Water Quality From Water-Harvesting Systems[1]

GARY W. FRASIER[2]

ABSTRACT

Water harvesting is a technique used to supply animal and domestic drinking water in areas where more conventional methods cannot supply sufficient water. The water collected by a water-harvesting system has the potential of being contaminated by deterioration by-products of the materials used in constructing the system, from dust that is deposited on the catchment surface, or from impurities trapped in the rain. During a 3-y period, runoff water samples were collected for water quality analyses from 10 types of catchment treatments on operational and experimental water-harvesting systems in Arizona. Atomic absorption spectrophotometry techniques were used to determine the concentrations of Al, As, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Hg, K, Na, V, and Zn in each water sample. There was no evidence that deterioration of the catchment treatments would cause a contamination of the runoff water. With the exception of As, most samples had significantly lower concentrations of these constituents than the maximum standards for animal or domestic drinking water supplies.

Arsenic was the only chemical consistently found in the water samples at potentially hazardous concentrations for domestic drinking water supplies. Excessive As concentrations were not associated with any specific type of catchment treatment. The logarithm of As concentration in the runoff was positively correlated with the logarithm of the time since the previous rain, and negatively correlated with the logarithm of the total rainfall quantity. Apparently, As was deposited on the catchment surface as dryfall dust, and/or was washed from the atmosphere by the rainfall.

Additional Index Words: precipitation, runoff water, drinking water, arsenic.

Rivers, streams, springs, and wells are major sources of drinking water for man and animals. Unfortunately, there are many areas that do not have access to surface water, and the ground water is below feasible drilling depths or of unacceptable quality. In these circumstances, cities and towns utilize large-capacity pipelines or canals to import the necessary water. Water hauling is frequently used to supply the domestic water for isolated ranches and farmsteads. These methods of water supply are expensive. Small earthen stockponds are a common method of supplying drinking water to livestock and wildlife on the rangeland. However, these small stockponds frequently go dry during periods of greatest need because of insufficient inflow. High seepage and evaporative losses from these ponds often exceed the quantity of water used by the livestock. Studies in Montana indicate that soluble salts in impounded

water can be concentrated by evaporation to levels potentially unsuitable for livestock use (Soiseth, 1975).

Water-harvesting techniques are being used to supply animal drinking water, and in limited instances, domestic water where more conventional water supplies are inadequate (Frasier, 1980). The basic components of a water-harvesting system are an impermeable, or slowly permeable, catchment surface for collecting precipitation, and a tank for storing the collected runoff water (Fig. 1). Various materials such as asphalt-fabric, sheet metal, concrete, etc., are used to cover the catchment surface. The storage tank can be any suitable water-tight container, and usually includes some method of evaporation control (Frasier, 1979).

The water collected by a water-harvesting system would normally be expected to contain only the impurities found in rain, droppings from birds and small animals, and constituents from the dust that settled on the catchment between rainfall events. Frasier and Myers (1970) found that photo-oxidation by-products of the asphaltic materials used in constructing the catchment and/or storage could create impurities that discolored the runoff water. These impurities were believed to be harmless, and did not impair usage of the water by cattle. The original objective of this study was to determine the effect of the treatment deterioration on the quality of water collected from various catchment treatments in Arizona.

PROCEDURE

The study was conducted from 1976 to 1979. Runoff water samples were collected from catchment treatments on test plots at the U.S. Water Conservation Laboratory's Granite Reef water-harvesting test site near Mesa, Ariz. A description of the catchment treatments on the plots is presented in Table 1. On the large plots (area > 180 m²), storm runoff was stored in buried concrete tanks. Runoff from the smaller plots (10 m²) was collected in partially buried, open-top, galvanized steel tanks. The quantity of runoff from each plot was measured for each runoff event, usually within 24 h, by pumping the collected water through calibrated water meters. As the water was being pumped from the storages, a grab sample was collected for chemical analysis. It was hypothesized that the maximum concentrations of potential contaminants in the runoff water would occur from small runoff events following extended dry periods. Consequently, water samples were collected from selected storms, which met this criteria (storm size < 23 mm; dry periods > 17 d). During one storm event (27 Sept. 1977), a supplemental set of runoff water samples was collected before the runoff reached the storage tank.

Concurrently, during the study, each time one of the operational water-harvesting systems throughout Arizona (Fig. 2) was visited, a sample of the 10-cm water surface in the storage tank was collected. One to four samples were collected from each site during the study period. A description of the treatments on each of the water-harvesting systems is presented in Table 2.

