Rainwater Harvesting

Maintains Our House Year-round in the Desert Near Tucson

TWENTY YEARS EXPERIENCE

Charles J. Cole and Carol R. Townsend

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Cover Photo: **Our house in autumn with vegetables in the raised garden beds.**

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Summary

Water resources are significantly limited in southern Arizona and we may not find abundant additional water to import at a cost that residents can afford. Data from 20 years of experience at our house show that rainwater harvesting is one of the viable options for conserving the water that we have. Planning committees should investigate ways to maintain healthy, vibrant, thriving, and pleasant communities without additional water, in case that becomes our future. Instead of being caught unprepared, we should think about all future possibilities innovatively and realistically.

The main reasons for reduction of water to southern Arizona are: reduction of water in the Colorado River (largely due to less runoff from the Rocky Mountains); human population demands being above a sustainable level in the desert; and wasteful uses of water.

This is important to consider first. Is it feasible to capture the rain? The main reasons for reduction of water to southern Arizona are: reduction of water in the Colorado River (largely due to less runoff from the Rocky Mountains); human population demands being above a sustainable level in the desert; and wasteful uses of water. Rainfall data that we recorded at our house in the Tucson Mountains shows no significant decrease between 2007 and 2024 (see Appendix 1, Annual Rainfall). A plot of the data (Figure 1) shows an average of 10.9 inches per year (ranging from 7.3 to 16.5 inches). Regression analysis indicates that the best fit for an annual average for the figure is a flat straight line along 10.9 inches. There is no indication of either increasing or decreasing average annual rainfall between 2007 and 2024, although the extremes in rainfall appear to be wider since 2020. It is important to allow for these extremes in planning cistern size.

Residents of southern Arizona have two major problems. One is a lack of sufficient water for the growing residential and commercial development (for example, references *a; b; c; d; e*). The second is that most residents and public officials do not take the water problem seriously enough (for example, *f; g; h*).

Discussions about the water problem often focus on unrealistic proposals of how to import water at a cost of many billions of dollars. We also need to address a related question. How will our communities get by if no additional water is forthcoming? In addition, leaders need to learn more about developing successful local economies in limited or alternative-growth scenarios (for example, *i; j; k; l*).

Benefits to capturing and storing the rain for later use are: the water itself is free, does not flow off to other places, and does not evaporate and blow away. Some people worry that by harvesting the rain we are depriving nature of water it needs. However, our household water comes only from the rain falling on the footprint of our house, and a half-inch of rain gives us about 1,300 gallons of free water.

This report documents more than 20 years of experience with rainwater harvesting in the Sonoran Desert near Tucson. We obtain basically all the water we need for our household. This demonstrates that rainwater has tremendous potential, as has also been discussed by others among Tucson's modern water conservation pioneers (e.g., Drs. James [Jim] Riley, Grant McCormick, Courtney Crosson, and the Water Resources Research Center, University of Arizona; references *m, n, o*; Brad Lancaster; and the Watershed Management Group). Important data documenting the experiences at our house are presented in appendices after the References at the end of this report.

