WATER HARVESTING IN ARID AND SEMI-ARID REGIONS

Peter F. Ffolliott[1], Kenneth N. Brooks[2], and Daniel G. Neary[3]

Water harvesting, also called rainwater harvesting, is a technique of developing surface water resources to augment the quantity and quality of water available to the people in arid and semi-arid regions where other water sources are not readily available or too costly to develop and use. A water-harvesting system consists of facilities for collecting and storing rainfall and the resulting surface runoff until the water is used for livestock, small-scale agricultural production, or domestic uses. A distribution facility can also be required unless the collected water is immediately concentrated in the soil profile to grow plants. For example, a distribution facility is needed when the stored water is used to irrigate an agricultural crop or provide water to households.Water harvesting is potentially applicable in almost any area receiving at least 100 millimeters (mm) of annual rainfall (National Academy of Science 1974). Larger volumes of water can be stored on sites where the annual rainfall is 250 mm or more and an adequate storage facility is available.

WATER HARVESTING SYSTEMS

How a water harvesting system is developed depends largely on the local topography; the treatment to be applied on the surface of the catchment (if any) to increase runoff efficiency by reducing infiltration losses; and the ultimate use to be made of the harvested water (Frasier 1975, Frasier and Myers 1983). Water harvesting systems, therefore, assume many differing characteristics and configurations. Among the more common water harvesting systems found in arid and semi-arid regions of the world are microcatchments, strip harvesting, roaded catchments, and harvesting aprons.

Microcatchments are suited to situations where drought-resistant perennial plants are to be grown (Frasier and Myers 1983, Renner and Frasier 1995). The size of the catchment area can range from 10 to 1,000 square meters (m^2) depending on the amount of rainfall on the site and the water requirements for the plants. Strip harvesting is a modification of the microcatchment method where berms are constructed on the contours with the area between the berms prepared as catchment areas. The water collected between the berms is concentrated above the downslope berm to irrigate the plants.

Roaded catchments are used to grow fruit or nut trees or grapes on gently sloping ground (Frasier and Myers 1983). These systems consist of parallel rows of drainages 100 meters (m) or less in length and 10 to 15 m apart with the trees or grapes to be grown planted within the drainages. The area between the drainages is shaped like a high-crowned road (hence the name) to facilitate the collection of water. The catchments are cleared of vegetation and other obstructions and the surfaces smoothed and often treated with sodium chloride (NaCl) or other material to reduce the infiltration of surface runoff. Water storage to provide supplemental irrigation is achieved by diverting excess water into a storage facility.

Harvesting aprons are used primarily to collect water for livestock, wildlife, or domestic uses. Apron-type systems are the simplest water harvesting system to design with the size of the apron dependent on the annual water requirement and average annual precipitation (Frasier 1975, Frasier and Myers 1983). The catchment area (the apron) is treated to reduce infiltration losses unless the surface of the apron is already impermeable to water. Gravel-covered asphalt-impregnated fiberglass is a common material applied for this purpose. A storage facility with the necessary pipes and valves to conduct the water into drinking troughs or people's homes is needed.

Compartmental ponds of three storage areas are often constructed to provide water for small-scale agricultural production (Reig et al. 1988). Pumps are needed to transfer water between the ponds and activate the irrigation system although a gravity system can be feasible in steep terrain. Treatment of catchments to reduce infiltration can be required since large quantities of water are usually required for irrigation. Application of NaCl is effective for this purpose where the soil has a sufficient quantity (about 10% or more) of expanding clays.

Catchment Area

The ideal catchment area should be impermeable to water and large enough to collect the amount of rainfall and surface runoff that is necessary for storage. Effective catchment surfaces are natural rock outcrops; smooth land surfaces cleared of vegetation and other obstructions; smooth surfaces

[1]University of Arizona, Tucson, Arizona (retired)

[2]University of Minnesota, St. Paul, Minnesota (retired)

[3]USDA Forest Service, Rocky Mountain Research Station, Flagstaff, Arizona

treated with NaCl, silicones, latex, or oils; and surfaces covered with concrete, butyl rubber, metal foil or plastic (Frasier and Myers 1983). The material used for treating a catchment surface when necessary must be resistant to damage by intense rainfall, moderate flows of surface water, excessive wind, animal trampling, and plant growth within the catchment. The material should also require minimum site preparation for its application with its maintenance kept simple. The runoff water that is collected must be nontoxic to plants, livestock, and people.

There are no standard shapes for a catchment area with flexibility in its delineation and treatment to reduce infiltration (if any) encouraged to take advantage of the natural topography and minimize the construction costs. The slope should be only as steep as necessary to facilitate collection of the surface runoff – often less than 5%. Slopes that are too steep can erode and produce large amounts of sediment in the runoff water. The catchment surface must be kept cleared of vegetation, rocks, and other debris that might reduce its durability.

