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Performance Evaluation of Water Harvesting Catchments

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Abstract

The runoff efficiencies of 14 operational water harvesting catchments were estimated using a small portable sprinkler. The sprinkler method was verified using actual rainfall-runoff data from test plots of various water harvesting treatments at the Granite Reef Test Site. Sprinkler results showed that membrane-type treatments yielded 90-100% runoff. The runoff from properly installed wax-type treatments averaged over 80%. The sprinkler method permitted evaluation of catchment runoff efficiencies without resorting to the time and effort required for large field-instrumentation projects.

The performance of a water harvesting system as a water source is directly related to the relative impermeability of the catchment apron. To determine the quantity of water that can be collected from a given rainfall, the runoff efficiency of the catchment surface must be known. A common practice is to compute the water yield from field catchments based on average runoff results obtained from similarly treated small instrumented plots. Membrane treatments of sheet metal, artificial rubber, or asphalt fiberglass are commonly assumed to yield 90 to 100% of runoff. Water repellents, waxes, soil dispersants, and gravel-covered sheeting treatments have runoff efficiencies somewhat less that 90% (Frasier 1975). Field catchments, installed under less-than-ideal conditions, may have rough or irregular surfaces which can retain or trap water. On large catchments, nonuniform application or variations in soil texture can leave areas inadequately water-proofed. These and other problems can reduce the runoff efficiency of an operational water harvesting system. A small portable sprinkler was used to estimate the runoff efficiencies of various catchment treatments on 14 operational water harvesting systems.

Procedure

The sprinkler system used in the studies is shown in Figure 1. Water was sprayed downward from a height of 152 cm onto a 1-meter square test area from a single, low pressure, wide angle, fine drop size, full square spray nozzle. The test area was located in the center of the spray pattern and defined by a metal shield sealed to the soil surface by a foam rubber cushion on top of a layer of bentonite clay. The runoff water from the soil was trapped at the lower side of these test area and collected by a small vacuum line for measurement in a graduate plastic chamber. Wind disturbance of the spray was minimized by a curtain fastened to the framework. Water sprayed outside the 1-square meter test area was collected in a channel around the metal shield and conveyed away from the test area. The spray application rate was set prior to testing by placing a metal pan over the test area and adjusting the water pressure at the nozzle until a constant spray rate of 45 to 50 mm/hr was achieved. Without shutting off the spray, the pan was removed, and the water was then sprayed directly onto the catchment surface within the test area for 10 to 15 minutes. The sprinkler was then moved to a new location on the catchment surface and the procedure repeated. Two to three sites were usually evaluated on each catchment.

The accumulative runoff from each test was recorded and plotted vs. the accumulative water applied (Fig. 2). The best fit straight line from least square regression analysis was fitted for all points after runoff had started. The *X*-axis intercept represented the threshold rainfall or the amount of water applied before runoff started. The slope of the line represented the runoff efficiency of the treatment after runoff started. The sprinkler method was compared with actual rainfall results obtained from 11 different types of water harvesting membranes and soil treatments on field-sized plots at the Granite Reef Test Site, located approximately 25 km northeast of Mesa, Ariz. The treatments are described in Table 1. Precipitation runoff from each plot was collected in an underground tank and measured after each storm event by pumping the water through precalibrated water meters. Precipitation was measured with a network of rain gages. For each plot, the actual rainfall threshold and runoff efficiency after threshold was determined by standard linear regression analysis of rainfall-runoff data from individual storm events, but omitting storm events with zero runoff (Fink and Frasier 1977).

