Expert Answers: Rainwater Harvesting

Is the quality of roof-harvested water acceptable?
BRETT MARTINSON

Is the cost of RWH acceptable?
BRETT MARTINSON

Is rainwater harvesting a useful part of water supply services everywhere?
ROBERT MEERMAN and MAARTEN ONNEWEER

Is RWH equally useful in urban and rural environments?
AFTAB OPEL

How can we measure the water harvesting potential of seasonal rivers?
IAN NEAL

Is the quality of roof-harvested water acceptable?

It depends on what is considered acceptable. Roof-harvested water is generally not as good as chlorinated water supplied trough a well-maintained municipal system, however, if properly collected and stored, it is usually better than surface water sources and shallow groundwater sources and often as good as deep groundwater sources.

There are few reported cases of disease outbreaks associated with rainwater consumption, though this is partially explained by the small-scale nature of the technology. Most of these are associated with poor practice or accidents. There have been a number of epidemiological studies, notably in Australia and New Zealand, that show the risk to health from drinking rainwater to range from better than the municipal supply to slightly worse and equivalent to the bacteriological infection risk of eating chicken.

It is worth considering the path that contamination must take to arrive in a human being. The most common path is for a contaminant to be deposited on the roof, survive there for some time, be washed onto the storage and survive there, before being collected along with the water and ingested. A number of studies have investigated rainwater quality at various points along the chain. Rainfall is generally clean, but material including suspended and dissolved solids, organic matter and microbiological contamination are collected from the roof's surface and washed into the store. The concentration of these contaminants starts high and then reduces over the course of the rainfall; this is the 'first-flush' effect and a reasonable rule of thumb is that for each millimetre of rainfall, the contaminant concentration halves. Once in the store, the calm conditions allow suspended material to settle, the pH of the water generally increases, causing some dissolved material to precipitate out,

http://dx.doi.org/10.3362/1756-3488.2014.011, ISSN: 0262-8104 (print) 1756-3488 (online)

and microorganisms begin to die off. As a result, water exiting a well-designed and maintained tank is of much better quality than the water entering it.

For these processes to work effectively, care should be taken with system design. The World Health Organization recommends that catchment surfaces are clean, storage containers are covered and that good hygiene practice is observed. In fact the main requirements for good water quality at the storage are that the tank must not allow light to enter and must also be well ventilated. It should also have *all* entry points covered or screened to prevent direct contamination by an animal entering the tank. The best place to take the water is about 10 cm below the surface of the water which can be achieved with a float made from hose and empty water bottles. If this isn't practical, ensure the outlet is well above the expected sludge level. A clean catchment is helpful, but unlikely to be practical with a sloped roof. A hard, sealed roof is essential though, as materials such as thatch and tar sheet will contaminate the runoff resulting in very poor quality water. It is also a good idea to keep gutters clear, not only for hygiene but for fire prevention and to reduce potential breeding sites for mosquitoes. Inlet filters are a useful addition, but simplicity is advised; a complex stone and sand filter may not have the required flow capacity and may be removed by users or incorrectly reinstalled after cleaning. The goal should be to keep organic material out of the tank as suspended mineral contamination will settle to the bottom. First-flush devices can work well, but many, particularly those employing a short section of downpipe, are too small to be effective.

A system with these features should provide water that is palatable and safe to drink so long as good practice is maintained after the water is collected and secondary contamination avoided.

D. Brett Martinson is a Senior Lecturer in the Environmental Engineering and Sustainable Development School of Civil Engineering and Surveying, University of Portsmouth

Is the cost of RWH acceptable?

The cost of a RWH system needs to be considered in the context of the cost of building and maintaining alternative supplies and the potential benefit of having water delivered directly to the home. In general, the capital cost of rainwater harvesting is more expensive than gravity distributions systems derived from springs and hand-dug wells, but may be less expensive than borehole water depending on depth and population density. Conversely, the maintenance cost of most rainwater harvesting systems is negligible whereas maintaining more centralized community-based systems can present a major challenge. Rainwater is also delivered directly to the household and so the opportunity cost of water collection may be significant or the social benefit of having water delivered to the infirm may need to be considered against other delivery options.

