humidity of a region can affect water retention. Stormwater retention rate in "semi-arid" Calgary is higher (67%) compared to 34% in Halifax, which has a "humid" climate (Sims et al., 2023). In humid Guangzhou, China, runoff retention rate was 28% compared to 84% in dry Urumqi (Yan et al., 2022).

- **Rainfall Qualities**: In cities like Beltsville, less intense rainfall results in "higher and more stable runoff reduction percentages (45-55%)" compared to Hong Kong, where it can be as low as 10% (Liu & Chui, 2019). In Georgia, an increase in precipitation depth from below 2.54 cm to above 7.62 cm decreased "precipitation retention" (Carter & Rasmussen, 2006).

- **Roof Qualities**: Substrates to be used in GRs are different based on regional availability. Commercially available GRs caused TP and TN leaching in Chengdu, China, with 14-18 mg/L TN concentrations within runoff in contact of GRs (Liu, 2019).

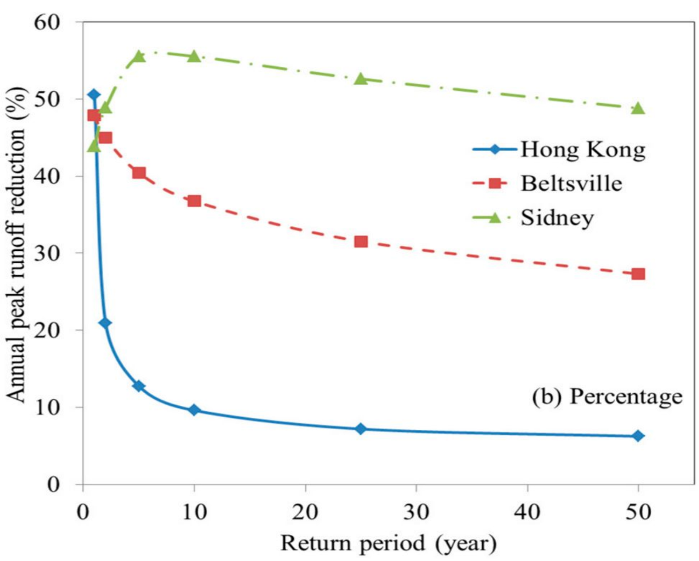

Figure 5: Annual Peak Runoff Reduction Comparison for Different Cities (Liu & Chui, 2019).

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From 1984-2010, "short duration rainfall extremes" have increased in "both intensity and frequency" (Yu et al,, 2020). This can have an impact on runoff retention (Liu & Chui, 2019).

Thus, the climate and environmental characteristics, as well as the local greenery and soil can affect the performance of GRs.

3.0 Conclusion

The global analysis in this report supports GRs as effective flood prevention in Toronto, as they can reduce runoff and function in cold climate. Current GR studies in Toronto indicate annual savings of $12,320,000 for managing urban heat islands or 33% of total annual savings, though no direct money is saved in retaining water, as shown in **Figure 6** (Banting et al., 2005). However, financial impacts such as $1 billion will be mitigated (Office of the Auditor General of Ontario, 2022)

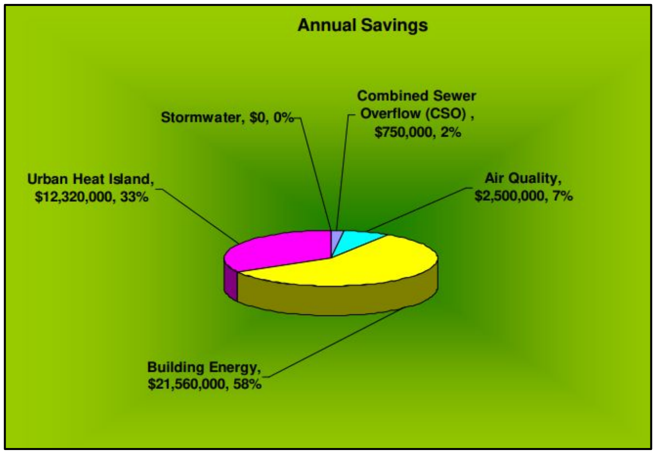

Figure 6: Annual Savings Using GRs in Toronto (Banting et al., 2005).