Results and Discussion

Granite Reef Test Site

Table 2 shows the sprinkler-runoff and the rainfall-runoff results for the 11 plots at the Granite Reef Test Site. Linear regression analysis showed that the sprinkler treatments overestimated the runoff efficiencies by 8% on the treatments with low runoff efficiencies (50−70%), but by only 2% on the treatments with good runoff efficiency (90−100%) (r^2=.8). This may have resulted from the relatively high sprinkling rate as compared with average rainfall intensities of actual storm events. The sprinkler overestimated the threshold rainfall by 0.8 mm on all of the treatments (r^2=.86). The sprinkler evaluation results for the silicone treatments showed large variations in the runoff efficiencies and threshold rainfalls within the catchment areas. Myers and Frasier (1969) showed that this could have resulted from non-uniform treatment application, soil erosion,

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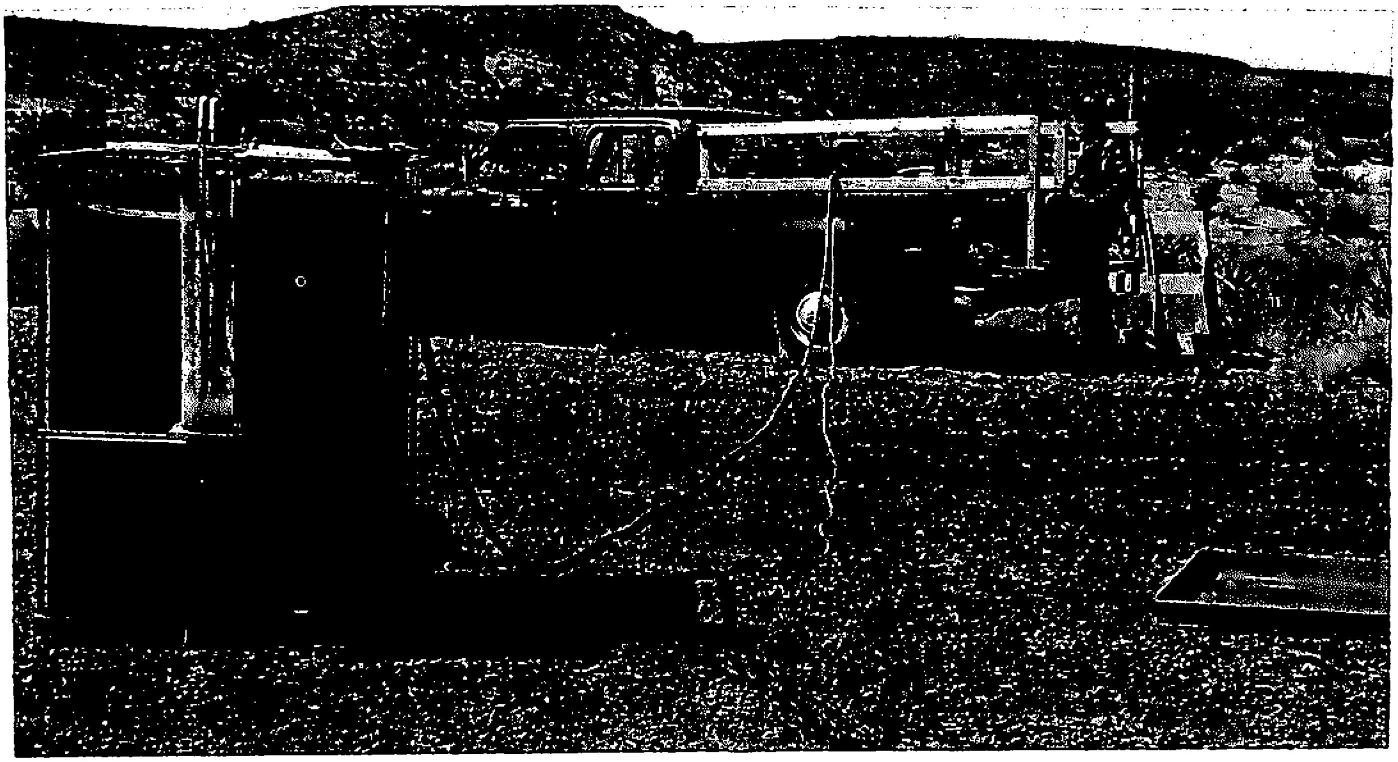

Fig. 1. Portable sprinkler for determining runoff efficiencies.

and treatment deterioration.

Based on these studies, we concluded that the sprinkler method could be used to estimate the performance of membrane and some chemical soil treatments.

