FEASIBILITY OF RAINWATER HARVESTING IN ARID ENVIRONMENTS

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RAINWATER HARVESTING

Rainwater harvesting (RWH), the practice of centralizing, collecting, and storing rainwater for later use, has the potential to help alleviate water stresses in rural and tribal communities in arid and semi-arid environments. This PDF is the physical component of a 6 part video series on RWH available on the Native Waters on Arid Lands' website. For more information about the RWH videos, please follow the QR code below. This paper will touch on the main components needed to determine the feasibility of rainwater harvesting in arid and semi-arid environments, yet scalable to more temperate climates. This paper will go over the rainwater harvesting equation to determine the volume of rainwater that can be collected, the area that can be cultivated solely using the harvested rainwater and the crop yield that can be harvested at the end of the growing season.

Figure 1: Maize is a staple crop grown in arid and semi-arid environments.

Rainwater Harvesting Equation

The rainwater harvesting equation is a simple formula that requires minimal information to calculate the volume of rainwater that can be collected based on the rainfall depths for the interested area, the area of the catchment (e.g., rooftop) and the runoff coefficient which is based on the material of the catchment.

$$V = R_d \, x \, A_r \, x \, R_c$$

V = Volume of Collected Rainwater (ft^3)
R_d = Rainfall Depth (ft)
A_r = Area of Rooftop (ft^2)
R_c = Runoff Coefficient (unitless)

Formula 1: Rainwater harvesting equation

Rainfall Depth

The rainfall depth is the average amount of rain that has fallen during a specific timeframe (e.g., growing season). Average monthly precipitation data is recommended to better represent the rainfall depths for the growing season as annual data can be too broad and daily precipitation data too complex. At least 20 years of monthly average precipitation data should be considered to encompass dry and wet years and produce a long-term average for each month.. PRISM Climate Group has an extensive database with precipitation and temperature information for most areas in the contiguous United States — making it a great resource if precipitation data is limited in an area.

Catchment Area

The catchment is the surface area that rain will hit before running off. A catchment area in a rainwater harvesting system can be a rooftop, concrete slab, metal sheet, etc. A catchment is the collection area before the rain is concentrated and then stored. The size of the catchment will dictate the volume of rainwater that can be harvested. A larger catchment area will have more surface area, meaning that more rain can be collected and then concentrated. The area of the catchment can be measured simply with a measuring tape if it is unknown.

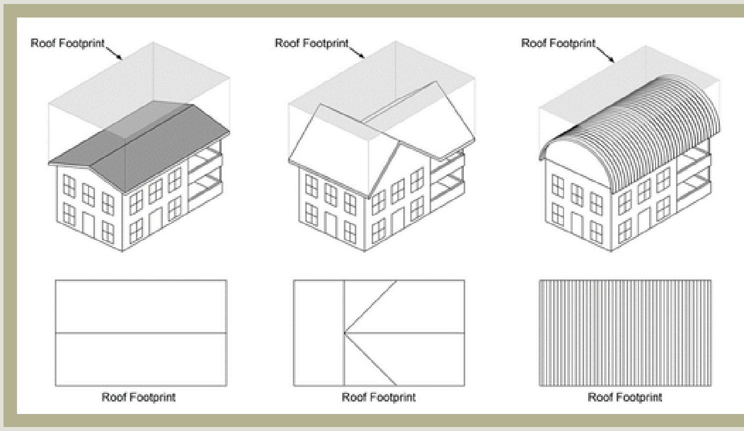

Figure 2: Catchment areas of various roofs. Illustration from Texas A&M Agrilife Extension

Runoff Coeffiecient

The runoff coefficient is a dimensionless coefficient that represents the amount of runoff to the amount of precipitation received. The larger the value, the more runoff that will occur, the lower the value the less amount of water running off and more water infiltrating into the subsurface. For RWH a higher runoff coefficient is preferred since more can be collected and not lost to infiltration. The runoff coefficient is dependent on the material of the catchment. Roofs that are galvanized metal will have a higher runoff coefficient than a roof made out of wood due to less absorption.

No.	Type of roof	Runoff Coefficient
1	Galvanized metal sheet	0.90
2	Shingle roof	0.85
3	Tiled roof (wood, asphalt, ceramic)	0.75
4	Concrete roof	0.70

Figure 2: Runoff coefficient values for various roof types.

Example

The volume of rainwater that can be harvested during a 1 inch (0.08 ft) rainstorm, on an a 2,500 sq. ft galvanized metal roof (0.90) is 188 cubic feet or 1,406 gallons of rainwater!

$$V = R_d \, x \, A_r \, x \, R_c$$

$$V = 0.08 \text{ ft} \times 2{,}500 \text{ ft}^2 \times 0.9$$

$$V = 188 \text{ ft}^3$$

$$V = 1{,}406 \text{ gallons!}$$

The rainwater harvesting equation is a quick way to determine the volume of rainwater that can be harvested based on easy and simple information.