The background, similarities and differences are summarized in the table below:

Table 3: Summarized key similarities and differences between countries using GRs.

Criteria	Description
Background	Finnish cities have scored GRs at 1.3-1.8 through the green factor method mitigate floods and other benefits (City of Helsinki Environment Centre, 2016). In the US, impervious surfaces can cost $3,600 more per year for additional area of impervious surfaces, following a similar trend in China (NASEM, 2019; Jiang et al., 2023).
Similarities	GRs reduced 10-84% of runoff from storms (Twohig et al., 2022; GSA, 2011; Yan et al., 2022). Intensive GRs can reduce/absorb 10-60% compared 10-60% runoff yearly (Twohig et al., 2022; Barnhart et al., 2021). They can function in cold climates (Kuoppamäki, 2021).
Differences	Humidity rates can affect retention, varying from “28-84” in China (Yan et al., 2022). Additionally, extreme rainfall conditions decreases runoff reduction rates. Certain substrates used in green roofs can lead to nitrogen leaching (Liu, 2019).

4.0 Recommendations

Currently, GRs face challenges when it comes to climate, greenery used, and their degree of absorption. To address these issues, the following recommendations are proposed:

- **Recommendation #1**: *Adjust for Torontonian climate.*
    - **Eliminate Humidity:** Toronto has a "continental climate" (SENES Consultants Limited. 2011). Drainage systems and moisture sensors can decrease the humidity of this climate and maximise runoff reduction ('Humidity Control Measures', 2023).
    - **Eliminate Excess Rainfall:** Rainfall in Toronto is predicted to have an increase in extreme daily rainfall, as shown in **Figure 7.** To reduce excess water, large pore spaces should be used (Sutton et al., 2014).
    - **Eliminate Winter Challenges:** Though functional in winter, GRs have a smaller retention rate of "30-40%" (Kuoppamäki, 2021). Using plants that can "withstand extreme weather" such as sedum can improve the use of GRs (Sempergreen, 2021).

- **Recommendation #2:** *Opt for local soil and native plants.*
    - **Use native plants:** Use native plants to improve "structural complexity, and green roof performance" (Cook-Patton & Bauerle, 2012).
    - **Use native soil:** Avoid commercially available substrates without first considering the local environment to prevent TN leaching (Liu, 2019).
    - **Use many native plants:** Improving native plant diversity can improve the performance of green roofs (Kyrö, 2020).

- **Recommendation #3:** *Build more intensive roofs.*
    - **Increase depth:** Increase in depth of substrates (7.0-10 cm depths vs. 4.0 cm) can prevent "severe temperature fluctuations" (Getter & Rowe, 2009).
    - **Increase drainage:** Increasing drainage can more effectively drain water (Liu, n.d.).
    - **Decrease use of Geofoam:** Avoid using Geofoam to reduce weight loads as it can be hazardous to the environment (*Intensive green roof*. 2021).

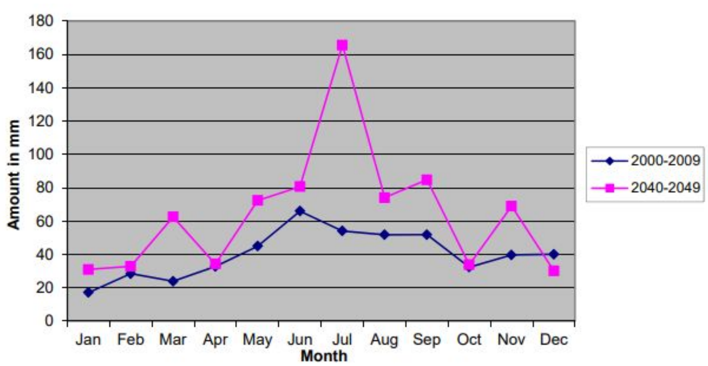

Figure 7: Extreme Daily Rainfall Projections (SENES Consultants Limited. 2011).

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5.0 Appendix: Figures

Figure 8 summarizes key characteristics of reviewed countries that have implemented GRs in their cities.