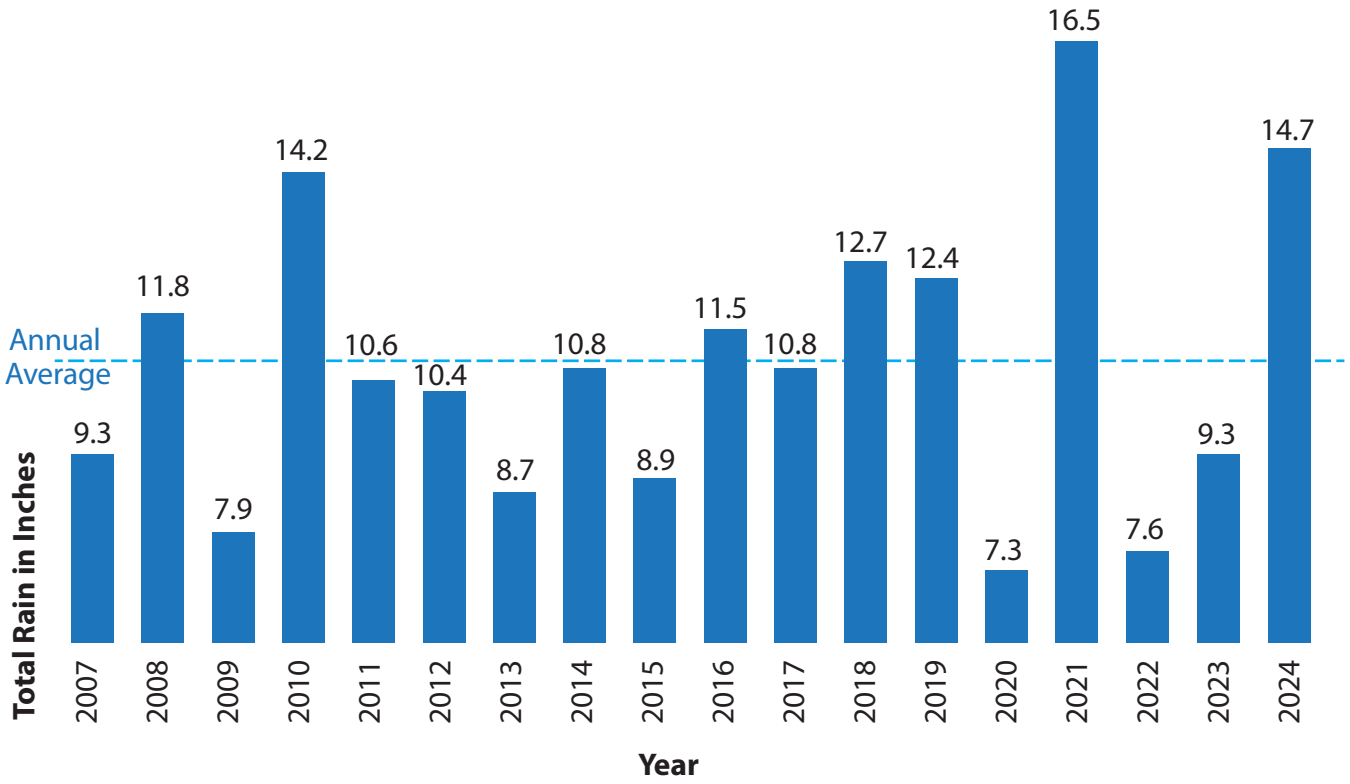

Figure 1: **Eighteen years of rainfall data at our house (years 2007 through 2024). Regression analysis indicates no change in average total rainfall (10.9 inches), although annual variation appears to have widened since 2020.**

Our House

The house was built in 2002—2003 in the foothills of the Tucson Mountains adjacent to Saguaro National Park West. The Contractor was Alain Provost (see Acknowledgments, below). The water system was based on an article in *Fine Homebuilding* magazine, which includes many construction details (*p*). Today there are alternative ways to do this, with different designs, materials, multiple buildings feeding into a very large cistern, and so-on (*q; r*), but here we simply describe briefly the successful system that has worked for us for more than 20 years. Initially, we were not certain how productive rainwater harvesting would be so we also drilled a well in 2002. It turned out that quality of the rainwater is so good and quality of the well water so awful that we use the well water for nothing more than the arid-land ornamental plants on the patio. We use the rainwater for all household purposes inside and the swimming pool and winter vegetable gardens outside (see Appendix 2, Amount of Water Captured, and Appendix 3, Amount of Water Used).

Water Collection System

The roof is galvanized sheet-metal with green color that was ceramically applied during manufacture. It is sloped and periodic application of chemical sealants is not necessary. The gutters and downspouts are green aluminum. In-ground pipes (ABS drain pipes) carry the water from the downspouts around the house to the cistern.

Roof Washer Filters (First Flush Filters)

These are simple filters positioned in the pipes shortly before the water enters the cistern. We used the ones originally built by The Water Filtration Company, Marietta, Ohio. The unit is a fiberglass box that directs the water through a ⅛" hardware cloth screen followed by fabric filters. This removes large debris like leaves, twigs, insects, and sediments, as the water goes onward to the cistern. Today, replacement filters are made by Rain Brothers, LLC (see Acknowledgments, below), but also there are now alternative designs for roof washers that may be easier to maintain and are available from local suppliers.

