LWS 548 – MLWS Major Project Report
2022 The University of British Columbia

Submitted to:
MLWS Program

Rainwater Harvesting

Harvesting rainwater for non-potable purposes

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Date: 2022.07.14

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Rainwater Harvesting

Abstract

The issue of water scarcity has been discussed for a long time, and there are many possible solutions offered by scholars and scientists, one of which is rainwater harvesting. Collected rainwater could be a useful water resource for non-potable water needs, instead of treated water. It could be used directly on-site, and it could reduce the cost of supplying water since it doesn't need to be treated. Conventional rainwater harvesting is collecting rainwater by existing surfaces without knowing if those surfaces are enough for needed water. As a result, the collected rainwater could exceed or be deficient for the need. This paper developed a framework to determine the size of impervious surfaces needed for a certain water use allocation. It also helps to estimate the right budget for collecting a certain amount of water. The UBC Farm located at the University of British Columbia, Vancouver campus, served as the case study. Based on the irrigation need of UBC farm, a model was developed to calculate how large an impervious surface is required. The model has the potential to be adapted for other applications that do not require potable water. The benefits and disadvantages of rainwater harvesting were assessed and although there are disadvantages, the advantages of rainwater harvesting are greater than disadvantages. Thus, rainwater harvesting is a valuable tool which can used to alleviate water scarcity and reduce the cost of unnecessary centralized water treatment.

What is rainwater harvesting?

Rainwater harvesting is the collection, storage, and reuse of rainwater instead of letting it run off. Related innovations such as, snowmelt harvesting in Europe and seawater purification in Oceania, are both aimed at collection as supplements for freshwater. In this paper, the focus is on rainwater harvesting in British Columbia, Canada, a region that is not recognized as water deficient. Rainwater harvesting can be simply thought of a human method to mimic Nature's water cycle of collection and catchments to regulate the water cycle. The requirements for collecting rainwater, includes barrels, tanks, and impervious surfaces such as rooftops, as well as constructed, wetlands, soil basins, and vegetation cover. There is no single way or unique method for collection. No matter what method is used, the principle should be sustainable and environmentally friendly. Low maintenance and cost efficiency are also criteria that need to be considered.

Why should we collect rainwater?

Water scarcity is an issue for many regions, freshwater has been constantly consumed (Figure 1.1 and Figure 1.2.). As the Figures show, the annual freshwater withdrawals in 2017 and the water withdrawals per capita in 2010 illustrate how much we consume. The freshwater resource is very limited and vital for all life on this planet. How limited is it? As Figure 1.3 shows, even though 70% of earth is covered by water, the freshwater resource is scarce. Therefore, we should value this renewable water resource as much as we can and reduce freshwater usage. Rainwater harvesting could be a good approach to alleviate the water scarcity concern.

Figure 1.1. Annual freshwater withdrawals, 2017 (Ritchie, 2017)

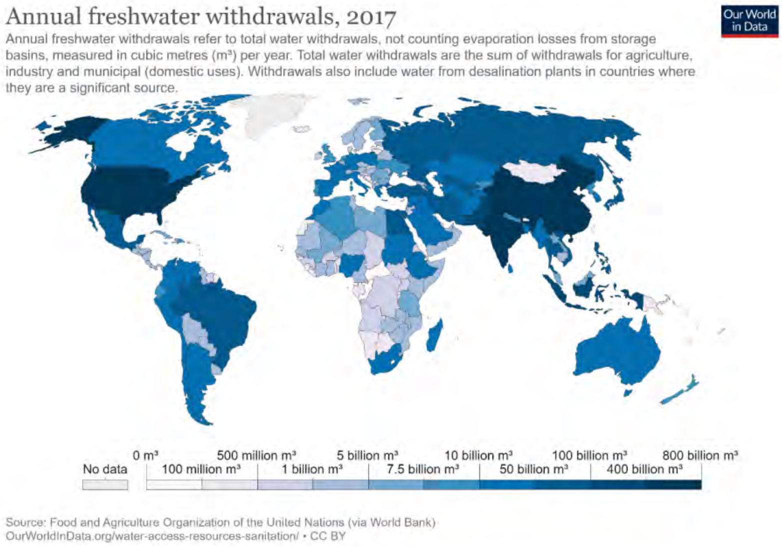


Figure 1.2. Water withdrawals per capita, 2010. (Ritchie, 2017)

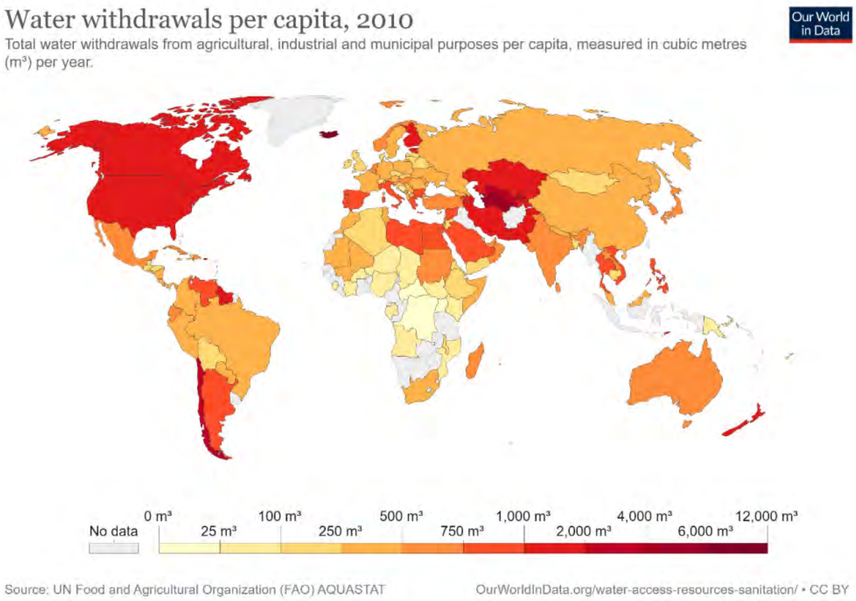
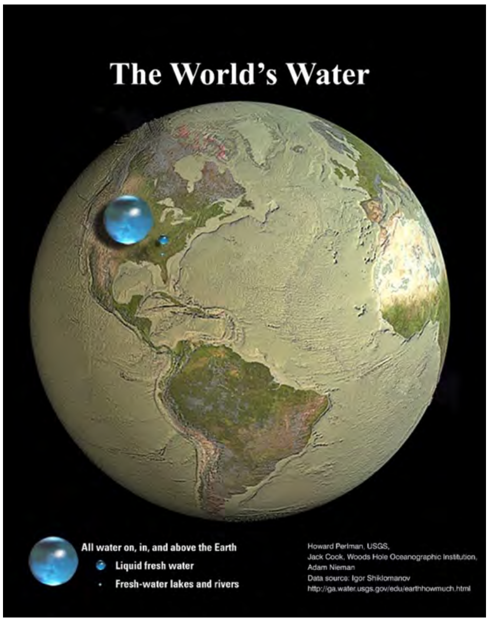


Figure 1.3. The world's water (Water Science School, 2019).



Precipitation is unpredictable, although the amount of precipitation isn't an issue, the variability is. During the last decades, precipitation has become more variable worldwide (Figure 2.1). Based on historical data (Figure 2.2), the anomalies and deviations for precipitation will become more extreme in the future. As a result, the average or total annual precipitation will not likely change, but the extreme events will bring hydrological unbalance, and this will bring disasters, such as drought and flood. Rainwater harvesting could help to mitigate extreme precipitation imbalances through collecting rainwater.

Figure 2.1. Precipitation Worldwide, 1901–2019 (Environmental Protection Agency, 2021)

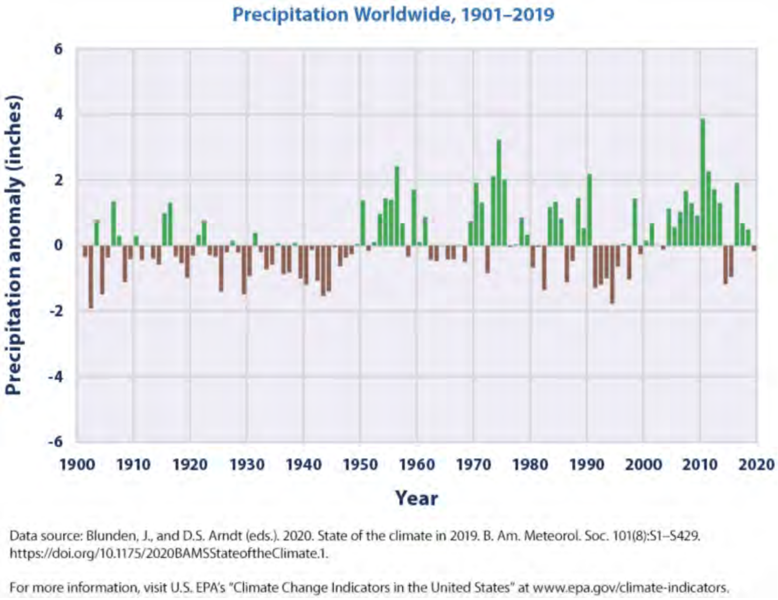
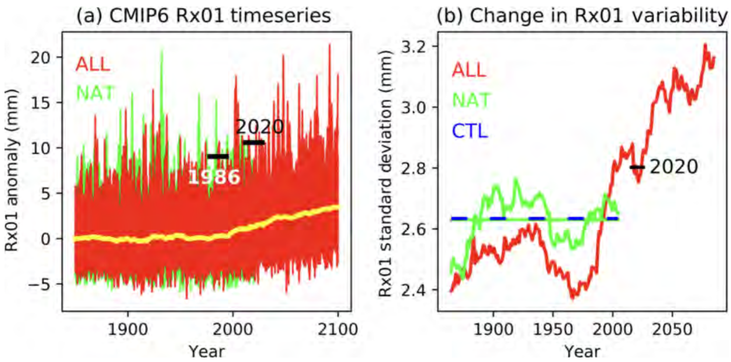


Figure 2.2. (a) Timeseries of Rx01 anomalies from the ALL and NAT simulations, (b) Human influence changes the mean state of Rx01 and its variability. ALL- simulations with all historical climatic forcings. NAT- simulations with natural forcings only. CTL- long control simulations of the preindustrial climate with no external forcings (Christidis, 2021).

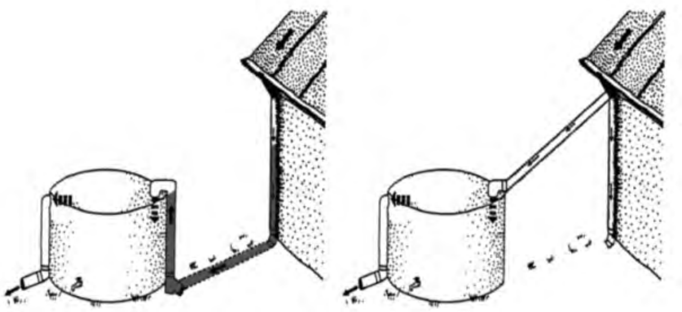


(a) Timeseries of UK mean Rx01 anomalies relative to 1850–1899 from model simulations with all external forcings (red) and natural forcings only (green). The yellow line represents the smoothed mean of the ALL simulations. Anomalies corresponding to years 2020 and 1986 are marked by the black horizontal lines. (b) Timeseries of the Rx01 *SD* constructed as the mean of individual simulation timeseries from the ALL (red) and NAT (green) experiments. The *SD* for the pre-industrial climate estimated from long CTL simulations is shown in blue. The present-day estimate is marked by the black horizontal line

How to collect rainwater?

There are many methods of rainwater harvesting, including using barrels, rooftop rainwater collectors, and rain gardens. The difference of conveyance are dry systems, and wet systems. For dry systems, there is no rainwater in the conveyance systems until it rains. For wet systems, water sits on the conveyance systems until replaced by new rainwater entering the systems. For example, the pipelines in Figure 3.1 are the conveyance systems that deliver the rainwater into the tank (Daily, 2017).

Figure 3.1 Example of wet (left) and dry (right) conveyance systems (Daily, 2017).