All water samples were collected in 2-L, high density polypropylene bottles that had been prewashed in deionized water. In the laboratory, each sample was divided and placed into 2 precleaned, 1-L bottles. Two milliliters of concentrated hydrochloric acid (HCl) were added to one bottle of each sample sub-set to preserve it until analysis at a later date. The pH and electrical conductivity (EC) of the water samples were measured on the nonacidified sample using standard laboratory analytical equipment and techniques. Atomic absorption spectro-
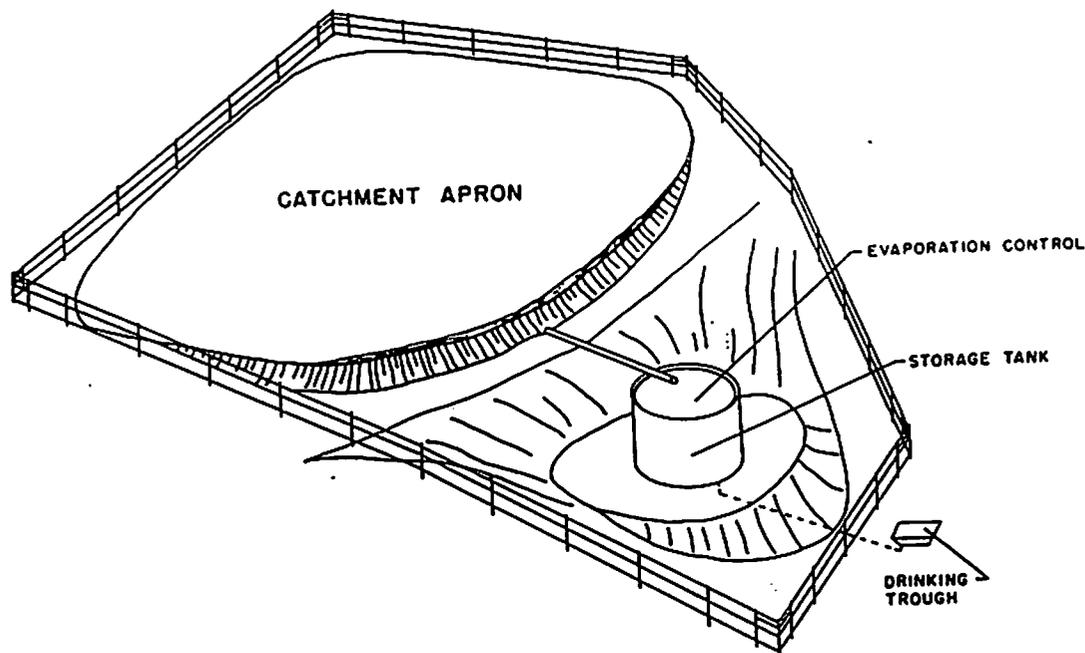
Fig. 1—Sketch of typical water-harvesting system for supplying animal drinking water.

photometry techniques were used to determine the concentrations of the following elements in each water sample: Al, As, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Hg, K, Na, V, and Zn.

Soil samples from selected water-harvesting sites were analyzed for water-soluble As using a 1:5 water extract procedure. A sample of the surface soil (0–10 cm) adjacent to the catchment apron was air-dried and sieved to remove stones and gravel (<2 mm). Fifty grams of soil was leached with water (250 g), and the As content of the extract determined.

Rainwater samples were collected near Tombstone, Ariz. using standard weighing rain gauges equipped with removable covers. The covers sealed against the rim of the rain gauges, preventing deposition of dust or dryfall in the collectors between storms. At the onset of a storm, a moisture sensor activated a motor circuit, which lifted the cover from the rain gauge. Following the storm, the motor repositioned the cover in place. The rainwater sample was removed from the rain gauge within 24 h and stored in prewashed, plastic bottles for analysis.

Table 1—Treatment description of plots at the Granite Reef test site.