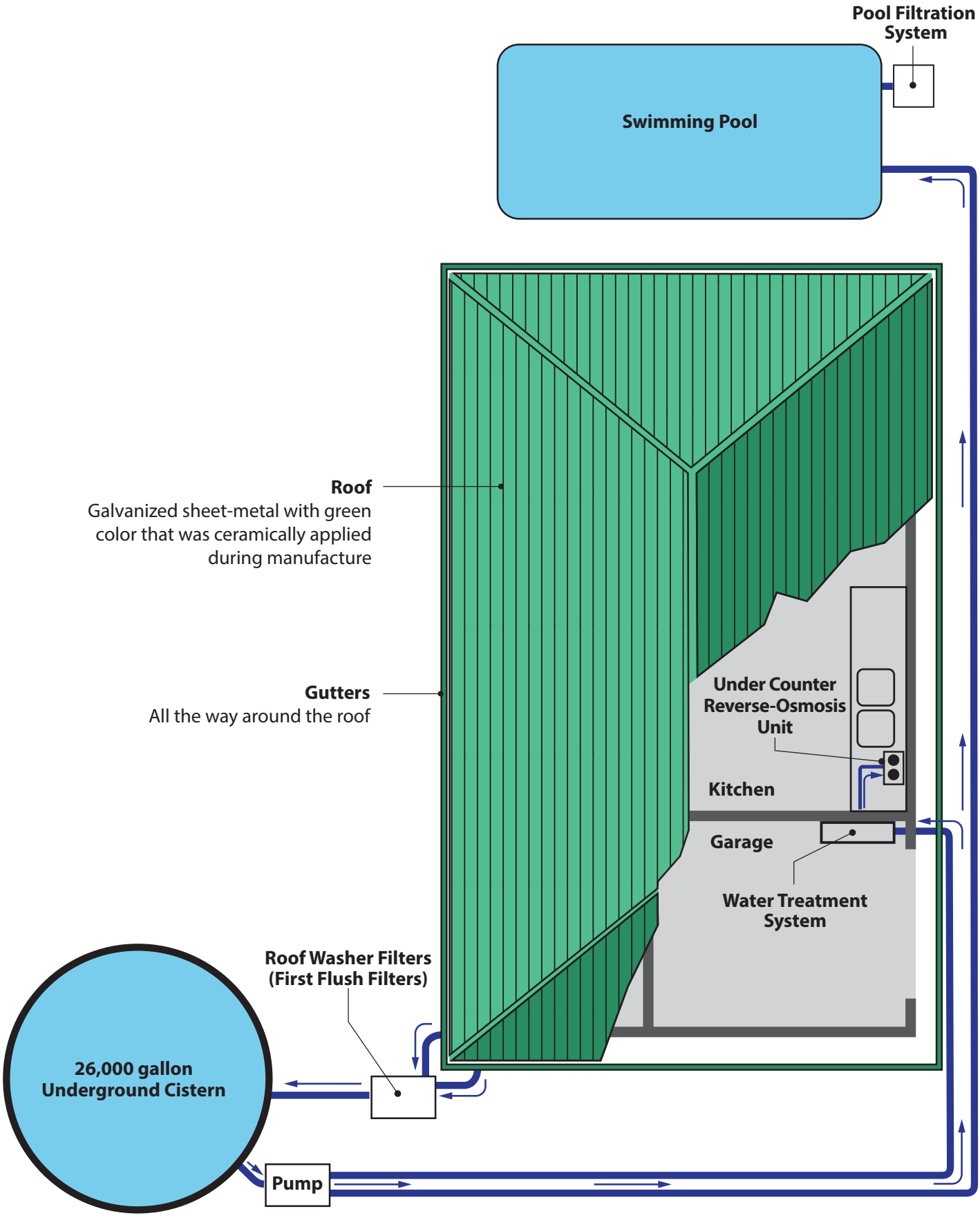

Figure 2: The rainwater harvesting system, viewed as a map, looking down on the house from above.