Additional rainwater harvesting methods are being developed, such as micro-catchment rainwater harvesting (Reddy, 2016), and soil storage and infiltration systems (Song, 2020). Micro-catchments were originally developed for agriculture purposes. However, since it doesn't require large land areas and it is very affordable with low maintenance, this method could be applied in urban regions, such as parks, gardens, surrounding residential areas, and sidewalks. The most common micro-catchments of rainwater include pits and basins, and cross-slope barriers (Song, 2020). Micro-Basins include negarims, meskats, and small semicircular bunds (Song, 2020). Cross-Slope Barriers include vegetative strips, contour bunds and ridges, tied ridges, stone lines and bunds, contour bench terraces (Song, 2020).

Figure 3.2 Planting pits for water harvesting and conservation (Song, 2020).

Figure 3.3 Effect of planting pits and conventional tillage on maize yields (Song, 2020).

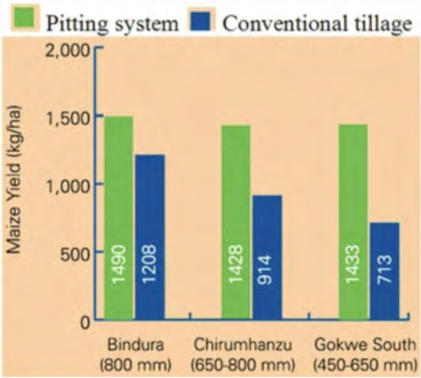


Figure 3.4 Negarims micro-catchments for tree crops (Song, 2020).

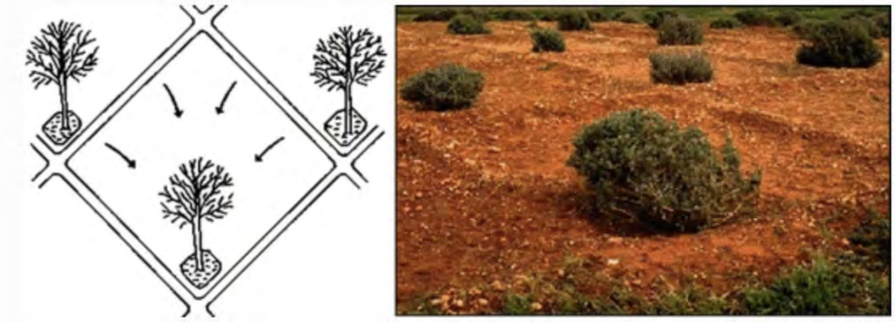


Figure 3.5 Meskat system of micro-catchment water harvesting (Song, 2020).

Figure 3.6 Semicircular bunds for micro-catchment water harvesting (Song, 2020).

Figure 4.1 Vegetative strips for micro-catchment water harvesting (Song, 2020).

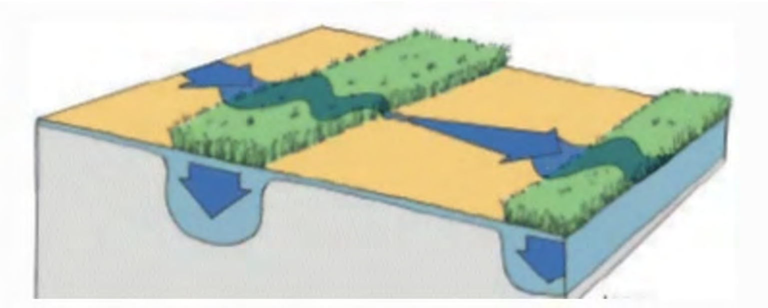


Figure 4.2 Contour bunds for micro-catchment water harvesting (Song, 2020).

Figure 4.3 Tied ridges for micro-catchment water harvesting (Song, 2020).

Figure 4.4 Stone bunds (Song, 2020).

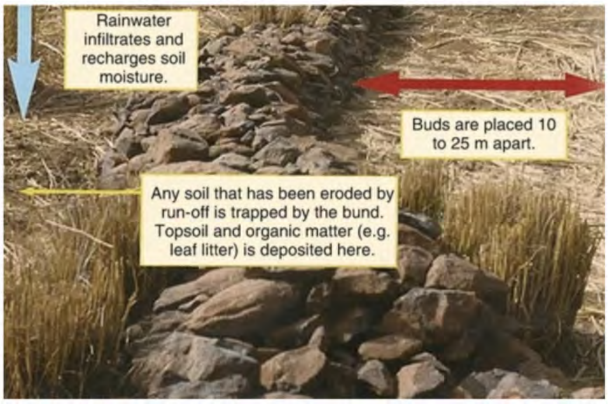
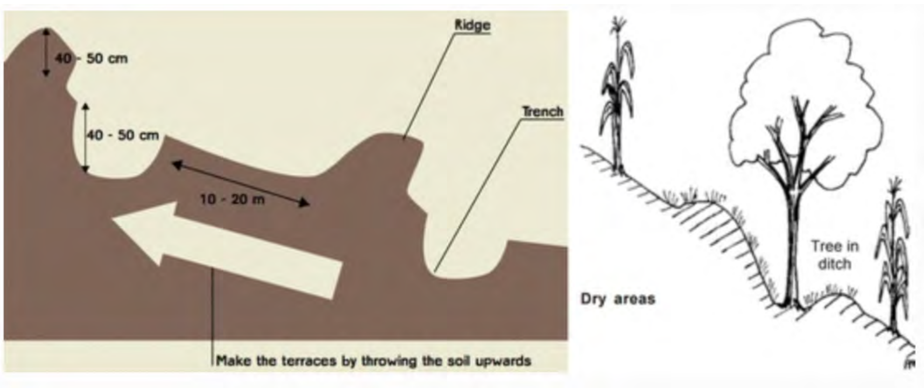


Figure 4.5 Contour bench terraces (Song, 2020).



Rainwater Harvesting Equation

Irrigation, flushing toilets, washing cars, industrial cooling, etc., are purposes that do not require the use of water from a municipal water supply, because these uses do not need treated water. The question becomes, is there an effective and simple way to solve this problem and obtain non-potable water for these uses? The answer is yes, we can collect rainwater, or melted snow, on site and use it directly. The long-term financial burden will be decreased not only for individuals, citizens, and governments. The government will not need to spend limited resources on building huge volume treatment plants, and most importantly, the relatively increasingly scarce surface water can be conserved.

To achieve the goal of using rainwater as a water resource for non-potable purposes, we need to know how much water is used for a certain purpose, does it vary by season, or constant over time? For example, the water used for flushing toilets or washing cars, is likely a relatively constant stable volume. However, for agricultural crop irrigation, the water need will fluctuate by the season. As there is probably no need for irrigation in winter, but during the dry season, at seeding time, or throughout the growing season, water will be crucial for the crop. This means the farm owners need to know how much water they need to prepare for the dry season until the next wet season. In this case, if the farm owners are going to use rainwater harvesting as the source of irrigation water, then the collected water required to meet the water need for irrigation until the next rain season needs to be collected and stored. For instance, in Vancouver (Figure 5.1), the rainy season is in the winter (November to January), and during the dry season when irrigation is needed, (Feb to Aug), the precipitation volume was very limited. Thus, establishing a rainwater irrigation system must be flexible and attempt to account for weather uncertainties.

Figure 5.1 Vancouver monthly precipitation from June 1, 2020, to July1, 2022 (Rainfall - monthly data for Vancouver).

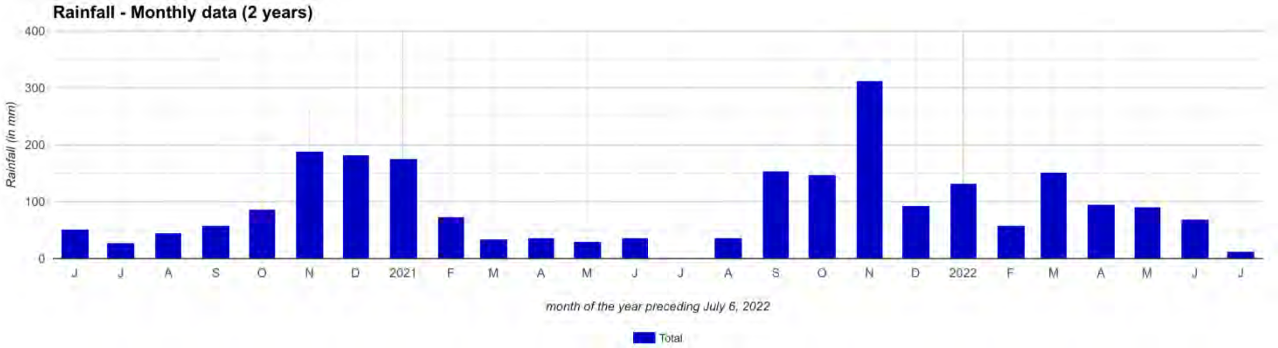


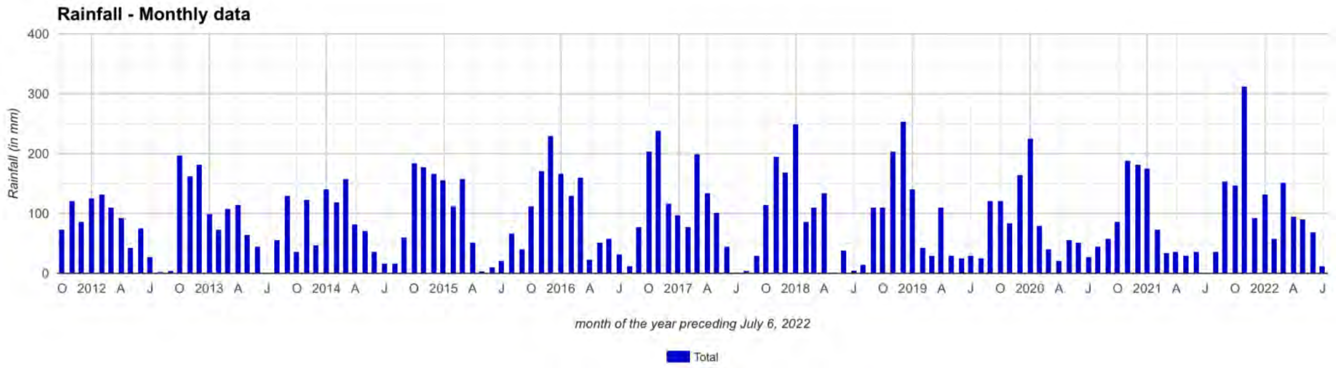
Figure 5.2 Precipitation Volume from June 1, 2020, to July 1, 2022 (Rainfall - monthly data for Vancouver).

Month starting on	Total
Jul 1 2022	12.3 mm
Jun 1 2022	69.7 mm
May 1 2022	92.1 mm
Apr 1 2022	94.6 mm
Mar 1 2022	153.0 mm
Feb 1 2022	59.7 mm
Jan 1 2022	131.7 mm
Dec 1 2021	93.5 mm
Nov 1 2021	312.4 mm
Oct 1 2021	148.4 mm
Sep 1 2021	155.0 mm
Aug 1 2021	36.7 mm
Jul 1 2021	0.0 mm
Jun 1 2021	37.2 mm
May 1 2021	30.2 mm
Apr 1 2021	38.0 mm
Mar 1 2021	34.0 mm
Feb 1 2021	75.0 mm
Jan 1 2021	175.7 mm
Dec 1 2020	182.2 mm
Nov 1 2020	189.3 mm
Oct 1 2020	87.5 mm
Sep 1 2020	59.2 mm
Aug 1 2020	46.5 mm
Jul 1 2020	27.2 mm
Jun 1 2020	53.2 mm

A review of the past 10 years monthly precipitation reveals the fluctuations in precipitation and the greater variability trend (Figure 5.3), notably in the spring and summer, which are also the seeding and growing seasons.

At the UBC Farm, crop irrigation uses municipal water. Relying on rainwater harvesting would require planning for the worst precipitation scenarios when designing a rainwater collecting system to be prepared for extreme weather events and future water needs. In other words, to collect the rainwater volume needs in the rainy season to meet the total annual irrigation water need. However, if the rainwater collecting systems are designed for regions that have relatively reliable precipitation during seeding and growing seasons, then the amount of collected rainwater could decrease, it only needs to meet the water deficiency that between water needs and the precipitation amount. Therefore, for community gardens, or in space-limited circumstances, this could save space for water storage.