RWH has an additional complication: costs are usually dominated by the cost of the storage tank and, as smaller tanks are filled and emptied more often than larger tanks, smaller tanks have a considerably lower cost per litre delivered than larger ones. There are actually very few places where providing *all* water for *all* uses by rainwater is economic, and useful benefits can be had by using quite small tanks at a low cost to supply a targeted *part* of the water demand. In the scenario where a small tank is used for partial supply, householders use the tank water exclusively in times when rain is abundant and progressively adopt alternative water sources as rainwater becomes more scarce, ultimately using the stored rainwater only for drinking and cooking. It has been observed that over time users become adept at creating strategies for conserving their rainwater and can make small stores of less than 1 m^3 bridge dry seasons of a few months under a bi-modal rainfall pattern as found in much of the humid tropics. The specifics in arid areas and locations with a single season monsoon will differ and the necessary volumes will increase, but the strategies will be similar.

If there is a need for greater security from the rainwater systems, another method of reducing cost is to reduce the material quality of tank. Membrane-based tanks such as the Ugandan tarpaulin tank and the EnterpriseWorks bob tank use plastic sheet for waterproofing and either a simple frame or the ground for support. They achieve cost savings of about 50%, however, the tarpaulin tank has a need for periodic replacement of various components and for continual upkeep. Its attractiveness therefore depends on the relative availability of capital to buy a higher quality tank vs. the need for smaller but continual amounts of money to maintain it. Such tanks do, however, put larger storage capacities within the grasp of lower-income households whereas large tanks with standard designs such as ferrocement are only affordable to middle- and higher-income households and NGOs.

D. Brett Martinson is a Senior Lecturer in the Environmental Engineering and Sustainable Development School of Civil Engineering and Surveying, University of Portsmouth

Is rainwater harvesting a useful part of water supply services everywhere?

Many good water technologies exist that harvest rain directly or indirectly and make it a source of water for people, animals and the environment. Appreciation for these technologies in water programmes has been slow, we believe because of the focus on one particular moment in the water cycle, namely, the point at which people extract water from somewhere to consume it. Roofwater harvesting provides such a source of direct consumption. If constructed and managed properly people can access water at their home directly from a tank that harvests rain from the roof. These systems can be installed in areas with more than 200 mm of water annually. As with any other water system, there is a cost–benefit analysis that should take a number of factors into account. These factors include the cost efficiency of other systems such as good quality groundwater or piped water. Limitations to these alternatives can be heavily mineralized water (containing fluorides, saline or arsenic), deep groundwater or unreliable groundwater. Tanks can provide an alternative or a backup for central supply systems, even in urban areas, if a proper filter is installed.

A tool exists that can calculate the optimum size of the tank for every region in the world (http://www.samsamwater.com/tools.php).

Collection from a rooftop is a classic case of rainwater harvesting for direct consumption. But how do we classify the storage of rainwater that flows from a large rocky surface into a storage tank for communal use? Is that still rainwater harvesting? And now storing the same water in a pond instead of a tank? Or the so called in-situ technologies such as terraces that bring more rainwater to the soil. Perhaps some invisible conceptual line has been crossed somewhere, but is that really important for the water itself or for the people who use it? Any definition of rainwater harvesting will end up in a conceptual quagmire when we try to separate the interplay of rain, ground and surface water that occurs in different ways all over the world. Besides rooftop harvesting tanks, many more options exist that might be called rainwater harvesting for buffering (see www.bebuffered.com).

Rainwater harvesting has a lot more to offer when we look beyond the moment of consumption. To put it boldly, there is no shallow well in any context that can do without a regular supply of water from the sky. Even in wetter tropical climates, wells or springs can dry up due to different land use, climate change or over-extraction. Strategically allowing rainwater to infiltrate into the soil higher up the hills can then be seen as rainwater harvesting in a more catchment- or landscape-based approach which does not only consider the point of consumption, but the flow of water in the landscape. The rainwater harvesting is part of a more systematic, landscape-based approach that moves away from the semantic programmatic boundaries of the technology (Is it WASH? Is it resilience?). Simple robust technologies such as bunds, checkdams or terraces, can stabilize peak flows and increase low water levels and other fluctuations expected to come with climate change, be it in a hot desert or a tropical city. In many places, a groundwater buffer can be used to store rainwater and runoff, augmented by flows from rivers and irrigation. In addition to groundwater, local surface water storage adds to the water buffer in a region, such as harvesting and storing rainwater in tanks; in urban Bangalore this is taken up on a large scale, even including rooftop agriculture (https://www.youtube.com/watch?v=xeE-BzCr8Gs). Added value is that these technologies alleviate pressure on the urban drainage systems.