Storage Facility

A storage facility can be the soil body, an excavated pond, or a tank or cistern. Ancient water-harvesting systems were simple arrangements where the surface runoff was directed immediately from the hillslopes onto a cultivated area to store the water in the soil for plant growth. A problem with this arrangement is that an insufficient amount of water is often stored to offset a prolonged drought (Brooks et al. 2013). Nevertheless, this method remains in use to grow drought-resistant varieties of plants.

An excavated pond is an economical way of storing water for small-scale agricultural production although evaporation and seepage of the stored water are potential problems (Frasier and Myers 1983). While simple, effective, and economical methods to limit evaporation losses are generally not readily available, chemical dispersing agents, bentonite, membrane liners, NaCl, or simple compaction can seal the impoundment to lessen seepage that can account for 60 to 85% of the annual water loss from a pond. A tank or cistern is often suitable for storing water for livestock, wildlife, or domestic use. Evaporation and seepage losses are less with these storage facilities than with an excavated pond. In reality, almost any container that is capable of holding the needed amount of water with minimal losses can be used as a storage facility.

External storage of the collected water is a component of runoff-farming where a form of irrigation is required to distribute the stored water on the cropped area (Frasier 1975, Frasier and Myers 1983). Also, external storage is frequently needed to supply drinking water for people. Parenthetically, a storage and water distribution facility is often the most expensive item in constructing many water harvesting systems.

Feasibility

A water harvesting system must have an adequate storage capacity to provide the amount of water of sufficient quality that is needed at the time it is needed for its intended use (Frasier and Myers 1983). The amount of water required for livestock production depends on the grazing system practiced and the distribution of rainfall in the area. A daily water requirement of 20 to 25 liters (L) for each animal is a general minimum (Holechek et al. 1998). However, the type of livestock also determines the water requirement with the daily intake of water for meat-producing livestock increasing to 30 to 35 L per animal while that of a high-grade milk-producing cow is nearly 95 L. Systems constructed to furnish water for agricultural production are more difficult to design because the water requirement for the plant to be grown from its germination to its harvest is not always known. According to the World Water Assessment Programme, a person requires an average of 20 to 50 L of water each day to meet their basic needs for drinking, cooking, and cleaning. However, the daily water needs for households in arid or semi-arid regions are quite variable.

Equally important to satisfying the water requirement for the intended purpose of a water harvesting system is when the rainfall and surface runoff occur (Renner and Frasier 1995). Mean annual rainfall is not always a good indicator of available water in arid and semi-arid environments, however, because there are often more years when the annual rainfall is less than the mean value than years with rainfall amounts are greater than the mean.

Water collected from a catchment area can contain unwanted organisms and water-soluble impurities from windblown dust deposited that is on the surface of the catchment; chemicals originating from the material applied to increase the catchment's runoff efficiency; or by-products created by the weathering of the treatment materials (Brooks et al. 2013, Frasier 1988). Fortunately, the quality of the water flowing off most treated catchment surfaces is usually suitable for livestock and wildlife consumption while the surface treatments applied in water harvesting systems to reduce infiltration losses do not generally affect plant production. But, a filter of some kind is often needed if the water is to be utilized for human use.

The feasibility of a water harvesting system should also be evaluated within the context of alternative water resources that might be available in the area (Frasier 1975, Frasier and Myers 1983). Such alternatives might be tapping a spring, tapping a shallow groundwater table, or tapping a perched water table with a horizontal well (Brooks et al. 2013). Alternative sources of water that are available should be evaluated with respect to their location relative to where the water will be used; their sustainable suitability in terms of yield and quality; and their developmental costs before embarking on the construction of a system to harvest water. If an alternative source of water can be developed economically but is deficient in its yield or dependability, it might still be useful as a supplement to the water harvesting system.

The feasibility of a water harvesting system can be assessed from a financial standpoint by the profit realized (if any) by the sale of livestock, an agricultural crop, or other commodities obtained from the system (Oron et al. 1983). Also, there can be environmental benefits such as mitigating the concentrations of livestock at a water source located on highly erodible soils that (in turn) leads to a decrease in erosion rates. More sustainable agricultural production and, therefore, a lessening of food shortages can be another benefit of water harvesting.

Example

An example of a water harvesting system to provide water for local people is found in the village of Stungopovi on top of a mesa of sandstone-rock on the Hopi Reservation in northeastern Arizona. Stungopovi did not have a reliable source of water when it was originally established, and, as a consequence, the villagers were forced to carry water up from the valley below initially by foot and later on the backs of burros. A water harvesting system was developed by the inhabitants of the village in the early 1930s to alleviate their persistent shortage of water (Chiarella and Beck 1975). One-third of a hectare was cleared of vegetation and loose soil to expose the underlying bedrock. A deep cistern was hewed into the rock to store rainwater and the resulting surface runoff and a concrete roof was constructed below the cleared area to protect the collected water from evaporation. This system was a key part in supplying water for the village for nearly 30 years, at which time when a well was dug and a pump installed on the valley floor and an uphill water distribution system was constructed to furnish a more reliable water source.