Figure 5.3 Vancouver monthly precipitation from October 1, 2012, to July1, 2022 (Rainfall - monthly data for Vancouver).



Now, the question becomes, which is the best option for rainwater collection in Vancouver? Except for the micro-catchments that have been mentioned previously, the other choices for collecting rainwater are impervious surfaces. For example, this could include roofs, driveways, sidewalks, streets, parking lots. But considering the presence of gasoline, metals, chemicals, and litter on the ground, the above ground catchments would be a better method since they minimize contamination and pollution.

Assume the following quantities:

- The needed amount of water for non-potable purpose during a period is **A** m^3.
  *It could be a daily need, weekly need, monthly need, or annual need. Normally **A** will be the largest amount of water need during a certain time throughout the whole year, also called the worst scenario. For example, if there is no rain from May to July, the needed water for May, June, and July is **A** in total. Thus, at least **A** m^3 need to be stored before May. For the rest time of the year because there is precipitation replenishment, it means the water stored in the storage of container for the worst scenario water need **A** will meet the water need for the rest of the year. Which is the actual precipitation we collect. One cubic meter equal to 1000 liters.*
- The precipitation is **P**, normally in millimeters.
- The catchment surface area is **S** m^2.
  Please note, the size would be floor space or projected area. The example will show how it looks.
- Collection efficiency is **E**, is a percentage.
  *This shows how effective the collected rainwater can be used for a certain purpose. It depends on different circumstances. Such as the roof material, or other unpredictable variables. **E** makes sure the number we calculate is more reliable in a real-world scenario and is normally between 75% to 90%.*
- The last issue that needs to be noted is the nominal capacity and the operational capacity (Figure 7.2). This information can be found on the collection containers. The operational capacity is the actual amount of water that can be stored for use.

To simplify the above content, if **A** cubic meter water is needed before a certain point of time; there is **T** days/months/years to collect it. During **T**, the precipitation is **P**, the collection efficiency is **E**, how large the area **S** is required for catching rainwater?

Since **E** is collection efficiency**, A** cubic meters divided by **E** will be the potential precipitation that we will collect. The unit is cubic meters or 10^3 liters. The rainwater storage equipment operational capacity needs to be equal or larger than this number. **P** can be found from weather database. Since the unit for **P** is millimeter. The result is **S** square meters:

$$\mathbf{S} = \frac{\boldsymbol{A}}{\boldsymbol{E}}\mathbf{10^3} \div \mathbf{P}$$

The ways to store rainwater varies case by case. Rainwater can be stored above ground, or below ground. For the above ground storage facilities, the rainwater can flow out by gravity with no need for a pump. Because it is above ground, maintenance is easier than with underground facilities. However, some people prefer not to see a tank or cistern. Then, a good choice is to put the facilities underground. However, this might cost more since pumps would be required and it is more costly to implement and maintain. In this case, a solar pump could be a good option to reduce the cost. Or in some circumstances, if the collected water is used for residential non-potable use, such as flushing toilets, washing cars, or watering home gardens, the facility can be placed on the roof, if the roof can hold the weight. The way of storing water depends on the needs of the system, therefore, no one way is better than another.

Case study

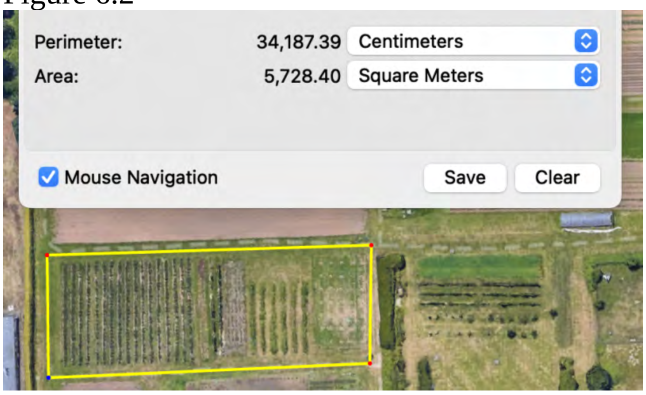
The UBC farm was selected as a case study as a practical example. The farm is located at The University of British Columbia Vancouver campus in Vancouver, British Columbia (Figure 6.1). The equation developed earlier will be used to calculate the required impervious surface for the UBC Farm irrigation water requirements.

Figure 6.1. UBC Farm map (UBC Farm).

The crops that are planted, soil type, root depth, infiltration rate, evaporation, and evapotranspiration determine how much water is needed for irrigation. Since there is no continuous data about how much water has been used for irrigation at the UBC Farm, the annual water use is estimated at roughly 9,000 cubic meters by UBC farm professionals, and the growing season lacks rain. The irrigation water need will be annual water need, which are 9,000 cubic meters. By collecting rainwater, UBC Farm can distributes the water as the crops need.

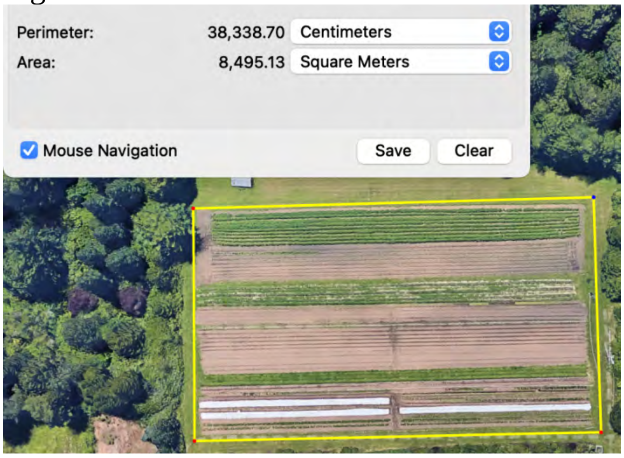
The listed fields illustrated below are the areas that need irrigation. To determine the size of those fields, Google Earth Pro software was used to draw the polygons. The irrigation area in total is 48,566.56 square meters. All the plots are listed respectively:

1. 2 Maya In Exile Garden and 3 Research Plot size: 5728.40 square meters.
Figure 6.2



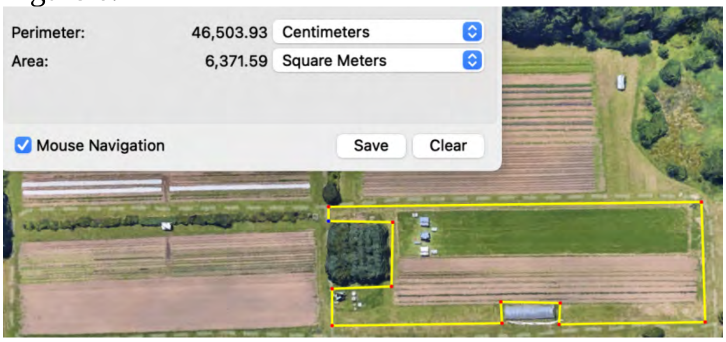
2. Research Plot size: 8495.13 square meters.

Figure 6.3



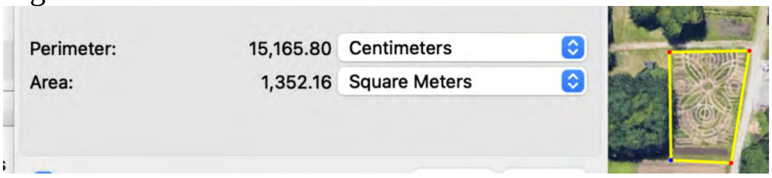
3. Research Plot size: 6371.59 square meters.

Figure 6.4



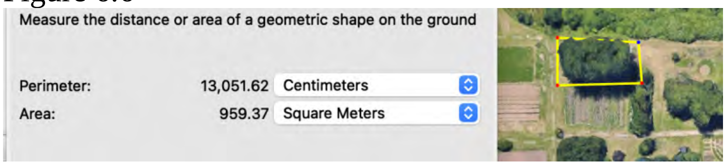
4. Indigenous Health Research & Education Garden size: 1352.16 square meters.

Figure 6.5



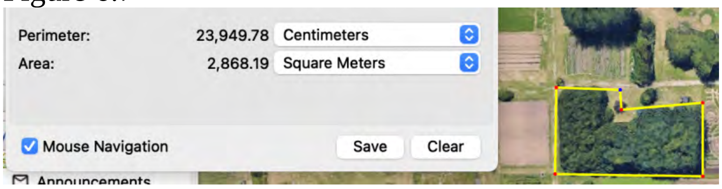
5.1. Poplar Grove size: 959.37 square meters.

Figure 6.6



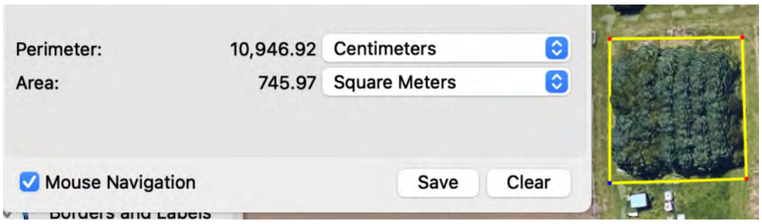
5.2. Poplar Grove size: 2868.19 square meters

Figure 6.7

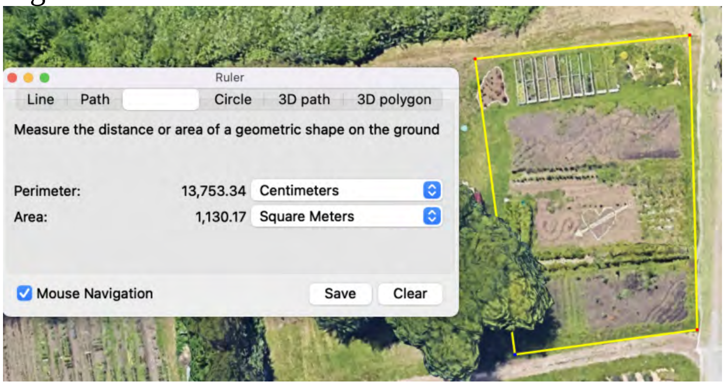


5.3. Poplar Grove size: 745.97 square meters.

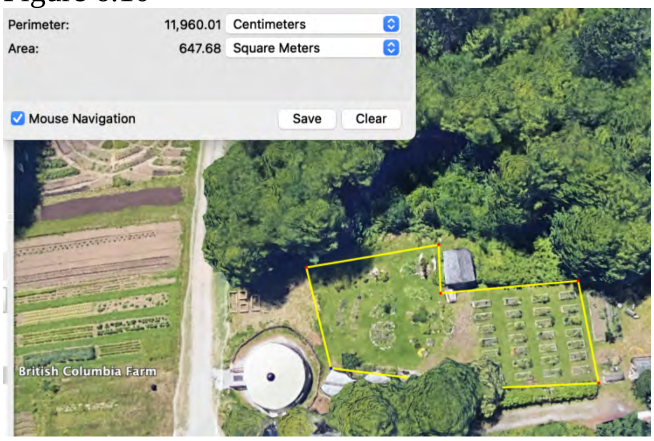
Figure 6.8



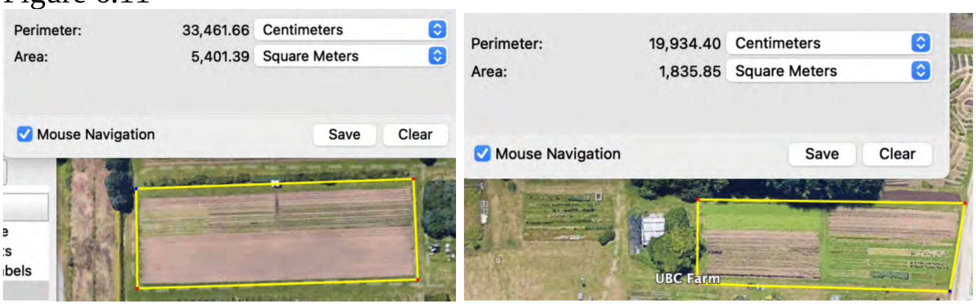
6. Tu'wusht Garden size: 1130.17 square meters.
Figure 6.9