Treatment	Catchment area	Shape	Slope	Treatment† age	Treatment description
	m²		%	years	
Gravel roofing	180	Rectangular	5	8.6	Standard rag-felt rock roofing
Wax (1)	197	Rectangular 'V'	10	3.8	Refined paraffin wax, 53°C AMP
Wax (2)	10	Rectangular	5	4.0	Refined paraffin wax, 63°C AMP
Wax (3)	10	Rectangular	5	0.3	Emulsified paraffin wax
Wax (4)	10	Rectangular	5	4.8	Slack wax—140
Wax (5)	10	Rectangular	5	4.8	Refined petroleum resin
Wax (6)	10	Rectangular	5	1.8	Crude nonrefined wax
Wax (7)	200	Square	5	0.9	Slack wax—140
Asphalt (1)	200	Square	5	0.7	Rapid cure asphalt (RC) sprayed on soil surface with sealcoat of anionic asphalt emulsion (SS2H)
Asphalt (2)	200	Square	5	6.3	Catonic asphalt emulsion invert (RSK Invert) sprayed on soil surface with sealcoat of cationic asphalt emulsion (SSKH)
Asphalt (3)	10	Rectangular	5	7.5	Medium cure asphalt (MC) sprayed on soil surface with sealcoat of cationic asphalt emulsion (RSK)
Asphalt-fabric (1)	10	Rectangular	5	7.5	Polypropylene matting saturated with anionic asphalt emulsion
Asphalt-fabric (2)	200	Square	5	0.2	Polypropylene matting saturated with anionic asphalt emulsion (SSH) with sealcoat of clay-filled asphalt emulsion
Asphalt-fabric (3)	1	Square	5	1.0	Fiberglass matting saturated with clay-filled asphalt emulsion
Asphalt-fabric (4)	200	Square	5	0.5	Polyester matting saturated with clay-filled asphalt emulsion
Rock-asphalt	10	Rectangular	5	7.5	Rubberized asphalt sprayed on soil surface with covering of gravel
Aluminized-asphalt (1)	180	Rectangular	5	8.5	Fiberglass matting saturated with anionic asphalt emulsion with sealcoat of polyvinyl chloride (PVC) and aluminum flakes
Aluminized-asphalt (2)	200	Square	5	0.1	Polypropylene matting saturated with anionic asphalt emulsion (SSH) with sealcoat of polyvinyl chloride (PVC) and aluminum flakes
Aluminum foil	200	Square	5	8.9	Aluminum foil bonded to soil surface with asphalt emulsion
Butyl	10	Rectangular	5	9.5	Nylon reinforced butyl sheeting 0.25 mm thick
Polyethylene	200	Square	5	8.2	Chlorinated polyethylene, 0.75 mm
Bare soil	200	Square	5	NA‡	Smoothed, bare soil surface
Silicone (1)	195	Rectangular 'V'	10	1.1	Silicone water repellent sprayed on soil surface
Silicone (2)	200	Square	5	1.1	Silicone water repellent sprayed on soil surface
Silicone (3)	180	Rectangular	5	4.7	Silicone water repellent sprayed on soil surface

† At time of first water sample collected.
‡ Not applicable.

RESULTS AND DISCUSSION

General

The various catchment surfaces were grouped into 10 general classes of treatments. A total of 112 water samples were collected and analyzed. A summary of the range of measured concentrations of each element in the water samples and the standards recommended for domestic and livestock drinking water is presented in Table 3.

Water samples collected from water-harvesting systems with steel-tank storages often contained Fe concentrations > 0.3 mg/L (the standard for domestic use), probably a result of corrosion of the tank walls. Iron was not a problem in water stored in concrete tanks, unless there were uncoated plumbing fixtures. Zinc concentrations in excess of the 5 mg/L standard for domestic use, were detected in 3 water samples collected from water-harvesting systems that had galvanized steel-tank storages. This was possibly a result of improperly applied or poor quality galvanized coatings. Water samples from other similar galvanized steel storages did not contain the high Zn concentrations.

A total of 12 water samples were found that contained Cr, Cd, Pb, and/or Hg concentrations that exceeded domestic water standards. Four other water samples contained Pb, Hg, and Zn that exceeded the standards for livestock drinking use. These water samples were not associated to any specific type of catchment treatment, sampling date, or water-harvesting site.

Arsenic Analysis

Arsenic was the only chemical consistently found in the water samples at potentially hazardous concentrations for domestic drinking water supplies. Although the As standard is 10 μg/L, if suitable water supplies are available, the limit for rejection and the standard used here is 50 μg/L (U.S. DHEW, 1962; U.S. EPA, 1976). The following discussion is primarily concerned with the results of the As analyses of the water samples.
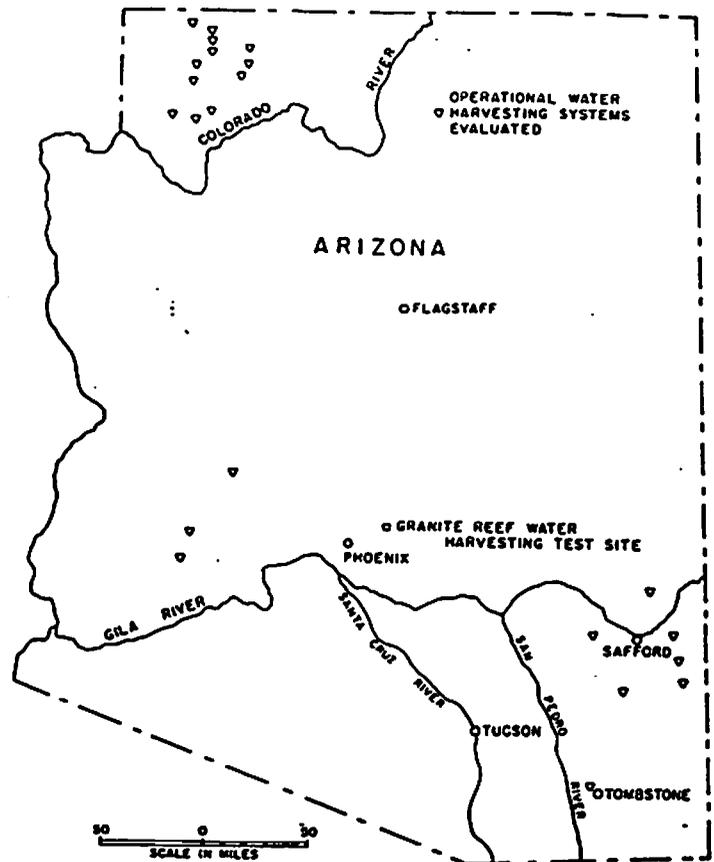