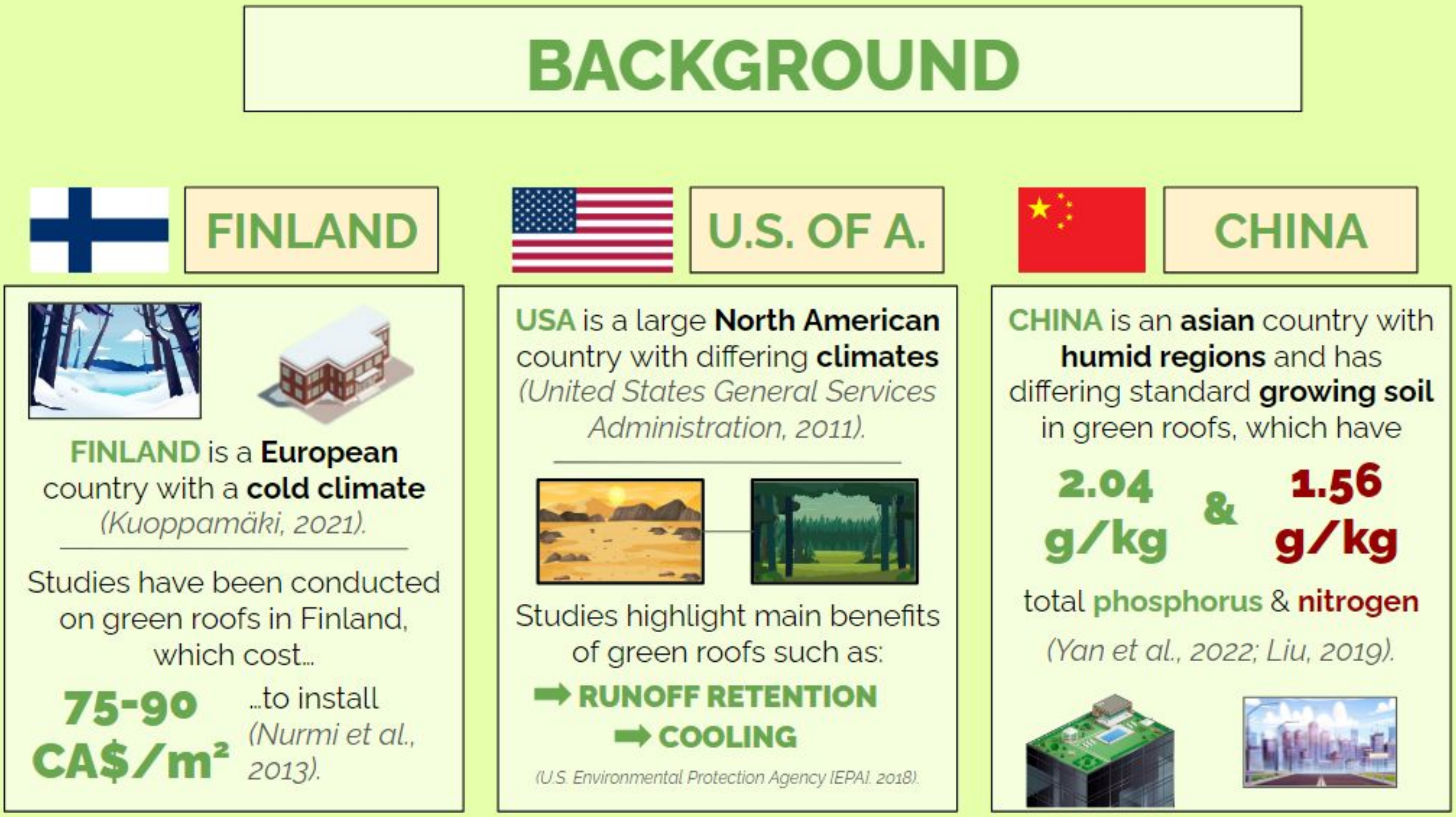

Figure 8: Background information on Finland, United States, and China on their developments with GRs.