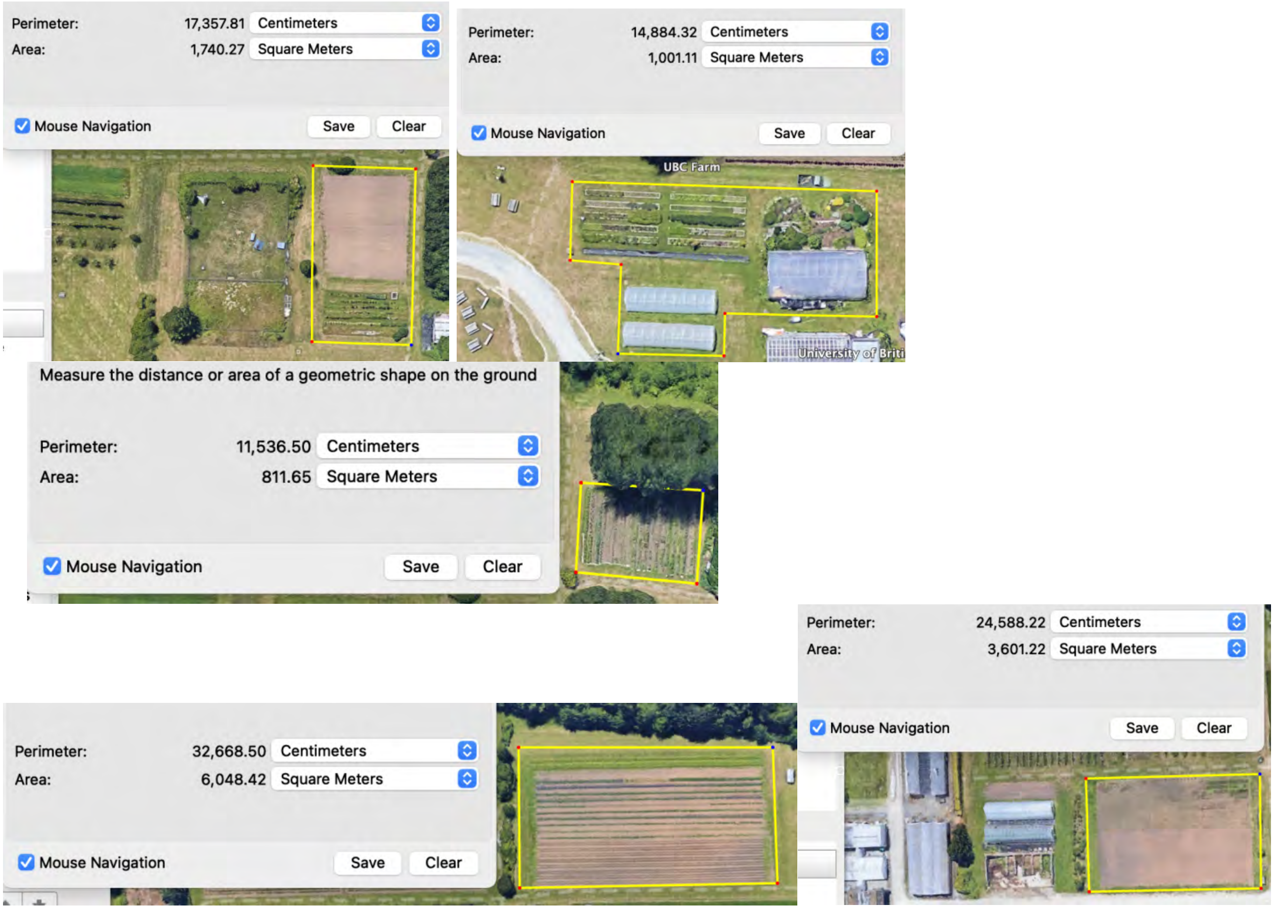


7. Children's Learning Garden size: 475.67 square meters.
Figure 6.10



8. Other plots size that might need irrigation in total: 20439.91 square meters.
Figure 6.11





UBC Farm has two major characteristics: shaded areas are very few and are not ideal for storing water in the soil, especially in dry season, cropped fields without any buffer zone could increase runoff. Therefore, creating rainwater collection catchments and increasing water retention are practical goals. Micro-catchment and roof catchment were chosen for the case study to assess the feasibility to collect rainwater.

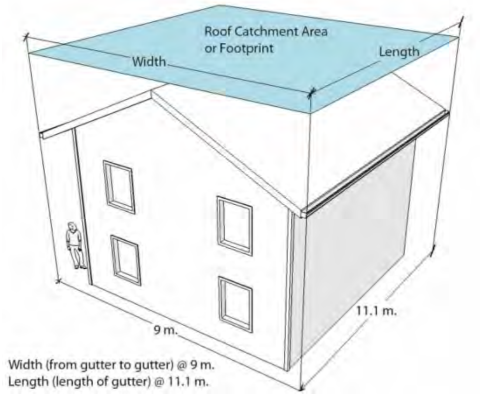
The most feasible and easiest way to achieve the goal of maintaining water retention is through plant pits. Although planting trees is a great option for offering shade to reduce evaporation, it also takes a lot of time for the trees to grow large enough to be effective. To minimize the amount of space needed at the current farm, soil pits would be a great option, which is one way to implement micro-catchments (Figure 3.2). For UBC Farm, a soil pit with small rocks surrounding the downhill position to form a dam would be a suitable option (Figure 13.1). The other option is to utilize roof catchments. Based on the current layout of UBC Farm, it would be a good choice to use transparent material roof catchments. This option would collect rainwater but would not interfere with the need for crop photosynthesis.

The rainwater collected by soil pits is not possible to calculate, but the required surface area for collecting the desired volume of water for the farm can be calculated. The method that was used for rainwater harvesting in the Reginal District of Nanaimo, which is the calculation of how much water can be collected by the known surface area (Regional District of Nanaimo, 2012).

The process is outlined as below:

Step 1: Potential Annual Rainwater Collection
1 m^2 of catchment area multiplied by 1mm of rain will produce 1 litre of water, therefore:
Potential water collection (in litres) = Roof Catchment Area (in m^2) multiplied by Annual Precipitation (in millimeters)

Figure 7.1 Roof catchment area (Regional District of Nanaimo, 2012).

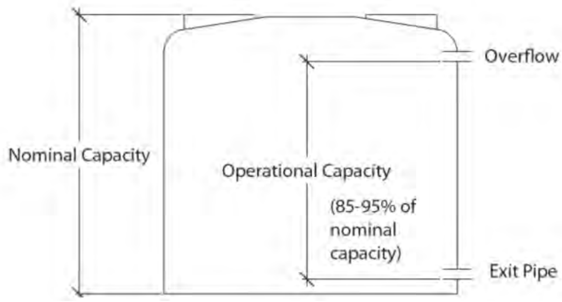


Step 2: Actual Annual Rainwater Collection
Actual Rainwater Collection = Potential Rainwater Collection multiplied by the Collection Efficiency.
For imperial gallons:
1 inch of rain on 1 sq. ft. of roof catchment area will potentially produce 0.52 imperial gallons of water.

Some organizations prefer to calculate the collection efficiency differently, depending on how efficiently the rainwater harvesting system collects rainwater. The typical range is between 75%-90% collection efficiency and is called the collection factor (Office of Energy Efficiency and Renewable Energy, 2022). Others choose to use a fixed number. Such as Farmwest, a non-profit organization that uses Effective Precipitation (EP), which is the amount of precipitation that is actually added and stored in the soil. The equation is: Effective Precipitation (mm) = (RAIN – 5) x 0.75 (Farmwest, 2021). RAIN is the precipitation data number.

When using containers to store the collected rainwater, tanks that have nominal and operational size capacities are readily available.

Figure 7.2 Nominal and operational capacity (Regional District of Nanaimo).



Collecting rainwater from a known surface without acknowledging of the water need would be inefficient and a waste of space and financial resources. Thus, to estimate the required water amount and to determine the size of the rainwater catchment that needs to be built are needed. It can be estimated by the following equation: $S = \frac{A}{E} 10^3 \div P$, to calculate the size of the catchment for rainwater collection. Use UBC Farm as an example:

Firstly, assuming the annual irrigation water need for UBC farm, is 9,000 cubic meters, which is A. The roof designed for UBC Farm is shown in Figure 7.3.3. It is from Figure 7.3.1, which is called black gap guzzler. The Black Gap Guzzler is a well-designed catchment that requires minimal maintenance. This system works in areas with a minimum of 8 inches of rainfall per year. It requires few construction materials and little maintenance after the system is built (Cathey, 2006):

Figure 7.3.1 Black gap guzzler structure (Cathey, 2006).

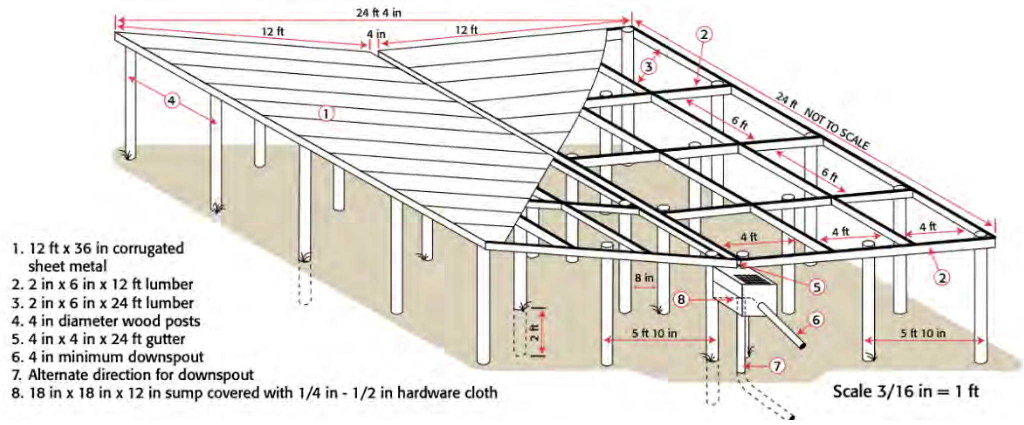
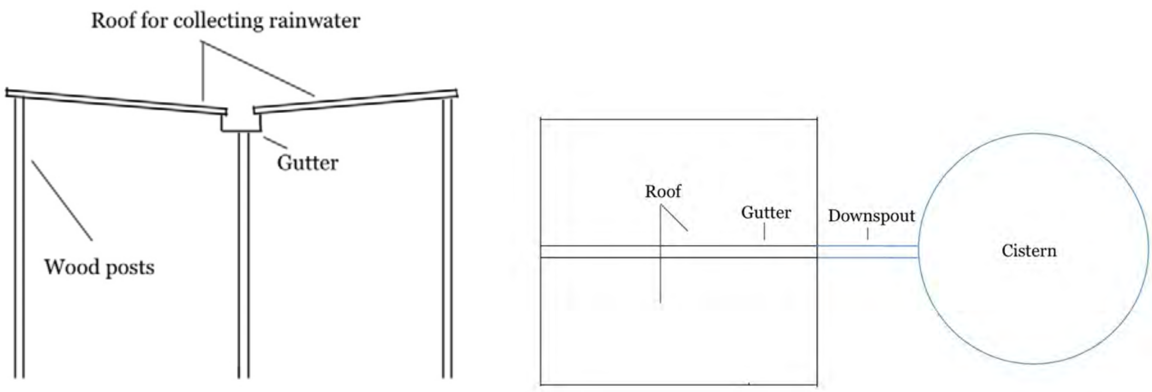


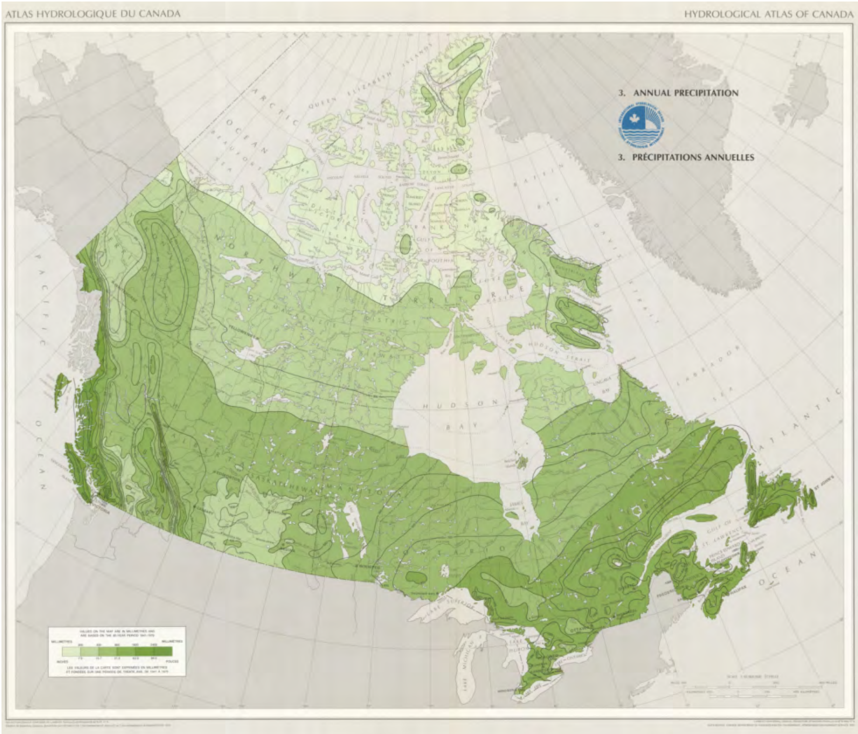
Figure 7.3.2 Black gap guzzler picture (Cathey, 2006).