The rainwater system consists of five main parts (Figure 2)**.**

1. **Water Collection System,** including the roof, gutters, and pipes that take the rainwater to a large cistern.
2. **Roof Washer Filters** (also called first flush filters).
3. **The Cistern.**
4. **The Pump and Pipes that take Water from Cistern to the House and swimming pool.**
5. **The Water Treatment System.**

The Cistern

Our round cistern is about 20′ in diameter, sunk about 10′ in the ground. It is constructed of steel-reinforced shotcrete with an 8″ thick wall and floor, with a generous coating of Thoroseal (certified for potable water contact) on the interior surfaces. The cistern roof is steel reinforced concrete with a hatch through which one can place an aluminum ladder and climb down for rare maintenance inside (none has been needed so far). To measure depth of the water in the cistern we have a 12′ long dip-stick. The cistern capacity is nearly 26,000 gallons and the water is cost-free, thanks to the power of gravity.

The Pump and Pipes that take Water to the House

Adjacent to the cistern is a small housing unit for a 2 horse-power pump that sends water from the cistern to a pressure tank with the water treatment system in the garage, automatically on-demand, when pressure in the tank is low. The first use of electricity by the system is to run the pump for 20 seconds to fill the pressure tank. This part of the system was designed and built by Jimmy Wise and his father (see Wise Pump and Tank Service, Acknowledgments, below). Just before water enters the pressure tank, it passes through a 20″ tall 30 micron filter as the first step of the water treatment system.

The Water Treatment System

When a water-tap is opened in the house (for example, sink, shower, toilet) the pressure tank sends water through the purification system and on to the final destination. The water passes through a 4′ tall carbon filter unit full of activated charcoal; a 10″ tall 5 micron pleated sediment filter; ultra-violet light; and a 10″ tall 10 micron carbon block before going into the house. This provides clean water for showering, flushing toilets, and other purposes, including the 12,000-gallon swimming pool (which we keep covered to retard evaporation and which also has a hygiene system). Water for drinking, cooking, and ice cubes is treated by a small reverse-osmosis unit under the kitchen sink, which eliminates the tiniest things of concern, including viruses.

Water Volume Needed, Rainfall Expected, and Cistern Size

It is important to estimate how much water is needed per year, how much annual rainfall is expected at the site, and thus how large the collection surface area should be (for example, our roof; other surfaces are possible also). Lancaster (*s*) shows a formula for this relationship:

collection surface area (in sq. ft.) x annual rainfall (ft.) x 7.48 gal. (per cu. ft.)

Preliminary planning also should include how many people are in the household and whether to have a swimming pool. We have two people in the house and a swimming pool of about 12,000 gallons. Evaporation from the swimming pool uses more water than any other single use—about 50% in warm seasons but it varies widely between summer and winter. Nevertheless, we collected sufficient water to serve us year-round every year (see below). At times in the dry season when water in the cistern gets low (we check the volume each month) we conserve by using paper plates, running the dishwasher only once per week, and having short showers. Normally also, when rinsing vegetables at the kitchen sink, we catch the water in a bowl and pour it on the patio plants. In addition, we keep a bucket in the shower, so when turning on the shower we catch the water until it runs warm, then later empty the bucket into the swimming pool. On one occasion in 2022 at the height of an extreme drought we ordered two truckloads of water (about 3,600 gallons) but rain arrived shortly thereafter and we did not need the trucked supplement after-all! In the extreme drought of 2025 we ordered trucked water again, but it is too early at this writing to see whether it was really needed.

Our Water Use

We use the treated water from the cistern for all water needs inside the house and for the swimming pool and vegetable beds outside. Our two-person household uses an average of about 90 gallons per day total (45 gal/person; Appendix 3, Amount of Water Used). As this includes evaporation from the swimming pool, it varies widely from an average of about 61 gallons per day in winter to about 121 gallons in summer.