Cultivable Area

Determining the area that can be cultivated solely using the harvested rainwater requires the net irrigation requirements from the desired crop or plant. The net irrigation requirement is the net amount of of water that must be applied as irrigation to ensure the full yield of the crop or plant. The AquaCrop Model developed by the Food and Agriculture Organization (FAO) of the United Nations, is a crop growth model that simulates the yield response of various crops to water focusing on conditions where water is the key factor in crop production.

The ease of use, minimal input of explicit parameters and ample degree of simulation accuracy, makes the AquaCrop Model a useful tool in determining the net irrigation requirements needed by farmers, gardeners and research scientist. The model can simulate the net irrigation requirements and dry yield for various crops including maize, tomatoes, beans, squash, etc. Other input parameters include climatic data (precipitation, temperature, evapotranspiration), crop and soil characteristics, information about the groundwater table (e.g., perched water table, depth to water), and field management practices (start of plant cultivation, growing season, etc.)

For more information about the AquaCrop Model visit the FAO website; www.fao.org/aquacrop/en/ or follow the QR code to the 6 Part Video Series on the Feasibility of Rainwater Harvesting for Arid Environments.

$$A_c = \frac{V}{Irr_{Net}}$$

Formula 2: The area that can be cultivated solely using harvested rainwater for a specific crop.

Once the Net Irrigation has been simulated, the area that can be cultivated by the desired crop can be calculated by simply dividing the volume of the harvested rainwater by the net irrigation required to sustain a healthy crop.

$$A_c = \frac{V}{Irr_{Net}}$$

$$A_c = \frac{188\ ft^3}{0.25\ ft}$$

$$A_c = 752\ ft^2$$

Example

If a net irrigation requirement for a specific single crop was simulated in the AquaCrop Model to be 3 inches or 0.25 feet, then dividing the total volume of the harvested rainfall from a 1 inch storm on a 2,500 sq. foot galvanized metal roof, approximately 188 cubic feet, by the net irrigation of 0.25 then an area of approximately 752 sq. feet can be cultivated solely using the harvested rainwater for that specific crop.

Note that the net irrigation is the required amount of water a plant needs to grow healthy during a growing season. The simulated net irrigation requirement takes into consideration the precipitation that occurs during the growing season as well as the temperatures and evapotranspiration of the plant.

For more detailed information about calculating the area for cultivation using harvested rainwater, follow the QR code to the 6 Part Video Series

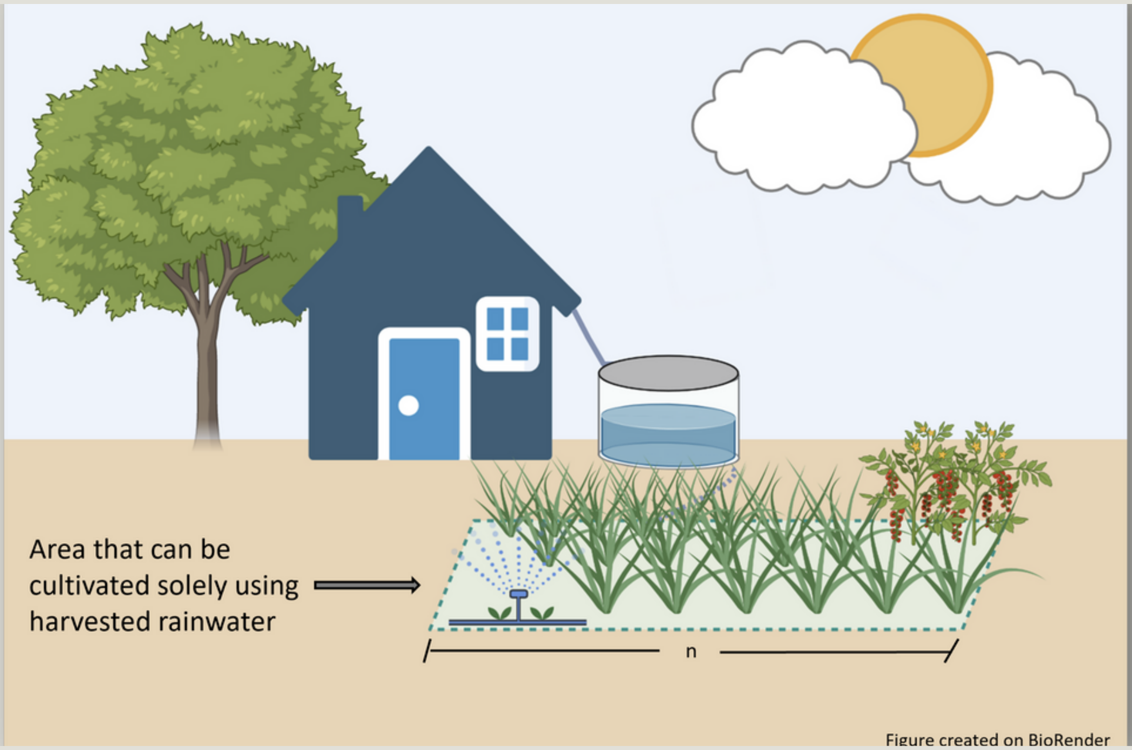

Figure 3: Schematic illustration of a rainwater harvesting system and the area that can be cultivated.