5.0 Appendix: Figures

Figure 9 summarizes key similarities of reviewed countries that have implemented GRs in their cities.

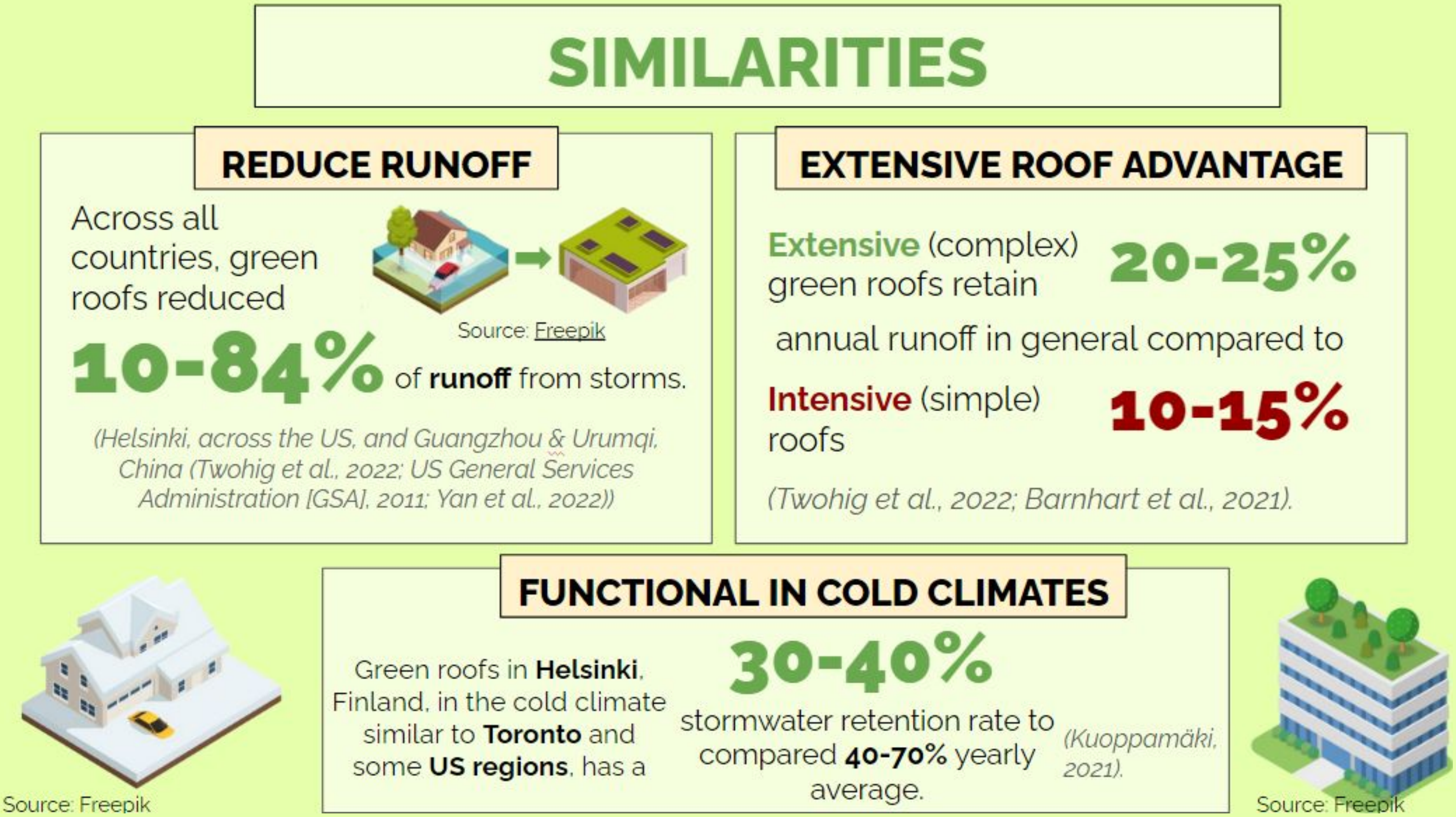

Figure 9: Similarities found between studies conducted in Finland, United States, and China.