Other water harvesting systems including those that have evolved historically but are still used by people and those that incorporate more modern technologies into their design are too numerous to describe in this paper. However, the reader is referred to the literature for examples of these systems (see Hillel 1967, Burdass 1975, Myers 1975, Mehdizadeh et al. 1978, Vashistha et al. 1980, Karpiscak et. al. 1984, Zohar et al. 1988, Agarual and Narain 1997, Rockstrom et al. 1999, Prinz 2001, and others). Information on the systems is also available through Internet linkages.

Summary

Water harvesting is a technique of capturing water to meet the needs of people in the arid and semi-arid regions of the world. Water harvesting systems include components for collecting and storing rainfall and surface runoff until it can be used for its intended purpose. More specifically, these systems require an effective catchment area for the collection of water and a sufficiently large facility for storing the water to satisfy its intended use. A distribution system needed is those systems furnishing water for irrigation and domestic use. Water harvesting can be feasible in almost any region with at least 100 mm of annual rainfall.

References

Agarual, A., and S. Narain. 1997. *Dying Wisdom: Rise and Fall of India's Traditional Water Harvesting System*. Centre for Science and Environment, New Delhi, India.

Brooks, K. N., P. F. Ffolliott, and J. A. Magner. 2013. *Hydrology and the Management of Watersheds*. Wiley-Blackwell, Hoboken, New Jersey.

Burdass, W. J. 1975. Water harvesting for livestock water in Australia. *In* Frasier, G. W., ed.. *Proceedings of the Water Harvesting Symposium*. USDA Agriculture Research Service, ARS-W-22.

Chiralla, J. V., and W. H. Beck. 1975. Water harvesting catchments of Indian lands in the Southwest. *In* Frasier, G. W., ed., *Proceedings of the Water Harvesting Symposium*. USDA Agriculture Research Service, ARS-W-22.

Frasier, G. W. 1975. Water harvesting: A source of livestock water. *Journal of Range Management* 28:429-433.

Frasier, G. W. 1988. Technical, economic and social considerations of water harvesting and runoff farming. Pp. 905-918 *in* Whitehead, E. E., C. F. Hutchinson, B. N. Timmermann, and R. G. Varady, eds., *Arid Lands: Today and Tomorrow*. Westview Press, Boulder, Colorado.

Frasier, G. W, and L. Myers. 1983. *Handbook of Water Harvesting*. USDA Agriculture Research Service, Handbook 600.

Hillel, D. 1967. *Runoff Inducement in Arid Lands*. USDA Final Technical Report, Project A-10-SWC-36.

Holechek, J. L., R. D. Pieper, and C. H. Herbel. 1998. *Range Management: Principles and Practices*. Prentice Hall, Upper Saddle River, New Jersey.

Karpiscak, M. M., K E. Foster, R. L. Rawles, and P. Hataway. 1984. *Water Harvesting Agrisystem: an Alternative to Groundwater Use in Avra Valley Area, Arizona*. Office of Arid Lands Studies, University of Arizona, Tucson, Arizona.

MEDHIZADEL, P., A. VARIZI, and L. BOERSMA. 1978. Water harvesting for afforestation, efficiency and life span of asphalt cover: II - survival and growth of forest trees. *Soil Science Society of America* 42:644-657.

MYERS, L. E. 1975. Water harvesting 2000 BC to 1974 AD. *In* Frasier, G. W., ed., *Proceedings of the Water Harvesting Symposium*. USDA Agriculture Research Service, ARS-W-22.

NATIONAL ACADEMY OF SCIENCE. 1974. *More Water for Arid Lands: Promising Technologies and Research Opportunities*. National Academy of Science Press, Washington, DC.

ORON, G., J. BEN-ASHER, A. ISSAR, and T. BOERS. 1983. Economic evaluation of water harvesting in microcatchments. *Water Resources Research* 19:1,099-1,105.

PRINZ, D. 2001. Water harvesting for afforestation in dry areas. Pp. 195-198 in *Proceedings of the 10th International Conference on Rainwater Catchment Systems*. Mannheim, Germany,.

REIG, C., P. MULDER, and L. BEGEMANN. 1988. *Water Harvesting for Plant Production*. The World Bank, Washington, DC.

RENNER, H. F., and G. FRASIER. 1995. Microcatchment water harvesting for agricultural production. Part I: Physical and technical considerations. *Rangelands* 17:72-78.

ROCKSTROM, J., M. FALKENMARK, C. FOLKE, J. BARRON, and P. FOX. 1999. Water harvesting for drought proofing of rainfed agriculture in semi-arid regions of Africa. *GRID Newsletter* 13:10-12.

VASHISTHA, R. N., M. L. PANDITA, and R. R. BATRA. 1980. Water harvesting studies under rainfed conditions in relation to growth and yield of okra. *Haryana Journal of Horticultural Science* 9:188-191.

ZOHAR, J. A., A. ARONSON, and H. LOVENSTEIN. 1988. Cultivation of multipurpose trees in rain water harvesting systems in the arid zone of Israel. *Commonwealth Forestry Review* 67:399-349.