Maintenance of the rainwater harvesting system involves hosing out the roof washer filters twice per year, once after the first heavy rain of the summer monsoon season and once after the first heavy winter rain, which we do ourselves. As we're not do-it-yourselfers, we hire a professional water treatment service to change the other filters, the ultraviolet lamp, and replace the activated charcoal.

Maintenance

The roof, gutters, pipes, and cistern have not needed maintenance over 21 years and do not need any now. Only the filters and UV lamp need periodic cleaning or change (see Appendix 4, Maintenance Costs).

Construction Costs

The initial cost for building and outfitting the rainwater harvesting system was about $35,000 in 2003, or equivalent at the time to installing a swimming pool or adding another room to the house. Maintenance costs through the years are discussed in Appendix 4. Note that the cost of rainwater on our roof is not increasing, but the cost to import and/or greatly increase purification of water from public water supplies (for example, toilet-to-tap) will increase by many millions to billions of dollars.

Our Water Quality

Quality of our treated rainwater is outstanding—we venture to say about as good as or better than any water in southern Arizona, including from public water supplies. When we started using the cistern water in 2003, we knew that our treatment system was so good that we did not need to test the water quality. Over time, though, we had samples tested. In each test listed below, possible contaminants were far below any level needed to satisfy EPA drinking water standards for public water supplies.

August, 2011: We had Turner Laboratories test treated rainwater from both our kitchen sink and the reverse osmosis taps for arsenic and lead.

August, 2021: We had Turner Laboratories test treated rainwater from the garden hose we use on our vegetable gardens; this was the same level of treatment as the kitchen sink tap without reverse osmosis treatment. We tested for arsenic, cadmium, lead, and mercury.

December, 2022: We had Turner Laboratories test treated rainwater from both our kitchen sink tap (with no reverse osmosis) and the kitchen reverse osmosis tap for arsenic, copper, lead, and mercury.

May, 2015: The University of Arizona tested our reverse osmosis water in the Arizona Laboratory for Emerging Contaminants (ALEC), while

planning to include our rainwater harvesting system in their film *Beyond the Mirage*. They tested for chromium, arsenic, selenium, silver, cadmium, barium, mercury, lead, PFOA, and PFOs (Figure 3). None was detected at a level needed to satisfy EPA drinking water standards. PFOA and PFOS, if present, were below the level of detection for the tests, which were at parts per billion.

Author: Thien Tran

Report for Water quality from Cole's house

1) Inorganic Results:

	52 Cr	75 As	78 Se	107 Ag	111 Cd	137 Ba	202Hg	208 Pb
	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ug/l]	Conc. [ng/l]	Conc. [ug/l]
Collected sample	0.01	0.03	0.18	0.00	0.00	1.74	BDL	0.02
US EPA MCL	100	10	50	100	5	2000	2	15

BDL = below detection limit

Analyst:	MKA
Job:	1217-1219
Date:	5/29/2015

Please use the following statement when acknowledging this work:

The analyses for _____ were performed by the Arizona Laboratory for Emerging Contaminants (ALEC) at the University of Arizona, Tucson.

2) Organic Results:

	PFOA (ppb)	PFOS (ppb)
Collected Sample	<LOD	<LOD
Provisional Health Advisory	0.4	0.2

LOD = Limit of Detection
(PFOA = 0.006 ppb, PFOS = 0.005 ppb)

3) Potential Health Effects:

Chemical	Potential Health Effects
PFOA	Decreased body weights, increased liver weights, bladder cancer, reduced reproductive, developmental, and systemic effects
PFOS	
Chromium	Decreased pulmonary function, pneumonia, asthma and nasal itching
Arsenic	High cancer risk, skin damage and problems with circulatory system
Selenium	Problem with circulation, fingernail or hair losses
Silver	N/A
Cadmium	Kidney damage, kidney stones
Barium	Increase blood pressure
Mercury	High cancer risk
Lead	Detrimental to the neurological development of children, premature birth, cardiovascular effects

Analyst:	TT
Date:	5/05/2015

Please use the following statement when acknowledging this work:

The analyses for _____ were performed by the Arizona Laboratory for Emerging Contaminants (ALEC) at the University of Arizona, Tucson.