Fig. 2—Approximate locations of water-harvesting systems monitored during the study.

GRANITE REEF TEST SITE

Table 4 presents the measured concentrations of As in the water samples collected during the 3-y study period from the test plots at the Granite Reef test site. Also presented are: (i) time (days) since the previous storm, (ii) total rainfall quantity (mm), and (iii) total runoff quantity (mm) for the storm event.

Table 2—Treatment description of operational water-harvesting systems monitored during the study (1976-1979).

Location	Catchment treatment	Treatment† age	Treatment description	Type of storage tank
Burnt Ridge	Wax	0.3	Refined paraffin wax, 53°C AMP	Steel rim, concrete bottom
Westwind	Wax	0.1	Refined paraffin wax, 53°C AMP	Steel rim, concrete bottom
Temple	Wax	0.1	Refined paraffin wax, 53°C AMP	Steel rim, concrete bottom
Toquer	Wax	0.1	Refined paraffin wax, 53°C AMP	Steel rim, concrete bottom
Snap Point	Wax	2.9	Refined paraffin wax, 53°C AMP	Steel rim, concrete bottom
Slope	Wax	1.7	Refined paraffin wax, 53°C AMP	Steel rim, concrete bottom
Gubler	Wax	0.7	Refined paraffin wax, 53°C AMP	Steel rim, concrete bottom
Graham	Wax	2.1	Refined paraffin wax, 53°C AMP	Steel rim, concrete bottom
Corner	Wax	0.7	Refined paraffin wax, 65°C AMP	Enclosed steel tank
Twin Butte	Rubberized asphalt	1.0	Rubberized asphalt sprayed on soil surface	Steel rim, concrete bottom
Highway	Asphalt pavement	>10.0	Asphalt paving mix on highway	Steel rim, concrete bottom
M-M	Asphalt-fiberglass	1.0	Rubberized asphalt sprayed on fiberglass matting	Steel rim, concrete bottom
Cemetery Ridge	Asphalt-fiberglass	1.0	Clay-filled asphalt emulsion sprayed on fiberglass matting	Vinyl-lined steel tank
Bighorn	Asphalt-fiberglass	0.7	Clay-filled asphalt emulsion sprayed on fiberglass matting	Steel rim, bentonite clay bottom
Van Gussic	Asphalt-fiberglass	7.7	Clay-filled asphalt emulsion sprayed on fiberglass matting	Steel rim, concrete bottom
Poverty Mt.	Asphalt-fiberglass	2.8	Anionic asphalt emulsion sprayed on fiberglass matting	Steel rim, concrete bottom
Cowhide	Resin-fiberglass	10.0	Polyester resin sprayed on fiberglass matting	Chlorinated polyethylene pit lining
Montijo	Aluminized asphalt fiberglass	0.5	Clay-filled asphalt emulsion spray on fiberglass matting with surface coating of polyvinyl chloride (PVC) and aluminum flakes	Enclosed steel tank
Seegmuller	Butyl	>3.0	Butyl sheeting, 0.75 mm thick	Enclosed steel tank
Tank Mt.	Sheet metal	>3.0	Galvanized, corrugated sheet metal	Vinyl-lined steel tank

† At time of first water sample collected.

Table 3—Range of concentrations of selected inorganic elements in runoff water collected from treatments on field catchments and test plots at Granite Reef.