Figure 7.3.3 Roof catchment structure for UBC farm (By author).



The second component needed is the required impervious area, S = $\frac{A}{E}10^3 \div P$, the value E-collection efficiency and P-precipitation. E has been chosen as 75% in this case. It can be any value from 75% to 95% as explained previously. To ensure the data is reliable, two precipitation datasets will be presented and compared: one is from hydrological atlas of Canada, and another is from precipitation data updated on live. The values are shown below:

Figure 8.1 Hydrological Atlas of Canada 1941-1970 (Annual precipitation).



The annual precipitation atlas for Vancouver precipitations between 1,000 to 1,600 millimeters.

Figure 8.2 Vancouver annual precipitation from 1941-1970 (Annual precipitation).

Figure 8.3 Annual precipitation data for Vancouver, BC (Total precipitation – annually data for Vancouver).

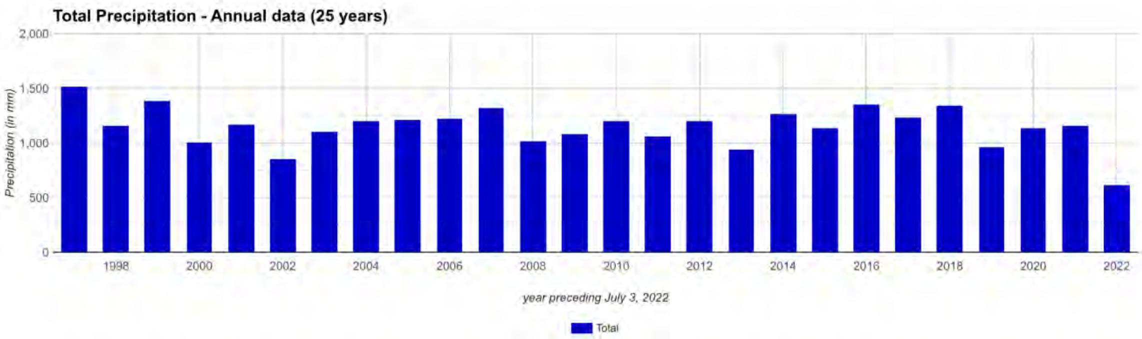


Figure 8.4 Annual precipitation data.

Year starting on	Total
Jan 1 2022	616.8 mm
Jan 1 2021	1,160.3 mm
Jan 1 2020	1,140.4 mm
Jan 1 2019	965.7 mm
Jan 1 2018	1,343.4 mm
Jan 1 2017	1,239.3 mm
Jan 1 2016	1,356.8 mm
Jan 1 2015	1,142.5 mm
Jan 1 2014	1,276.3 mm
Jan 1 2013	944.0 mm
Jan 1 2012	1,211.3 mm
Jan 1 2011	1,068.5 mm
Jan 1 2010	1,207.0 mm
Jan 1 2009	1,090.6 mm
Jan 1 2008	1,025.8 mm
Jan 1 2007	1,322.4 mm
Jan 1 2006	1,224.2 mm
Jan 1 2005	1,215.2 mm
Jan 1 2004	1,210.6 mm
Jan 1 2003	1,106.1 mm
Jan 1 2002	857.6 mm
Jan 1 2001	1,178.5 mm
Jan 1 2000	1,010.8 mm
Jan 1 1999	1,394.4 mm
Jan 1 1998	1,160.5 mm
Jan 1 1997	1,521.8 mm

The annual precipitation data are in the range from 1,000 to 1,600 millimeters in Vancouver. As the UBC does planting in the dry season and in the rainy season large amounts of crops are not being grown, there is an unbalance of rainwater distribution. With more and more extreme weather predicted, the available irrigation data for UBC farm is estimated as 9,000 cubic meters annually. It would be more precise and efficient if the monthly water consumption data for irrigation was available because the replenishment rainwater volume can be added on and save space in the rainwater collection container. The calculation for the precipitation needed for 2021 was 1,160.3 mm (Figure 8.4).

Thirdly, entering all the values into the equation the impervious surface S is required for collecting the corresponding amount of rainwater:

$$S = \frac{A}{E} 10^3 \div P = \frac{9{,}000}{75\%} 10^3 \div 1{,}160.3 = 10{,}342\ m^2$$

The required roof catchment area S is 10,342 square meters. Can UBC farm meet the requirement? For low maintenance, there is no need to use an underground rainwater container. It would be suitable to use on-site rainwater harvesting systems combine with the above ground container. It is centralized and close to the irrigation fields. Comparing building new rooftops with the existing roof tops, the previous option seems more reasonable. It saves money and time to build a new roof, but it would require a long pipeline to deliver the collected rainwater, and it needs to cross the current streets even from the nearest existing rooftops to reach the UBC Farm. Therefore, it is recommended that any pipeline systems be built above ground in case of leakage or broken parts cannot be detected in time, as it is more difficult to fix leakages and broken parts from underground systems.

After checking different materials, features, and properties, the results show that tempered glass or polycarbonate is the most suitable choice for UBC farm as the roof material. It is transparent, it doesn’t block solar energy and light for photosynthesis. Therefore, if those field are going to be used for planting in the future, the roofs would not have a negative impact. By measuring multiple fields' size through Google Earth Pro, 4 sites for building the rainwater collecting system were selected (see Figures 9.1 and 9.2). The exact size of the rooftops can be seen in Figure 9.3. The simulation distributions of the rainwater collecting rooftops are demonstrated in Figure 9.4.

Figure 9.1 Roof area sites on UBC Farm map (UBC Farm).

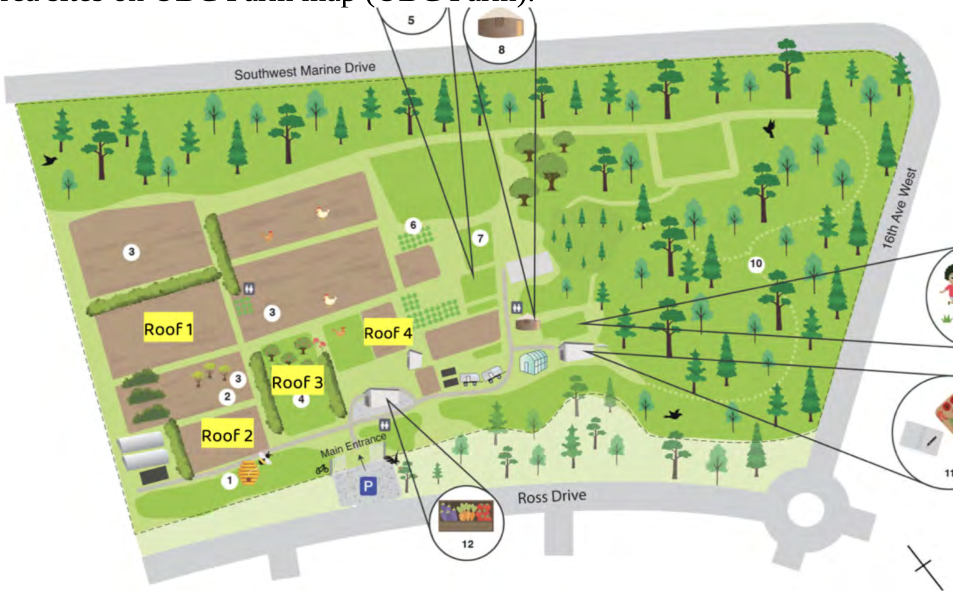


Figure 9.2 Roof area sites on Google Earth Pro.

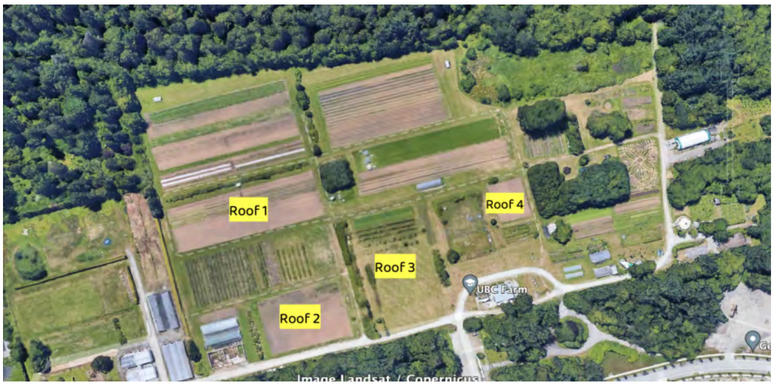
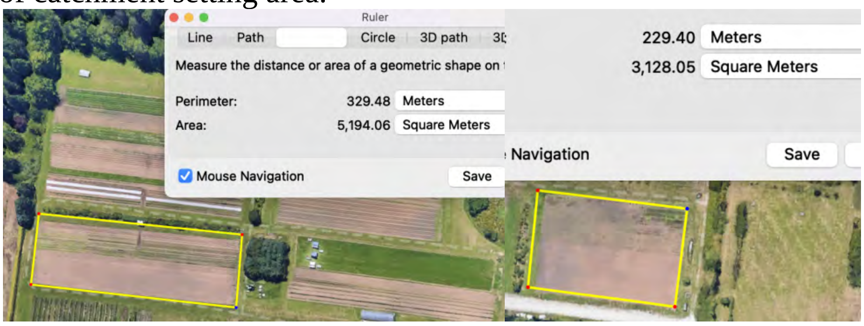


Figure 9.3 Size of roof catchment setting area.



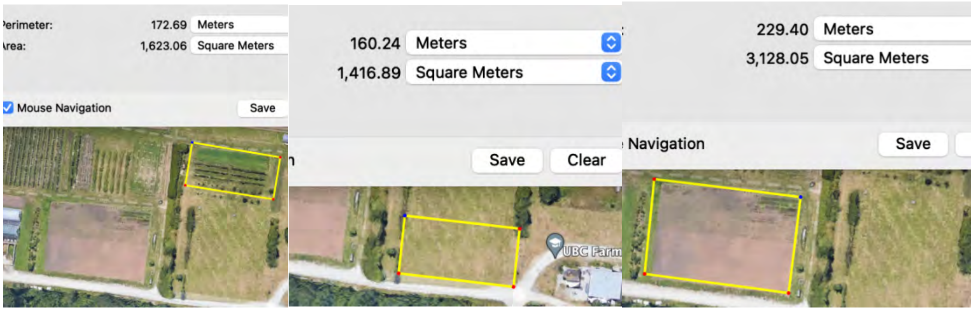


Figure 9.4 Roof catchment distributions simulation.

The size of roof and the length of post can adjust by need.