Figure 4: Illustration of various common garden vegetables

Dry Yield of a Crop

Understanding how much of a crop can be harvested at the end of the growing season can help determine if it is feasible and cost effective to install a rainwater harvesting system.

The AquaCrop Model also simulates the dry yield of various crops when simulating the net irrigation requirements. The model simulates the dry yield in tons over hectare which is dependent on the net irrigation requirements being met throughout the growing season. With some simple unit conversion, the total pounds of a specific crop, in this case Maize, can be calculated based on the area that can be cultivated. The example below demonstrates the total dry yield of Maize when the model simulates a total of 14.2 tons of Maize can be harvested if the net irrigation is met. Note that the dry yield was simulated with input parameters from northwestern Arizona. For more information on how to simulate the dry yield and calculate the total harvest in pounds, watch Part 3 and Part 4, respectively, of the 6 Part Series Video component to this paper.

Simulated from AquaCrop

Cultivable Area

$$\frac{14.2\ ton}{Hectare} \left| \frac{2000 \text{ lbs}}{1\ ton} \right| \frac{1\ Hectare}{107{,}639\ ft^2} \left| \frac{752 \text{ ft}^2}{1} \right. = 198 \text{ lbs of Maize}$$

Unit Conversion

Cost and Maintenance

The cost and maintenance for a rainwater harvesting system will be dependent on the existing presence of a gutter system on the catchment or roof, the volume of rainwater that will be collected and the type of material desired of a cistern, as well as the preferred distribution system.

Gutter System

Gutters and downspouts channel rainwater from the roof to a cistern. Most buildings in areas with wet storms (winter, monsoonal) usually have a gutter system in place, which would reduce the cost. However, if a gutter system needs to be installed there are various materials (e.g., vinyl, plastic, aluminum, galvalume) which would influence the price as well if the installation requires professional installment.

Cisterns

Cisterns allow for the concentration of rainwater in one place. The cost of cisterns will depend on the material and the size. The size of the cistern should be large enough to hold the desired volume of rainwater that can be harvested based on the catchment size and rainfall depth. Cisterns are usually the most costly item in a RWH system. . Cisterns are available in various materials, polyethylene, wood, plastic bags, and metal. Polyethylene tanks seem to be the most cost-effective and widely used type of cistern. Polyethylene tanks also come in a variety of sizes, unlike a lot of the other cisterns. Note: that in order to avoid the growth of unwanted bacteria or algae, a dark or opaque color should be considered to reduce the penetration of sunlight

Item	Cost (USD)	Comment
Cisterns	$100 - $11,000	Dependent on size and material
Gutter System	$ 0 - $12 per foot	Dependent on existing gutter system or installation
Distribution System	$ 0 - $500	Dependent on desired irrigation system
Average Cost	$1000 - $3,500	With a 5,000 gallon polyethylene tank

Table 2: Average cost for a rainwater harvesting system

Distribution System

The distribution system moves water from the cistern to the point of use. For outdoor irrigation, the distribution system will depend on the the desired irrigation (e.g., drip line irrigation, gravity fed irrigation, or surface irrigation. An irrigation system that require pressure will need a hydraulic pump or an elevated platform for the cistern to create a pressure gradient. All cisterns will need a strong, sturdy platform to reduce the risk of damaging of the tank. Additional supplies might include piping, drip line, irrigation timers and filters.

Maintenance

The required maintenance for a rainwater harvesting system for outdoor water use will consist of keeping the gutters clean of debris and leaf litter, painting the PVC pipes for UV protection, adding chlorine tablets to the cisterns periodically to avoid the growth of unwater bacteria, and conducting regular inspections for leaks, algae, discoloration and odor. If the harvested rainwater is desired for other potable uses, then additional filter systems will be needed. The interested party should research the rainwater harvesting regulations for indoor use for their desired area.

Key Takeaways

Rainwater harvesting can be a great way to increase the water supply for outdoor uses. Although RWH will not completely replace current irrigation practices, it can help alleviate some of the stresses that are common in arid and semi-arid environments. With a single inch of rain, thousands of gallons of rain can be collected from an average sized roof. As the climate changes, finding additional resources to augment water supplies is crucial. In areas where food insecurity persist, RWH can help attain the security by using the water for food production.

Video Series

A six part DIY video series on the feasibility of rainwater harvesting in arid environments, was created to guide interested parties in RWH to determine if it is feasible and cost effective to install a system. Please follow the QR code or link below for more information.

Resources

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