Chemical constituent	Standards A†	B‡	Wax	Silicone	Asphalt	Aluminized asphalt coating	Aluminum foil	Galvanized steel sheet metal	Poly-ethylene	Butyl	Gravel roofing	Bare soil
pH	5.0–9.0		6.0–7.1(8)¶	6.4–6.5(3)	3.9–7.2(10)	5.5–6.4(2)	6.4(1)		6.5(1)	6.6–7.2(2)	6.3–6.6(3)	6.4(1)
						μg/L						
Arsenic	50	200	7–100(31)¶	6–45(6)	8–190(33)	8–29(8)	10–20(4)	6–158(2)	8–43(4)	9–11(2)	7–18(5)	8(1)
Cadmium	10	50	0–7(31)	0–1(6)	0–3(32)	0–2(8)	0–1(4)	1(1)	1–15(4)	<1(2)	<1(5)	0(1)
Chromium	50	1,000	0–88(31)	0–18(6)	0–586(32)	0–16(8)	0–38(4)	2(1)	0–15(4)	2–3(2)	1–3(5)	3(1)
Lead	50	100	0–150(31)	0–26(6)	0–37(32)	0–21(8)	0–15(4)	0(1)	0–14(4)	0–8(2)	1–11(5)	14(1)
Mercury	2	10	<1–33(22)	<1(6)	<1–4(27)	<1–1(6)	<1–3(3)	<1(1)	<1(2)	<2(2)	<1(5)	<1(1)
Vanadium	NS§	100	0–4(30)	0–1(6)	0–7(32)	0–10(8)	0–1(4)	2(1)	<1(4)	0(2)	<1(5)	–
						mg/L						
Aluminum	NS	5	<1–10(31)	<1–10(6)	<1–9(32)	<1–10(8)	1–6(4)	<1(1)	<1–5(4)	6–10(2)	<1–9(5)	2(1)
Calcium	NS	NS	1–46(30)	4–15(6)	1–57(32)	1–27(8)	2–6(4)	25(1)	2–32(4)	3–4(2)	5–24(5)	5(1)
Cobalt	NS	1	<1–5(26)	<1(4)	<1–2(28)	<1(6)	<1–1(3)	1(1)	<1(1)	1(1)	<1(5)	<1(1)
Copper	1	0.5	0–0.2(31)	0–0.1(6)	0–0.2(32)	0–0.1(8)	0–0.4(4)	0(1)	<0.1(4)	0(2)	<0.1(5)	<0.1(1)
Iron	0.3	NS	0–16(31)	0–5(6)	0–19(31)	0–3(8)	0–0.5(4)	0(1)	0–0.5(4)	0.4–7(2)	0–1(5)	2(1)
Magnesium	NS	NS	1–5(29)	1–3(6)	<1–6(31)	<1–2(8)	<1(4)	1(1)	<1–2(4)	<1(2)	1–2(5)	2(1)
Potassium	NS	NS	1–16(26)	1–5(5)	<1–21(28)	<1–4(8)	1(3)	3(1)	1–2(4)	1–2(2)	1–7(5)	5(1)
Sodium	NS	NS	<1–8(28)	1–9(5)	<1–75(31)	<1–3(7)	<1–2(4)	60(1)	1–3(4)	1(2)	2–3(5)	3(1)
Zinc	5	25	0–30(31)	0(5)	0–12(32)	0–73(8)	0(4)	<1(1)	0(4)	0–4(2)	0–3(5)	0(1)
EC	NS	NS	61–175(17)	20–96(5)	15–225(22)	20–195(6)	15–55(3)	460(1)	10–125(2)	20–55(2)	55–95(5)	70(1)

† Column A denotes standards for domestic water.
‡ Column B denotes standards for livestock water.
§ No standard recommended.
¶ Numbers in parenthesis are the number of water samples analyzed.

The results showed that, with 2 exceptions, the samples collected on 14 Apr. 1976, 23 July 1976, and 27 Sept. 1977 contained < 15 μg/L As. Conversely, most of the samples collected on 13 Nov. 1976, 5 July 1977, and 28 June 1978 contained As concentrations > 18 μg/L.

There was no consistent relationship between the As concentration in the water samples collected directly from the plots during the storm on 27 Sept. 1977 and the As concentrations of the samples taken from the storage tank. One possible explanation is that the As concentration in the runoff water is nonuniformly distributed temporally and spatially, thus the few samples taken were not representative of the total storm runoff.

The highest concentrations of As were measured in the water samples collected on 28 June 1978. Most of the samples contained As concentrations from 20 to 45 μg/L. The runoff water sample from the Wax (5) treatment contained 100 μg/L of As, which may be an artifact.

Four water samples collected on 28 June 1978 contained other elements (Cr, Pb, Hg, and Cd) in excess of domestic drinking water standards. There was no apparent association between elevated concentrations of these elements and the type of catchment treatment.