The total size of rooftop catchmentscalculated is 12,515 square meters. The UBC Farm has enough space to use the rooftops for achieving the required size of 10,342 m^2.

Besides irrigation, the equation can be used for calculating catchment areas of rainwater collection for other purposes. Since water resources are scarce and has no substitute, rainwater is the only water resource that can be used directly to supply water to plants without depleting surface water resources and requires almost no treatment. The same innovation can be adapted to harvest melted snow. If the rainwater can be used, then there is no reason not to consider it as an alternate non-potable water source and eliminate the cost of treated water sources.

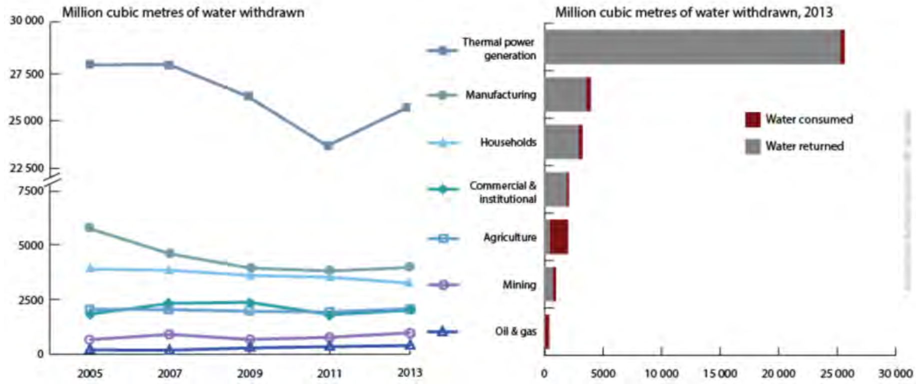
The interpretation of the results suggests rainwater harvesting can be applied nation-wide for household and industrial non-potable water use, as done in Singapore. It is not about how much water an activity is going to cost, but it is about how people could protect the freshwater water resources to meet the global goals of sustainability. Rainwater should not be seen as only weather, but a sort of treasure. There are many advantages of rainwater harvesting even there are several disadvantages that have not been identified.

Advantages of rainwater harvesting

1. Water conservation

In Canada, thermal power generation withdrawal for cooling and producing steam to drive turbines for electricity generation is the biggest water user, but most of the water is circulated back to nature. In contrast, agricultural water withdrawal without any water return, uses the biggest portion of the whole water resource usage (Environment and Climate Change Canada, 2017). However, for industrial cooling and agriculture irrigation, potable water or fresh water is not necessary. Rainwater was the agricultural water resource used from the very first-day people invented agriculture. By applying rainwater harvesting correctly, rainwater can be used as an agricultural water resource to reduce freshwater usage. Thus, rainwater harvesting could be an alternative way to meet irrigation and industrial water needs and preserve water resources.

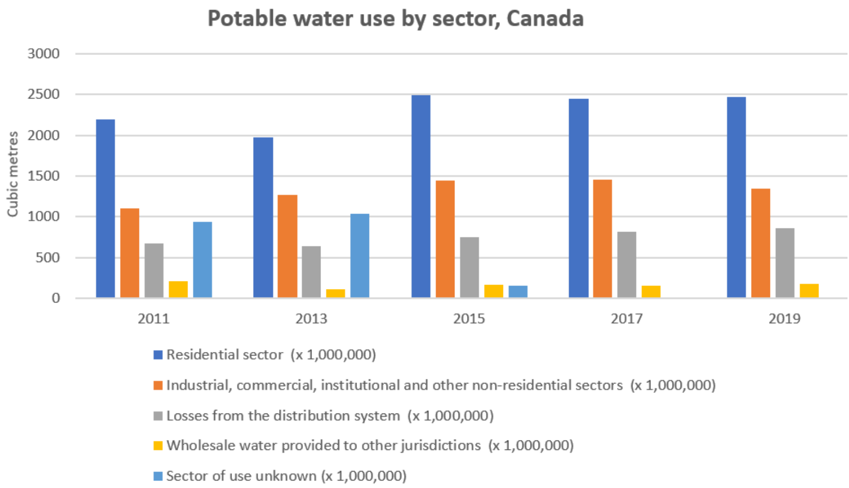
Figure 10.1 Water withdrawal by sector, Canada, 2005-2013 (Environment and Climate Change Canada, 2017).



Besides industrial and agriculture water needs, residential water use also is a large consumer of the total water consumption, used for such activities as showering, watering the garden or lawn, flushing toilets, and washing cars. It would be wise and rational to use rainwater as a water resource for non-potable purposes. Fresh water out from municipal water supply could be saved and using rainwater could reduce water loss during delivering through pipelines by using on-site rainwater collection systems. Therefore, from a water conservation perspective, rainwater harvesting could be a perfect alternative for many non-drinking purposes.

As Figure 10.2, illustrates there is a sector of use of unknown water use, it is caused by respondents not knowing how their water uses were utilized. This number dropped dramatically in 2015 because beginning with the 2015 collection, respondents were asked to report their best estimate of water use by sector (Government of Canada, 2021).

Figure 10.2 Potable water biennial use by sector, Canada (Government of Canada, 2021).



2. Prevent floods and droughts.

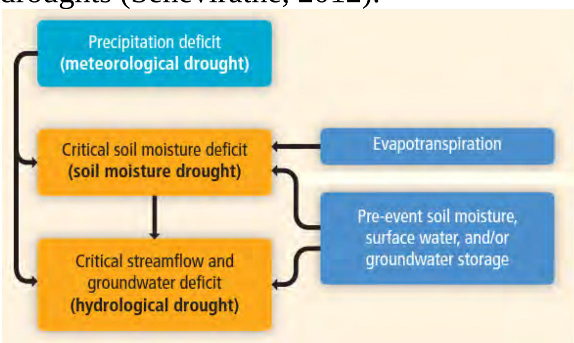
As is recognized, the cause of flooding, is excess precipitation (Water quality, 2013). A recent and local example was the Sumas Lake floods that happened in British Columbia in 2021. After a long heavy intensive rainy season, the farmland and highway roads in Sumas Prairie, B.C. were damaged severely, by the extended flood event (Picture 1 - CBC News, 2021). Exceedance of channel or stream flow and urban stormwater runoff are also significant causes but are dominated by excess precipitation. However, the precipitation impacts can be managed if the rainwater can be collected before it accumulates and turns into a flood.

Picture 1. Before-and-after satellite images show flood devastation in B.C.'s Sumas Prairie (CBC News, 2021).

Rainwater harvesting can reduce the amount of water that falls on land surfaces, which can mitigate urban runoff, and be used to recharge underground water. The stored rainwater is also useful for a coming dry season. Droughts are caused by long-term low precipitations (NASA, 2022). Hence, if the rainwater can be collected in the rainy season, it can mitigate the risk of flooding and be a replenishment water resource for the dry season. Extreme weather and unbalanced precipitation cannot be controlled thus people need to adapt to and prevent floods and droughts.

Furthermore, droughts are not simply caused by the lack of precipitation. It is an unbalanced water supply status (Seneviratne, 2012). Seneviratne (2012), defined droughts in different perspectives, using dryness instead of droughts in his book (Figure 10.3), sketches of different droughts.

Figure 10.3. Simplified sketch of processes and drivers relevant for meteorological, soil moisture (agricultural), and hydrological droughts (Seneviratne, 2012).



Rainwater harvesting and distribution can help to mitigate the unbalanced status by collecting excess precipitation, storing it, and releasing it when there is a water shortage. Figure 10.5 illustrates the differences between two sites; one with installed rainwater harvesting tanks and the second without installed rainwater harvesting tanks. The flood volume dropped. From the linear relationship between rainfall and flood volume, not only the flood volume is reduced, but also the number of flood events were reduced from 24 to 12 (Freni, 2019).

Figure 10.4 Annual flood volumes in absence and presence of the RWH tanks (Freni, 2019).

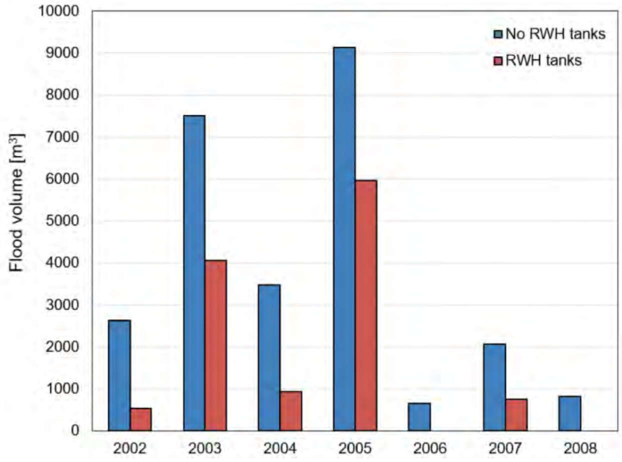
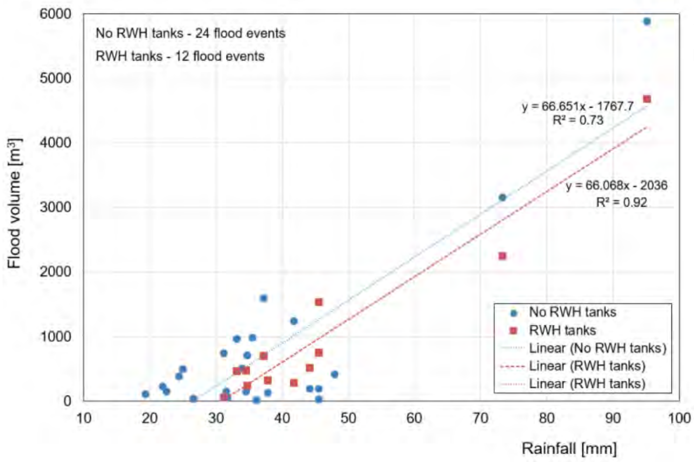


Figure 10.5 Comparison of the urban catchment response to rainfall in absence and presence of the RWH (Rainwater harvesting) tanks (Freni, 2019).



3. Reduce runoff and increase soil water retention.

Stormwater is rain or melting snow that flows over the ground, that flows into sewage systems and treated as wastewater. A study in the Middle East Region, compared 3 different sites and applied rainwater harvesting techniques. As a result, runoff could be reduced as high as 65%-85% and sedimentation by 58%-69%, and soil moisture was also increased (Al-Seekh, 2009).

In a natural catchment that is covered by vegetation, the vegetation canopy catches rainwater, and by evapotranspiration, the water goes back to the atmosphere. The rest of the water becomes stormwater, which can soak into the ground or flow overland into a nearby surface water body, including rivers or lakes or wetlands. If the rainwater is collected in a natural catchment before it evaporates or flushes into water bodies, the water can stay longer on the soil and penetrate deeper, increasing the water retention in the soil which will benefit future vegetation growth.

4. Mitigate soil erosion, prevent the excessive nitrogen, phosphorus, fertilizers, and manure from flushed from farmlands into water bodies.

Soil erosion is caused by three main factors: water, wind, and tillage (Ritter, 2012). Raindrop splash changes the soil infiltration capacity significantly. Once an intensive heavy rainstorm occurs in a short time, the topsoil, such as fine sand, silt, and clay can be easily removed. Even when the rainfall intensity is not heavy, but long-term a mild rainfall may still erode the soil but more slowly. When the dry season comes, there could be a sandstorm/dust storm, resulting in poor air quality that can negatively harm people's health (lung). The surface and unconfined water bodies may become contaminated by excess nutrients, fertilizers, and manure. Unconfined aquifers are extremely difficult to remediate if there is contamination/pollution. The manure from the farmland will be a severe hazard to unconfined aquifers, as pathogens may harm the health of humans and other species. Fertilizer runoff can create a series of water-related problems, such as oxygen depletion, algae blooms, and ammonia toxicity. (Berg, 2017).

Rainwater harvesting cannot solve those problems completely, but with proper rainwater harvesting management, it can reduce the amount of water that is flushing the land, causing soil erosion, and excess runoff of nitrogen, phosphorus, fertilizers, and manure into rivers and lakes to cause contamination and pollution. Thus, rainwater harvesting has significant impacts on agricultural soil erosion and contamination control.