When we look at the catchment level it also becomes clear that rainwater harvesting yields numerous environmental, social and economic benefits and can contribute significantly to poverty alleviation and sustainable development. Simple stone bunds or terraces that reduce runoff, allow water infiltration and increase production can give people the means and confidence to protect their livelihoods in response to climatic changes, and to improve local water management to ensure reliable access to water, economic development and the integrity of their environment. The main idea is that tackling a local water crisis is not so much about allocating scarce water, but catching water where it falls and where it can do no harm and extending the chain of water use and its reuse as much as possible within a basin, taking account of all people and the environment across this basin.

Robert Meerman and Maarten Onneweer are affiliated to the RAIN Foundation

Is RWH equally useful in urban and rural environments?

In Bangladesh it is often the low- income households of cities that suffer most from flooding and waterlogging during the rainy seasons. Yet it is these same households that are often paying much higher unit prices for water from informal vendors as compared to the richer households who are generally served by public utilities. In addition, women often have to walk a long distance, and carry loads of water on their backs, to meet everyday water demand. Is there anything we can learn from water management in the rural areas of Bangladesh that would help solve this problem?

In coastal districts of Bangladesh, surface and groundwater sources are often seriously affected by saline intrusion. Households here have turned to harvesting rainwater to help meet their immediate drinking water needs and are also storing rainwater in pots and pitchers to provide drinking water over the longer term.

Can we learn anything from their example in urban scenarios? Yes, we can. We can improve building designs so that rainwater can be harvested, stored and used on site. Turning public buildings and open spaces in slums into safe and protected catchments for rainwater harvesting – as well as building underground storage – is an option to be explored, particularly in slums. It isn't necessarily difficult or expensive to convert the roof of a building for catchment or construct underground storage. It can also be quite straightforward to install separate plumbing to bring rainwater for the use of flushing and washing. This would also save potable water that could then be used to increase access to drinking water in urban areas. On-site recycling of water is another option that could prove cost effective in the long run if environmental benefits are taken into account. Although some of these options might require external investment, operation and management might not be too difficult if community-based management systems are adapted to urban areas.

We can also think of systems and technologies that use rainwater to recharge groundwater. This might be complex but it shouldn't be more costly than the big drainage projects undertaken to manage urban flooding. Additionally, appropriate filtration methods could be used to keep rainwater safe before being pushed into the aquifer.

We have seen experiments and piloting in Bangladesh to find effective and efficient harvesting and storage systems as well as groundwater recharge mechanisms but the issue needs wider attention so that the potential of rainwater to reduce water scarcity in urban areas is maximized. **Don't let it drain away, rainwater can improve water security!**

Aftab Opel (AftabOpel@wateraid.org) is Research Manager at WaterAid, Bangladesh

How can we measure the water harvesting potential of seasonal rivers?

Africa is an agricultural continent, but its agricultural productivity is the lowest in the world. Eighty-five per cent of Africa's poor live in rural areas and mostly depend on agriculture for their livelihoods. Most crops rely on rain — despite irregular and insufficient rainfall, frequent drought, and the existence of ample, untapped water resources. In Asia, 37 per cent of farmland is irrigated. In Africa, only 5 per cent is irrigated. Yet this land accounts for 20 per cent of agricultural production, pointing the way to greater food security. Because irrigated crop yields are double or more than for comparable rainfed yields, tapping this irrigation potential is essential for boosting the continent's agricultural productivity.

Over 40 per cent of Africa is classified as drylands. In these regions, the majority of streams are seasonal and rainfall is highly variable – temporally and spatially – characterized by intense convectional storms and long dry periods and droughts. In these regions, there is tremendous potential to harvest seasonal flood waters for domestic and productive purposes such as livestock watering, fish ponds and irrigated horticulture using a range of rainwater harvesting (RWH) technologies such as sub-surface and sand dams, riverbed wells and abstraction galleries, flood spreading weirs, rural road crossings and lateral bunds, also known as swales, jessours or tabias. Each technology is suited to different geophysical conditions and positions within a catchment.