At present, the sources of the As in the runoff water are not definitively known. A rainwater quality study in northern California postulated that various chemical constituents could occur on a surface as dry fallout and be washed from the atmosphere by rain (Kennedy et al., 1979). If we assume that the source of As in the runoff is of atmospheric origin, which is deposited on the catchment surface as both rainfall and dry deposition between storms, and there is instantaneous and complete mixing between the rainfall and the dry deposition before runoff, we would expect the As con-

centration in the runoff to be inversely proportional to the rainfall volume, and directly related to the mass of dry deposition. This can be expressed in a regression relationship of the form

$$\log C_A = \log A + b_1 (\log P) + b_2 (\log T) \quad [1]$$

where, C_A = arsenic concentration, in μg/L; P = storm precipitation, in mm; T = time since previous storm, in days; and A, b_1, and b_2 = coefficients. The As concentration from the Granite Reef test site was fitted to equation [1] by least squares techniques. Performing the log transformations yielded

$$C_A = 14.3 \, (T^{0.54}/P^{0.86}) \quad [2]$$

with $r^2 = 0.56$, showing that the As concentration was approximately proportional to the square root of the time between storms, and inversely proportional to the quantity of precipitation.

The roughness of the catchment surface is a factor which could influence the measured concentration of As in the runoff water. A rough catchment surface, such as gravel-covered polyethylene, can trap significantly larger quantities of wind-blown particles than a smooth surface such as asphalt-fiberglass. To examine the possible association between elevated concentrations of As and the catchment treatment, deviations from the regression equation (Eq. [1]) were calculated for each class of catchment treatment. The mean deviations for each class were not significantly different from zero. This finding suggests that the quality of runoff water from different treatments is governed primarily by rainfall quality and dry fallout, rather than by the catchment treatment.

Table 4—Concentration of As in runoff water from various catchment treatments at the Granite Reed water-harvesting test site.

Sample date	Rainfall	Time since previous rain	Catchment treatment	Runoff	As concentration
	mm	days		mm	µg/L
14 Apr. 1976	11.4	42	Gravel roofing	6.8	7†
23 July 1976	22.3	76	Gravel roofing	16.9	8
			Wax (1)	17.6	12
			Wax (2)	23.8	10
			Asphalt (1)	16.7	11
			Asphalt (2)	9.9	11
			Asphalt (3)	13.4	11
			Asphalt-fabric (1)	NM‡	9
			Rock-asphalt	20.3	11
			Aluminum-asphalt (1)	20.7	8
			Aluminum foil	18.3	10
			Butyl	21.7	9
			Polyethylene	21.3	11
			Bare soil	9.6	8
			Silicone (1)	17.9	11
			Silicone (2)	7.1	13
			Silicone (3)	15.3	6
13 Nov. 1976	3.8	21	Wax (1)	2.6	13
			Wax (3)	2.6	19
			Asphalt (1)	1.6	46
			Asphalt-fabric (1)	3.1	19
			Asphalt-fabric (2)	2.2	28
			Aluminum-asphalt (1)	3.3	18
5 July 1977	4.8	53	Aluminum-asphalt (1)	6.1	13
			Aluminum-asphalt (2)	6.1	22
			Asphalt-fabric (3)	NM	20
27 Sept. 1977	8.1	18	Gravel roofing	5.0	12 (18)§
			Wax (1)	6.3	10 (13)
			Wax (2)	6.6	27 (11)
			Asphalt (1)	4.7	11 (12)
			Asphalt-fabric (1)	7.4	37 (9)
			Aluminum-asphalt (1)	8.0	9 (6)
			Aluminum-asphalt (2)	8.0	9 (1)
			Aluminum foil	6.2	10 (12)
			Polyethylene	8.0	8 (22)
			Silicone (3)	3.5	13 (19)
28 June 1978	7.4	81	Wax (1)	4.9	38
			Wax (4)	NM	31
			Wax (5)	NM	100
			Wax (6)	NM	23¶
			Wax (7)	NM	32#
			Asphalt-fabric (1)	NM	29
			Asphalt-fabric (4)	6.3	25††
			Aluminum-asphalt (1)	4.8	29
			Aluminum-asphalt (2)	7.5	31
			Aluminum foil	5.0	20
			Polyethylene	6.7	43‡‡
			Silicone (2)	NM	45

† Standard for domestic water is 50 µg/L.
‡ Not Measured.
§ Water collected during runoff event before entering the storage tank.
¶ Also contained 33 µg/L Hg (standards, 2 µg/L).
# Also contained 88 µg/L Cr (standards, 50 µg/L) and 150 µg/L Pb (standards, 50 µg/L).
†† Also contained 4 µg/L Hg (standards, 2 µg/L) and 586 µg/L Cr (standards, 50 µg/L).
‡‡ Also contained 15 µg/L Cd (standards, 10 µg/L).

Table 5—Concentration of As in runoff water from various operational water-harvesting systems.