5. Recharge groundwater

Urbanization cuts off the channels for groundwater replenishment by turning pervious surfaces into impervious. This coupled with huge water demand by constantly pumping water from underground and surface water bodies, has serious environmental and social concerns. Therefore, if freshwater resources from aquifers cannot get replenishment, the result is depletion. The precipitation is the water resource to recharge the groundwaters, to collect precipitation and recharge the groundwater levels artificially would be a feasible option to explore for this problem.

Tons of rainwater run into sewage systems, being collected, and treated as wastewater in cities. In B.C. Canada, one-quarter of residents are using groundwater as their drinking water (Ministry of Environment and Climate Change Strategy, 2022). All cadastral aquifers and licensed groundwater are shown in British Columbia (Figure 11.1, Figure 11.2). The highest density population Cities are centralized in Metro Vancouver, lower mainland, which also have a high density of aquifers and licensed groundwater distribution extractions, a situation which is more likely to keep growing in the future. With population growth, water need will increase, and urbanization will lead to the impervious surface area increase, with the result of groundwater levels declining (Figure 11.5). The consequences of groundwater depletion could be seawater intrusion, water quality issues, surface water depletion, and land subsidence (Tularam, 2017). Thus, finding a way to maintain the groundwater level becomes urgent and necessary. Since the groundwater is always recharged by precipitation, thus, collecting rainwater systemically and recharging the groundwater like nature does would be a very effective way to cope with the groundwater depletion issue and related consequences.

Figure 11.1 Cadastral Aquifers in BC (Ministry of Environment and Climate Change Strategy, 2022).

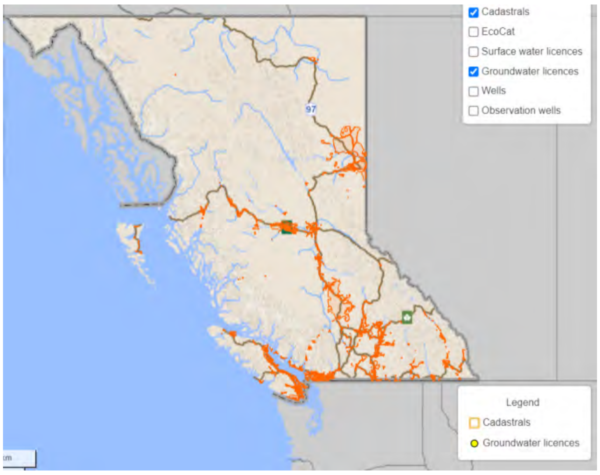


Figure 11.2 Cadastral Aquifers and licensed groundwater in Metro Vancouver, B.C. (Ministry of Environment and Climate Change Strategy, 2022).

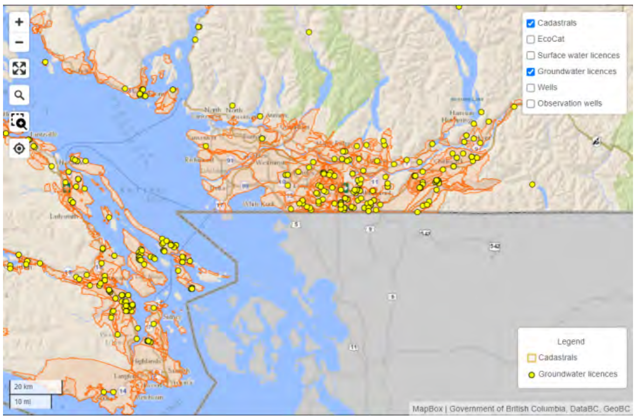


Figure 11.3 B.C. Population Size & Density by Regional District, 2017 (Environmental Reporting BC, 2016).

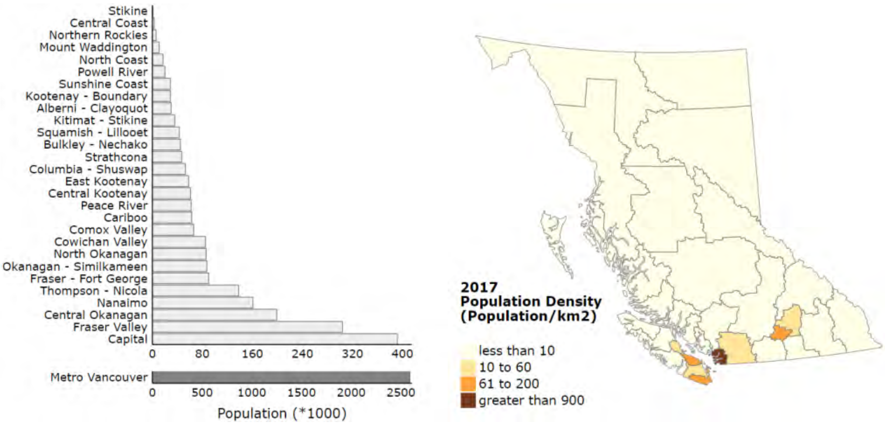


Figure 11.4 Long-term Change in British Columbia's Population Size, 1971-2021 (Ministry of Citizens' Services, 2022)

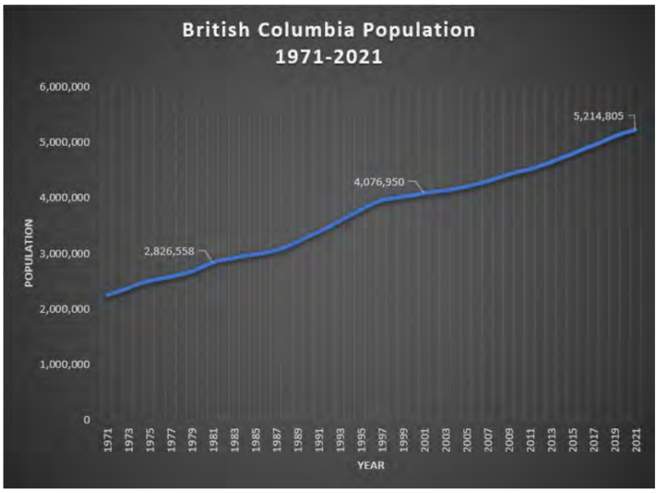
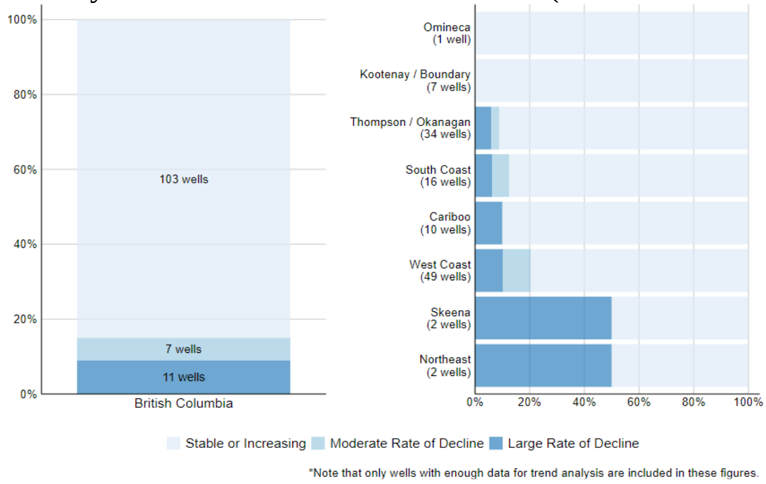


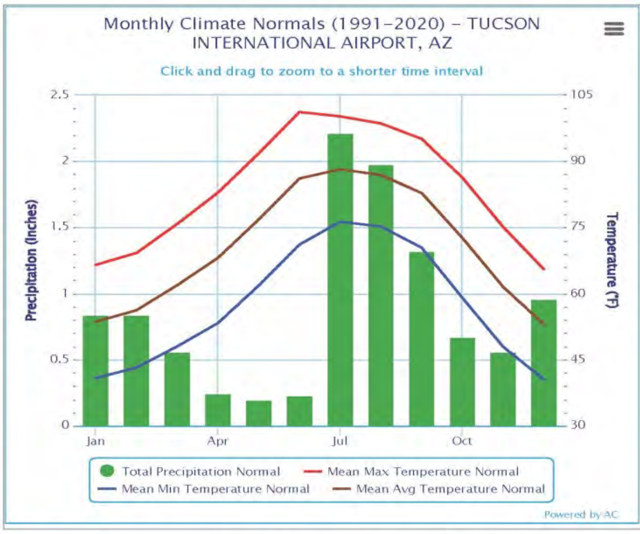
Figure 11.5 Provincial Summary of Trends in Groundwater Levels (Province of British Columbia, 2019)



6. Change landscapes

Rainwater harvesting contributes significantly to landscapes shaping. Especially in regions that do not have enough precipitation year-round. There is a case for this that worthy to be introduced to readers, which is Tucson city, Arizona, United States.

Figure 12.1 Monthly Climate Normals (1991-2020)-TUCSON INTERNATIONAL AIRPORT, AZ (NOAA, 2022)



Month	Total Precipitation Normal (inches)	Mean Max Temperature Normal (°F)	Mean Min Temperature Normal (°F)	Mean Avg Temperature Normal (°F)
January	0.84	66.5	40.8	53.6
February	0.84	69.2	43.2	56.2
March	0.56	75.8	48.0	61.9
April	0.24	82.9	53.3	68.1
May	0.20	91.8	61.8	76.8
June	0.23	101.2	71.1	86.1
July	2.21	100.2	76.3	88.2
August	1.98	98.6	75.2	86.9
September	1.32	95.1	70.4	82.8
October	0.67	86.3	59.0	72.6
November	0.56	75.1	47.9	61.5
December	0.96	65.5	40.5	53.0
Annual	10.61	84.0	57.3	70.6

The total average annual precipitation is 10.61 inches (269.49 mm) in Tucson (Figure 12.1), it be called as desert city for this. Let see how rainwater harvesting changes the landscapes (Lancaster, 2022).

Location 1: University Blvd and 9th Avenue looking west, Tucson
Photo: Brad Lancaster

Year: 2010

Year: 2012

Year: 2021

Location 2: Public right-of-way in front of 825 N. 9th Avenue, Tucson.
Photo: Brad Lancaster

Year: 2007

Year: 2021

Location 3: Public right-of-way in front of 828 N. 9th Avenue, Tucson.
Photo: Brad Lancaster

Year: 2010

Year: 2021

The landscape becomes more desirable, which is a great thing for the local people to live around. Furthermore, on a larger scale, when the landscape becomes a greener region with more vegetation cover, this not only benefit rainwater harvesting, but also creates better habitats for native species.

7. Ecosystem reservation and restoration

When the plants/trees/grasses/bushes survive due to enough water as the benefits that rainwater harvesting brings, however it usually requires more than one method. According to a handbook from Livelihoods Centre in 2020, there were multiple practical activities taken in some areas, such as soil pits or “Zai” (Figure 13.1) or semi-circular ponds. The technique is traditionally used in the dry areas of the Sahel to restore degraded drylands and increase soil fertility (Livelihoods Centre, 2020). Once there is a vegetation cover instead of exposed degraded soil, restoration becomes possible. For most animals to survive, they require food and water, which create a better environment for most animals.

Figure 13.1 Soil Pit with small rocks surrounding downhill to form a dam shape (Livelihoods Centre, 2020).

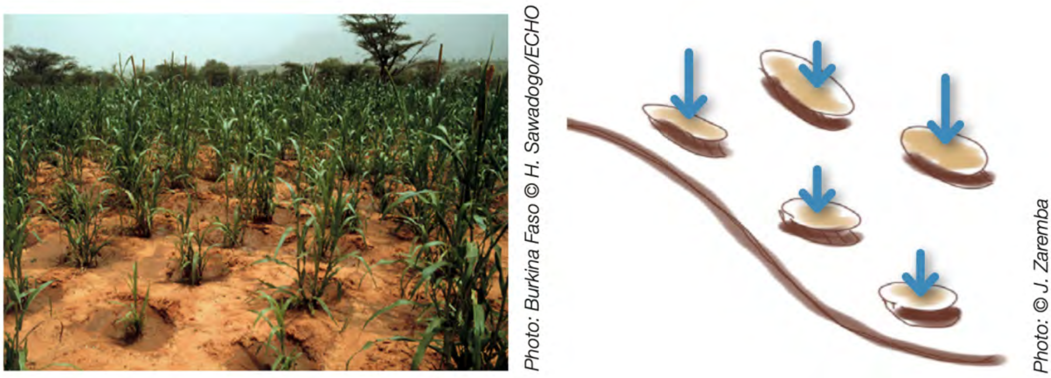


Figure 13.2 Semi-circular bunds or ’half-moons’ (Livelihoods Centre, 2020).