Figure 3: Results of analysis of our drinking water (treated rainwater) from the Arizona Laboratory for Emerging Contaminants. Everything is well within EPA limits, with better quality than for many public water supplies.

In addition, we occasionally test for Total Dissolved Solids (TDS in parts per million). The kitchen sink tap without reverse osmosis treatment usually has about 27, whereas the water after reverse osmosis treatment usually has 4. We assume that the low TDS is easy on appliances that use water.

Alternative Water Collection and Use

Rainwater harvesting can be applied in many ways, as mentioned in the Introduction. For example, systems can be built to provide some or all the water needed to support homes, gardens, parks, and businesses. Professionals have been designing and building local projects and these need much more serious attention, as any amount of water conserved is useful. Greywater systems and modern composting toilets (including indoors) are effective today also. If each of the approximately 250,000 homes on single-family residential lots captured an average of 1,000 gallons of rainwater per year, 250,000,000 gallons would be conserved. If they captured 5,000 gallons, that would be well over a billion gallons per year.

The Future

As documented above, there is considerable reduction in the amount of water flowing in the Colorado River and in many groundwater aquifers. While we may be hopeful about the future, we must admit that new sources of affordable water for southern Arizona might not be found. We cannot ignore this possibility. Fortunately, our data from 2007 through 2024 indicate that the average annual amount of local rainfall around our house near Tucson has not decreased in the last 18 years although there is wide variation (Figure 1; Appendix 1 [appendices follow References]). In periods of unusually extreme drought, authorities should allow purchase of rare truckloads of water from public water supplies for homes that have extensive rainwater harvesting systems.

Who We Are

The following is for readers who might be concerned because we are not hydrologists. As biologists who have worked professionally in scientific research for more than 50 years (with around 130 peer-

reviewed technical publications), we recognize the importance of potable water to living things, have experience in studying evolutionary biology in desert and tropical environments, have a broad knowledge of important research in related fields, and have a long-time view of the history of life (for example, *t; u*). We have spent decades in science working in the field and laboratories with the American Museum of Natural History in New York City, developing working hypotheses, accumulating observations, tabulating data, applying statistical analyses and making conclusions based on objectively gathered evidence. Our decision to build a rainwater harvesting system was based on experience with such systems in Guyana, South America and on robust scientific evidence that indicates the following.

1. Climate change has always been a part of Earth History and it is happening now. Will we change with it?

2. The most extensive and fast-moving environmental changes occurring today are a result of human activities disrupting natural processes by adding tons of pollutants such as carbon dioxide into the atmosphere each year.

3. Due primarily to climate change the amount of water in the Colorado River has greatly decreased and is not likely to be restored in the foreseeable future; yet people are planning to use more and more water.

4. People are also pumping considerable water from many aquifers, removing more water than is replaced each year. Consequently, the water table is falling rapidly in many places.

5. Despite all this, many people are encouraging population growth and industrial development beyond what can be supported by our current water supply. While the search for additional supplies for importation is admirable, what if no significant affordable water is found?

6. If we fail to manage our water supply realistically, our communities will collapse. We need to think about all future possibilities innovatively and realistically.

Acknowledgments

Alexander Mendes of Dubulay Ranch, Guyana, South America introduced us to household rainwater harvesting. In addition, the following individuals provided comments on an earlier version of the manuscript: Dennis Caldwell, Val Little, Ben Lomeli, Alain Provost, Doug Siegel, Skye Siegel, and Tom Wiewandt.

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Overall House Construction and Design: A. M. Provost, Inc.

Rain Brothers, LLC, Yellow Springs, Ohio sells replacement filters for our roof washers; catchingtherain@gmail.com.

Pump and Water System Details: Wise Pump and Tank Service, LLC, 7110 E. 29th St., Tucson, AZ 85710. Telephone 520-882-6288.