Location	Treatment	Sample date	As concentration
			µg/L
Northwest Arizona			
Burnt Ridge	Wax	29 Aug. 1977	11
		9 May 1978	17
Westwind	Wax	24 Aug. 1976	18
		31 Aug. 1977	9
		10 May 1978	11
Temple	Wax	24 Aug. 1976	95
		30 Aug. 1977	10
		11 May 1978	14
Toquer	Wax	31 May 1977	11
		10 May 1978	20
Snap Point	Wax	29 Aug. 1977	11
Slope	Wax	11 May 1976	8
		23 Aug. 1976	10
		31 Aug. 1977	9
		10 May 1978	17
Gubler	Wax	9 May 1978	34
Twin Butte	Rubberized asphalt	25 Aug. 1976	8
		30 Aug. 1977	11
M-M	Asphalt-fiberglass	25 Aug. 1976	9
		30 Aug. 1977	12
		10 May 1978	18
Poverty Mt.	Asphalt-fiberglass	10 May 1978	17
Cowhide	Resin-fiberglass	31 Aug. 1977	14
		10 May 1978	12
Seegmuller	Butyl	24 Aug. 1976	11
Southeast Arizona			
Graham	Wax	3 Apr. 1978	23
Corner	Wax	4 Apr. 1978	28†
Highway	Asphalt pavement	29 Apr. 1976	8
		7 Sept. 1976	9
Van Gussic	Asphalt-fiberglass	4 Apr. 1978	19
Montijo	Aluminized asphalt fiberglass	5 Apr. 1978	16
West Central Arizona			
Cemetery Ridge	Asphalt-fiberglass	10 June 1977	190‡
		21 Apr. 1978	79
		15 June 1979	70
Bighorn	Asphalt-fiberglass	10 May 1976	16§
		15 Mar. 1976	18
Tank Mt.	Sheet metal	10 June 1977	158
		15 June 1979	6

† Also contained 94 µg/L Pb (allowable = 50 µg/L).
‡ Also contained 106 µg/L Cr (allowable = 50 µg/L).
§ Also contained 240 µg/L Cr (allowable = 50 µg/L).

One set of rainwater samples collected on 13 Mar. 1982 near Tombstone, Ariz. was analyzed for As. None was detected (detection limit 0.2 µg/L). Small et al. (1981) reported background As levels of 0.008 ± 0.001 µg/m³ of air from samples collected by aircraft at heights of 150–1,000 m above the ground. If all this As is washed from a 1,000-m column of the atmosphere by a single 10-mm precipitation event, the expected As concentration in the water would be approximately 0.8 µg/L. Andreae (1980) showed that the As concentrations in rain from oceanic air masses in the northern hemisphere is < 0.1 µg/L, and estimated that continental precipitation might contain 0.2–0.4 mg/L As.

OPERATIONAL WATER-HARVESTING SYSTEMS

Table 5 presents the As concentrations in the water samples collected from the operational water-harvesting systems. Most of the measured As concentrations were > 10 µg/L, but < 50 µg/L, the rejection limit for drinking water supplies. The samples that exceeded As standards were collected from the Temple water-harvesting system in northwestern Arizona, and from the Cemetery Ridge and Tank Mountain systems in west-central Arizona.

Three water samples contained Cr and Pb in concentrations exceeding domestic drinking water standards. These high concentrations were not associated with a specific catchment treatment.

For most of the treatment classes, the small number of samples collected preclude the making of definitive

Table 6—Arsenic (As) content of soils near selected water-harvesting sites.[†]

Location	Concentration	Total As in a 10-mm soil layer
	$\mu g/g$	g/m^2[‡]
Granite Reef test site	0.012	1.50×10^{-4}
Westwind	0.0085	1.06×10^{-4}
Bighorn	0.036	4.50×10^{-4}
Temple	0.013	1.60×10^{-4}
Slope	0.0535	6.69×10^{-4}

[†] Determined as a 1:5 water extract.
[‡] Bulk density of soil assumed at 1.25 g/cm³.

statements concerning the differences in water quality. However, it is possible to test the Null hypothesis that there is no difference between the proportion of runoff samples (sample P_W and P_A) from wax treatments and asphalt treatments that exceed 50 $\mu g/L$ As concentrations. Let

$$P_W = K_W/N_W, \qquad [3]$$

where N_W is the total number of water samples from wax catchments and K_W is the number of samples for which the As concentration exceeds 50 $\mu g/L$, and

$$P_A = K_A/N_A, \qquad [4]$$

where the subscript A denotes asphalt treatments. To test the Null hypothesis,

$$H_O : P_W = P_A = \pi, \qquad [5]$$

we calculate the test statistic Z,

$$Z = \frac{P_W - P_A}{[\pi(1 - \pi)(1/N_W + 1/N_A)]^{-2}}. \qquad [6]$$

When N_W and N_A are sufficiently large, Z will be approximately normally distributed with $E(Z) = 0$, and $V_{AR}(Z) = 1$ (Yamane, 1964).