They created ponds and dams in “Water Harvesting and Conservation” to capture rainwater and control erosion, as illustrated in figures 13.3 and 13.4. Meanwhile, it could be water resources for irrigation and livestock (Livelihoods Centre, 2020).

Figure 13.3 A check dam (Livelihoods Centre, 2020).

Figure 13.4 A sand dam (Livelihoods Centre, 2020).

8. Affected by chemicals and pollutants.

When rainfall reaches the urban impervious surfaces, it could pick up grease, oil, chemicals, metal, plastics, and other pollutants, that could pollute rivers, lakes, and other water bodies. If the rainwater can be collected onsite before it hits the ground, water pollution can be prevented. That means water can be directly used for non-drinking purposes, such as watering plants/lawn, flushing toilets, and irrigation which is the biggest portion of water consumption as mentioned previously. And many initiatives are occurring for collecting rainwater and used locally, such as a program called Soak Up the Rain. However, not every city can do this. Rainwater in parts of the US contains high levels of PFAS (polyfluoroalkyl substances) and chemicals which can cause serious health issues, such as cancer, immune system, and thyroid problems (Bourzac, 2021).

9. Reduce water bill.

Once people use rainwater for non-drinking purposes, such as flushing toilets, washing cars, and watering lawns. Only using municipal potable water supply for drinking, cooking, washing up, brushing teeth, and showering their water bill may be reduced, a direct economic incentive. Rainwater also could be used for drinking water, such as in tropical communities, people use treated rainwater for drinking (Khayan, 2019). How much money could be saved depends on how much rainwater is used as an alternative to tap water.

Challenges for rainwater harvesting

1. Universal implementation

It's not easy to implement rainwater harvesting to the public as they are accustomed to the convenience of the municipal water supply, as it involves initial associated costs, such as capital, operation, and maintenance expenses. It also may not “look good” for some people who care about the aesthetics of their property. Some people don’t mind paying more for tap water, so why bother to install rainwater harvesting systems?

From my perspective, industrial and agriculture organizations could consider rainwater as a supplemental water resource if there are no significant technique barriers or drawbacks, and the expense is lower than municipal water in a long term. For urban regions, two possibilities might make the public more widely accept rainwater harvesting. One, in arid and semi-arid regions where water resource is scarce, the government could encourage people to collect rainwater and offer supports incentives. Second, collect rainwater by the centralized system and distribute it to end users, which means it would be part of multiple water supplies, as implemented in Singapore.

Singapore has developed a very robust, diverse, and cost-efficient water supply system to meet its water demand (Pub, 2022). There are three main strategies they use: recycle used water, collect rainwater, and desalinate sea water (Pub, 2022). They are still evolving the system to develop a better version (Figure 14.1, Figure 14.2). Water from local catchments and imported water from Malaysia is also a source in Singapore. However, the Singapore government works hard to become self-sufficient by using water from local catchments and importing as little as possible. As estimated, the water demand will double by 2060 in Singapore. NEWater (high-grade reclaimed water) and desalinated water can meet up 85% of the water demand in the coming future. Singapore is expanding the current rainwater collection catchment from two-thirds to 90% of the nation’s land area (IWA, 2021).

Figure 14.1 The Water Loop in Singapore (Pub, 2022).

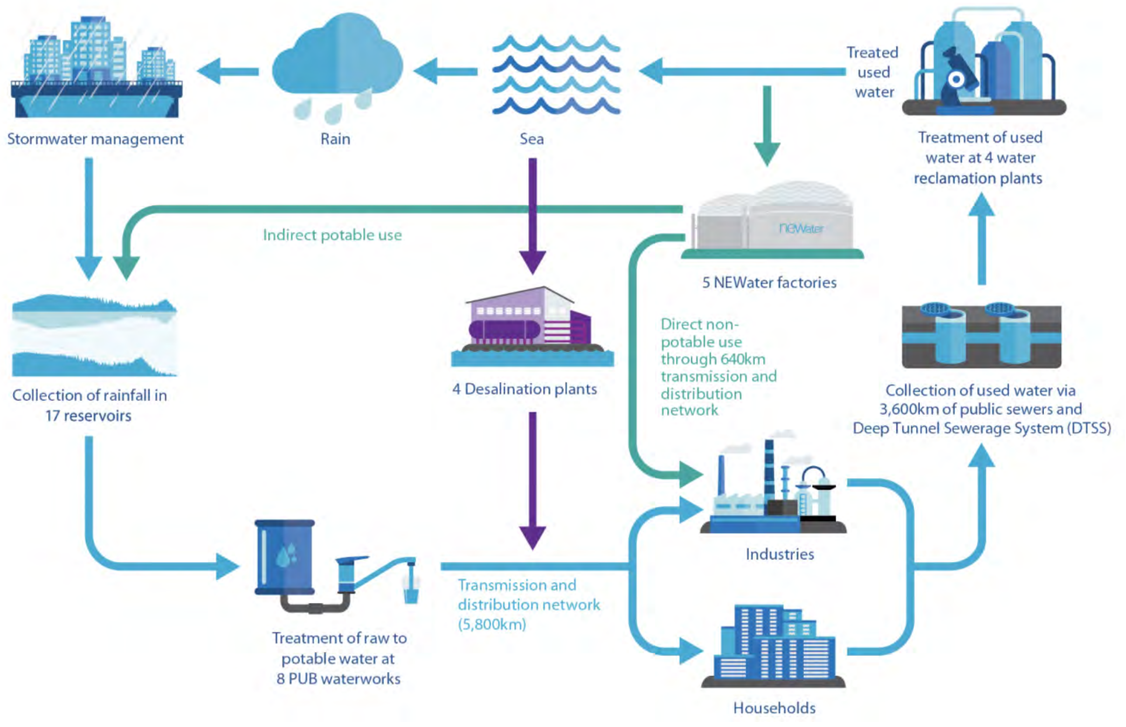
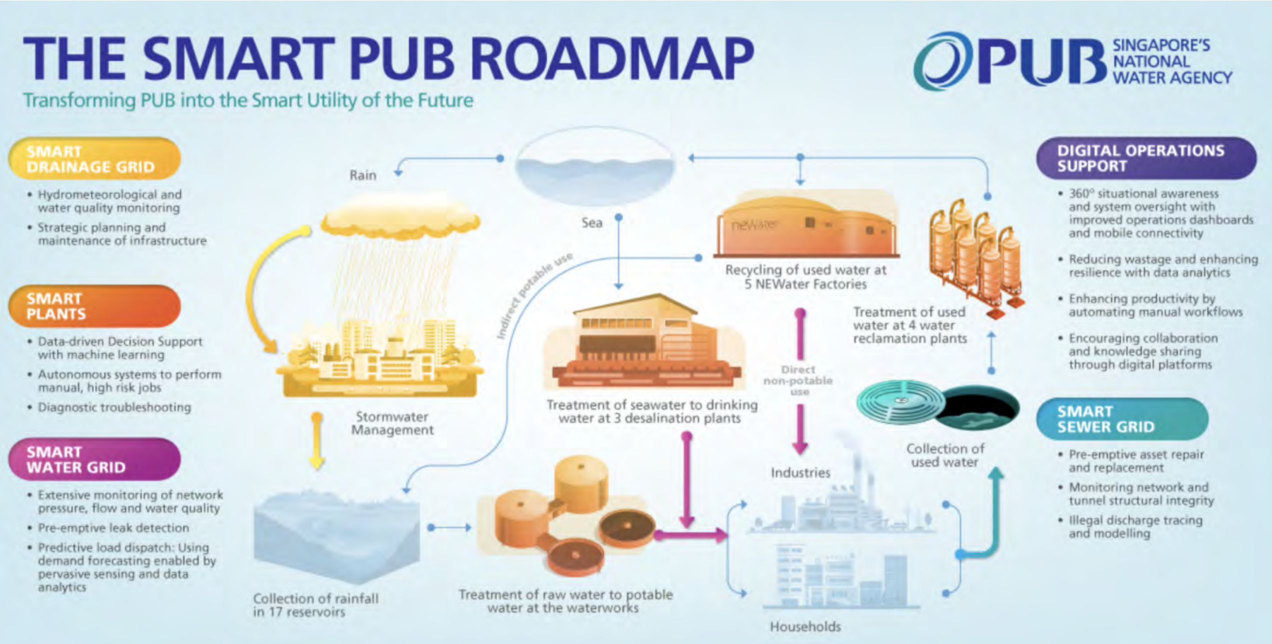


Figure 14.2 The smart PUB road map in Singapore (Pub, 2022)



A universal implementation is a possible approach, it has already been applied in Singapore. Thus, even in water relatively abundant country like Canada, it still might be a wise choice, as a measure to adapt to the uncertainties of climate change since the water resource is scarce and there is no substitute for it.

2. Pollutants, and contaminations

Gases and particles from the air can contaminate rainwater before it lands in the catchment for rainwater harvesting. For example, acid rain can result when sulfur dioxide (SO2) and nitrogen oxides (NOx) are emitted into the atmosphere and react with water, oxygen, and other chemicals to form sulfuric and nitric acids, then mixed with raindrops, becoming acid rain (Environmental Protection Agency, 2021). More than half of Canadian geology consists of vulnerable hard rocks, such as granite, which offer poor defenses from acid deposition (Government of Canada, 2018). Pollutants and chemicals that could also be introduced into the rainwater by the materials of the catchments include bird droppings and the compounds which include dissolved metals (arsenic, cadmium, copper, lead, and zinc) and organic compounds [polycyclic aromatic hydrocarbons (PAHs), phthalates, and polybrominated diphenyl ethers (PBDEs)] from roofs (Winters, 2014). These contaminations captured in the atmosphere or the catchments, harm the lakes, rivers, forests, soils, wildlife, our buildings and contribute to human health concerns.

3. Variability

Unlike municipal water, which is from fixed surface water bodies or aquifers, rainwater has variability which makes it not as easy as surface water or aquifers to maintain safe water for use. To be specific, it is hard to predict the amount and intensity of rainfall, even when there is a forecast of the weather. Every city or every country has its features of geography, topography, and economics. It is hard and complex to uniformly apply rainwater harvesting systems design and implementation for an entire city in many countries. For countries that have abundant water resources, might not see rainwater harvesting as necessary. Some countries whose main goals are developing economics and expanding urban regions, they might not value rainwater harvesting enough to even consider the possibility. It is necessary to consider the local situation to make decision about rainwater harvesting.

Conclusion

Even with disadvantages that need to be addressed, rainwater harvesting is still extremely valuable and can be applied worldwide for many different applications. A lot of water needs don't require purified or treated municipal water thus it is a cost-efficient and effective water solution for non-potable uses. Not to mention with proper treatment, it can be a great alternative for potable uses as well. Treating rainwater is much easier and cheaper than grey and black water in wastewater plants because it is not heavily polluted. Water scarce regions should consider rainwater harvesting because the freshwater resource is becoming increasingly limited. It is also necessary to consider rainwater harvesting in water redundant regions because the hydrological cycle is connected on the earth (USGS, 2016). As every single country, and every individual is the water consumer, it should be human beings' obligation to reduce water consumption and protect water recourses. Rainwater harvesting has immense benefits, and it can bring many incredible positive changes if it can be applied widely and correctly.

Recommendations

- It is recommended that local governments evaluate the economics of supplementing water supplies by rainwater harvesting as a means to reduce both costs of water treatment and as a hedge to address climate change variability.
- Community gardens and urban located agricultural enterprises should implement rainwater harvesting and not rely on treated domestic water, and
- Communities and government agencies could hold information sessions open to the public as information on the benefits conserving water and advantages of rainwater harvesting for non-potable uses.

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