The potential to expand dryland irrigation using water harvested from seasonal rivers is huge:

- 3.3 million ha is under spate irrigation in 14 countries around the globe yet in Africa, the practice is little known beyond North Africa and the Horn of Africa.
- There are more than 1,000 sand dams in SE Kenya with further examples reported in 13 more countries including Ethiopia, Namibia and Mozambique. Yet this represents a tiny fraction of their potential.
- There are 2.6 million kilometers of rural roads in drylands Africa with tens of thousands of seasonal river crossings, many with the potential to be adapted and equipped to harvest water.

So what is preventing this potential from being realized? A 2010 International Food Policy Research Institute (IFPRI) study of irrigation potential in Africa argues that the root of the problem isn't a lack of water – but a dearth of informed policies and targeted investments that are tailored to a region's specific landscape and economy. This, in turn, is seriously hampered by the lack of high-quality data. In Africa, the lack of weather stations and stream gauges, for example, seriously limits our understanding of the hydrology and water harvesting potential of dryland watersheds and limits our ability to correctly predict peak floods and design robust climate-resilient infrastructure.

The good news is developments in technology have opened a world of possibilities to close this gap. It is now feasible to map the key variables that shape hydrology and water harvesting potential (such as catchment size, slope, rainfall and river flow) and to share this knowledge with stakeholders in real time over the internet. The technology advances include:

- The advent of small, accurate, low-cost sensors that can record multiple variables including rainfall, water quality, soil moisture and river flow levels.

Examples of datasets	*Field Sensors*	*Crowd/field observations*	*Geo-satellite data*	*Examples of Information Generated*	*Examples of Knowledge and Application*
Time	X		X	Rainfall intensity (mm/hr)	Mapping extent of seasonal rivers and suitability of different RWH structures
Location (GPS)			X	Rainfall variability	
Catchment area			X	Runoff coefficient	Design dams and road-river crossings spillways to accommodate design flood
Slope			X	Aridity Index	
Vegetation density			X	Peak floods (1, 5, 10 year ...)	Informing farmers on the amount and spacing of irrigation
Soil water	X			River regime and discharge	
Rainfall	X			Flood hydrograph	Comparative cost–benefit analysis of different RWH technologies
Temperature	X			Storage capacity and yield	
Stream flow depth	X	X		Sediment drainable porosity	Monitoring water abstraction and groundwater recharge
Stream flow velocity	X			Sediment transport	
Flood duration & freq.	X	X		Hydraulic radius of channel	Data to monitor green water credit and payment for environmental services models
Groundwater depth	X	X		Drainage density	
Channel width & depth		X		Stream sinuosity index	Monitoring downstream impacts of upstream watershed management
Channel slope		X		Downstream impacts	
Stream networks		X		Groundwater recharge	Mapping areas of technical feasibility and greatest potential
Sediment depth		X		Water point functionality	
Sediment grain size		X		Watershed boundaries	Calculation of runoff from roads and design of storm drainage
Water point flow	X	X		Adaptation to climate change	
Water quality	X	X		Drought and flood forecasting and modelling	Guidance on technology choice and design
Mapping RWH structures		X			Ground truthing hydrology models

- The development of small, plug-and-play, solar-powered data loggers designed for isolated locations with the capacity to host and network multiple sensors and store and transmit data over the mobile network and internet.
- The growth in coverage of the mobile network across much of Africa and the world.
- Google earth imagery, data and mapping combined with other satellite data such as climate and digital elevation data openly available.
- Cloud computing.
- Smart phones and their apps.
- Growing opportunities for crowd science, where citizens and organizations collaborate to collect and pool data to create massive datasets.

These advances open up countless possibilities: the 'internet of things' in the jargon of its pioneers. Prior to these leaps in technology, it was financially and technically infeasible to collect, store, analyse and share this data. Now, technology combined with the knowledge of local people through crowd science, opens up the tantalizing prospect of mapping seasonal rivers and their water harvesting potential like never before and developing the **informed** policies and investments Africa so badly needs. Figure 1 describes some of the many ways in which (1) low-cost, networked field sensors, (2) field and crowd-sourced observations and (3) geo-satellite data could be combined to generate the information required to assess RWH potential, design RWH structures and integrate and monitor RWH and groundwater recharge within watershed management programmes. Excellent Development is working with others to explore this opportunity further. If you would like to be involved in this ambitious project, please contact the author: ian@excellent.org.uk.

Ian Neal is Technical and Development Manager at Excellent Development, a UK-based charity promoting food and water security amongst dryland farmers through agro-ecology, sand dams and water-harvesting