Using the data in Table 5, $N_W = 18$, $P_W = 0.0555$, $N_A = 15$, $P_A = 0.200$, $\pi = 0.1212$, and $Z = 1.267$. Under the Null hypothesis, the difference between P_W and P_A could occur by chance 1 time out of 10. Therefore, the Null hypothesis that there is no effect of catchment treatment on the concentration of As cannot be rejected.

Even though the majority of the runoff water samples from the field catchments and the plots at Granite Reef contained < 50 $\mu g/L$ As in the standards, the measured quantities from 10 to 190 $\mu g/L$ were greater than initially expected, but are similar to measured As concentrations in surface water samples collected from 130 points in the United States (5–336 $\mu g/L$, mean 64 $\mu g/L$; Kopp, 1969).

To gain an insight into the source of the As in the water samples, soil samples adjacent to 5 water-harvesting sites were obtained and analyzed for total water-soluble As, using the 1:5 water extract procedure. The total water-soluble As per unit area (m²) for a soil layer 10 mm thick, assuming a bulk density of 1.25 g/cm³, was calculated for each of the 5 sites. Total As in the sampled soils was from 1×10^{-4} to 6.7×10^{-4} g/m²

(Table 6). With an As concentration of 10 $\mu g/L$ in the runoff water, there are 1×10^{-5} g of As per mm of runoff per m². Assuming a total runoff from a catchment surface of 200 mm/y with 10 $\mu g/L$ As there would be a total of 2×10^{-3} g As/m², which is greater than the total water-soluble As extracted from a 10-mm soil layer. Sediment measurements on the Slope catchment showed an average soil loss of < 2 mm/y. Arsenic can occur in soil as several forms, of which not all are measured in the water extract procedure used. Even so, these data imply that there is significantly more As in the runoff water than would be expected from local dust deposition on the catchment surface or surface erosion.

Franzin and McFarlane (1980) found a positive correlation of As in snow around a base metal smelter in Canada. There was a general decline of As deposition with increasing distance from the smelter. The direction of the prevailing wind did modify the deposition pattern. Andreae (1980) found As concentrations from 10 to 25 $\mu g/L$ in rain and snow for distances of up to 35 km downwind of a large copper smelter. Small et al. (1981) reported As concentrations in plumes of Cu smelters in southeastern Arizona were 1,500–5,000 times greater than the background As concentrations. The absence of wind-movement data prevents the development of any specific correlations of the measured As concentrations in the runoff water to the proximity of the smelters.

SUMMARY AND CONCLUSIONS

Water harvesting is a technique used to supply animal and domestic drinking water in areas where more conventional methods cannot supply sufficient water. The water collected by a water-harvesting system has the potential to be contaminated by deterioration by-products of the materials used in constructing the system, from dust that is deposited on the catchment surface, or from impurities trapped in the rain.

A 3-y study was conducted to evaluate the potential hazard of deterioration by-products of materials used in the catchment construction for contaminating the runoff water. During the study period, water samples were collected from 10 types of catchment surfaces on 20 operational water-harvesting systems and 21 plots at the U.S. Water Conservation Laboratory's Granite Reef water-harvesting test site. These samples were analyzed for various cations and heavy metals. With the exception of As, most of the samples had significantly *lower* constituent concentrations than the standards allowed for animal or domestic drinking water. Water samples collected from galvanized steel tank storages often contained Fe or Zn concentrations at levels higher than allowed, which indicated rust-corrosion of the storage and improperly applied or formulated galvanized coatings.

A total of 12 out of 112 water samples were collected that had concentrations of Cr, Cd, Pb, and/or Hg that exceeded the standards for domestic water supplies. The presence of these elements was not associated to specific catchment treatments, indicating that the source of the contaminants was not caused by weathering deterioration of the catchment treatments.

Arsenic was the only chemical consistently found in the water samples in potentially hazardous concentra-

tions for domestic drinking water supplies. Arsenic was found in 6 samples at concentrations greater than the allowable 50 μg/L. Most water samples contained 10–30 μg/L As, similar to reported As concentrations of surface water in the United States. The measured As concentrations were not associated with any specific type of catchment treatments.

The data indicate that the As concentration in the runoff water is directly proportional to the square root of time between precipitation events, and inversely proportional to the total precipitation quantity. Analyses for As in the surface soil near selected water-harvesting catchments indicate that local wind-blown dust was not the major source of the As. Possible sources of the As are suspended particles washed from the atmosphere by rainfall, or airborne particles deposited on the catchment surface, then washed into the storage tank in the runoff water.

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