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Appendix 1: Annual Rainfall

We measure rainfall with a Bosmere Rain Gauge. It has a capacity to capture 2.0 inches of rain (more than 50 millimeters) and is graduated in both inches and millimeters. For inches, the first mark at the bottom is at 0.05 inch and upward the marks are at every 0.10 inch, so estimating total for a storm is reasonably accurate to a hundredth of an inch. Our measurements of rainfall for 2007-2024 are reasonably accurate, but possible sources of error include the following: we ignored days with only a trace of rain; on events of very heavy rains accompanied by wind and/or hail, some water splashed out of the gauge; and while on vacation we received rainfall data from neighbors who had different kinds of rain gauges.

The data in inches are:

2007=9.3	2016=11.5
2008=11.8	2017=10.8
2009=7.9	2018=12.7
2010=14.2	2019=12.4
2011=10.6	2020=7.3
2012=10.4	2021=16.5
2013=8.7	2022=7.6
2014=10.8	2023=9.3
2015=8.9	2024=14.7

(Fig. 1). Average (mean) = 10.9 inches/year, observed range = 7.3 to 16.5, slope = 0.

Appendix 2: Amount of Water Captured

Using the equation from Lancaster (q: p. 128), our roof of about 5,250 sq. ft., and average rainfall of 10.9" (=0.91 ft.), on an average year we capture about 35,736 gallons of water. As we use water between rainy seasons, we can capture more volume year-round than the capacity of the cistern. At the minimum of 7.3" per year (=0.61 ft.) this would be 23,955 gallons and at the maximum, 16.5" (1.38 ft.) this would be 54,193 gallons. Plan cistern size to accommodate wide variation in annual rainfall.

Appendix 3: Amount of Water Used

Upon moving into our house the builder gave us an estimate of the inside diameter and depth of the cistern. From this we estimated its capacity for water storage (volume of a cylinder X gallons/cubic foot). This allowed us to measure depth of the water at any time, figuring it contained about 216 gallons/inch.

In 2016 we calculated use of our rainwater to average a total of 90 gallons/day for two, or 45 gallons/person. About 33% of this is evaporation from the swimming pool (up to 50% during warm months even though we keep it covered until it becomes uncomfortably hot), much less from watering the small vegetable gardens in cool months. A swimming pool wastes a lot of water, even if covered (*v*). A new cover since 2023 conserves more water. Also, we have significantly improved water conservation while living with the system. During the early years, after we used water for an event we considered how we could have done it by using less water—this thinking becomes automatic when you know you are not connected to an apparently infinite supply of water but have a limited supply in a cistern beside the house.

Appendix 4: Maintenance Costs

Maintenance of the rainwater harvesting system involves hosing out the roof washer filters twice per year, once after the first heavy rain of the summer monsoon season and once after the first heavy winter rain, which we do ourselves. As we're not do-it-yourselfers, we hire a professional water treatment service to change the other filters, the ultraviolet lamp, and replace the activated charcoal. This means that the costs are higher than if we bought the materials and did the jobs ourselves. We replace the filters in the roof washers about every 10 years. The 30 micron filter is replaced every 1.5 years. Contents of the activated charcoal unit are replaced every four years. The UV lamp and reverse osmosis filters are replaced every year. The 5 micron and 10 micron filters are replaced together after 8 to 14 months, when the need is indicated by a reduction in water pressure in the house.

Annual costs for maintenance of the system varied from $342.00 to $2,345.75 from 2009 to 2024. Wide variation occurred because different parts require different maintenance schedules and in 2024 a new reverse osmosis unit was needed after 21 years. Also during the early years we replaced things more frequently than necessary and had professional water quality testing done as we learned about the system. Anyway, the average annual cost for 16 years was $898, or $74.85 per month, including the water for the vegetable gardens and swimming pool (the weekly pool service was not included in this). Considering that the cost per day was $2.45 ($74.85 monthly/30.5 days) and we used about 90 gallons per day, our cost was about 3 cents per gallon.

Anybody who compares their water costs with ours needs to realize that our cost includes obtaining and treatment of all our water, including the drinking water, swimming pool water, and watering small vegetable gardens. To make proper comparisons, one must include not only the monthly water bill but also costs for any treatment one might provide (water softener, iron filter, reverse osmosis), cost of services from any water purification company, and cost of all drinking water one might purchase from supermarkets or other outlets for drinking water.