5.0 Appendix: Figures

Figure 10 summarizes key differences of reviewed countries that have implemented GRs in their cities.

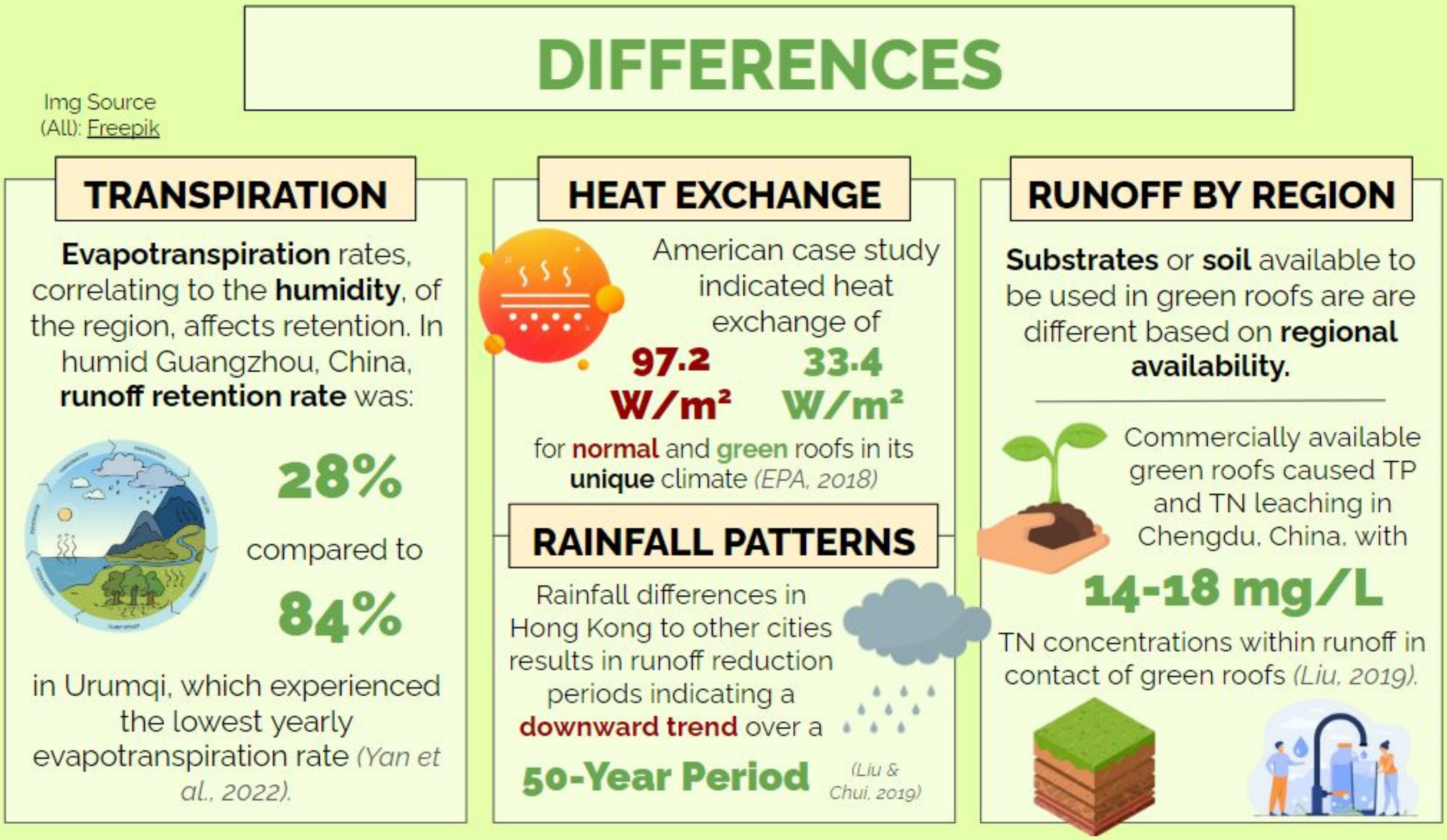

Figure 10: Differences found between studies conducted in Finland, United States, and China.

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