Operational Water Harvesting Catchments

Table 3 summarizes results of sprinkler tests on 14 operational water harvesting catchments in Arizona with various surface treatments. The first five catchments have membrane-type treatments. The gravel-covered polyethylene catchment (Boggs Ridge) had the highest threshold rainfall (4.4 mm) plus relatively low runoff efficiency (57%). Inspection of the plastic sheeting under the gravel revealed numerous small holes, probably caused during installation which contributed to the poor runoff performance. The resin fiberglass, asphalt-fiberglass, and butyl-rubber catchments each had good runoff efficiencies and low threshold water retention.

The remaining nine catchments were water repellent treatments of paraffin wax, installed 2 months to 3 years prior to testing. The Slope catchment has been tested five times since installation. The average threshold rainfalls were essentially the same for all tests. The lower runoff efficiencies measured in the spring as compared to the fall tests indicated climate and/or soil

Table 1. Treatment description of plots at the Granite Reef Test Site.

Treatment	Catchment area (m^2)	Shape	Slope (%)	Treatment age (Years)	Treatment description
Chlorinated polyethylene	200	Square	5	8.5	30 mil chlorinated polyethylene bonded to soil with asphalt emulsion
Asphalt-polypropylene	200	Square	5	0.2	Polypropylene matting and anionic asphalt emulsion (SS-2) (1.5 kg asphalt/m^2) sealed with clay asphalt emulsion (1.4 kg asphalt/m^2)
Asphalt fiberglass	180	Rectangular	5	9.3	Chopped fiberglass matting and cationic asphalt emulsion (RSK) (1.5 kg asphalt/m^2) sealed with clay asphalt emulsion (1.4 kg asphalt/m^2)
Wax	197	Rectangular "V"	10	4.2	Refined paraffin wax, 55 C AMP (0.7 kg/m^2)
Aluminum foil	200	Square	5	9.3	1 mil aluminum foil bonded to soil with RSK asphalt emulsion (0.7 kg asphalt/m^2)
Sprayed asphalt	200	Square	5	13.6	Basecoat of rapid cure asphalt (RC) (1.5 kg asphalt/m^2). Sealcoat SS-2 asphalt emulsion (2.0 kg asphalt/m^2)
Concrete	112	Rectangular	4	8.2	Concrete slab 15 cm thick
Gravelled roof	180	Rectangular	5	9.3	Standard rag felt-rock roofing
Silicone (1)	200	Square	5	1.5	Silicone water repellent (0.057 kg/m^2)
Silicone (2)	195	Rectangular "V"	10	2.1	Silicone water repellent (0.030 kg/m^2)
Silicone (3)	180	Rectangular	5	6.1	Silicone water repellent (0.036 kg/m^2), plus soil stabilizer (0.024 kg/m^2)

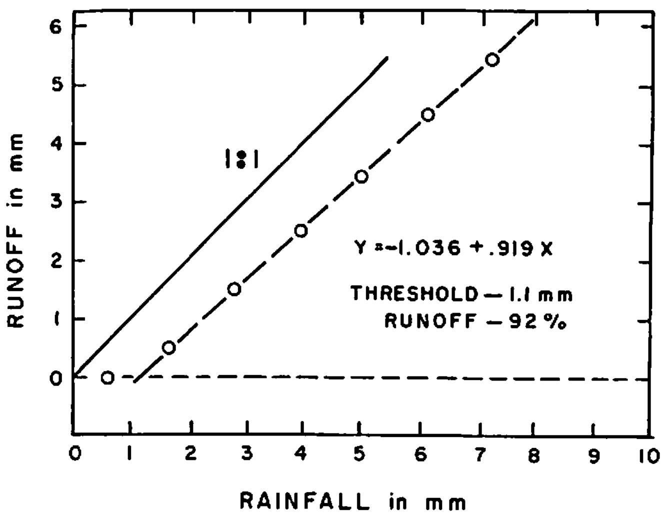

Fig. 2. *Rainfall runoff relationship as determined with portable plot sprinkler.*

temperature may have affected the performance of the treatments. During cooler periods, the wax may crystallize and crack, which could reduce the soil water repellency. During the summer, the soil temperature would be sufficient to remelt the wax and restore the water repellency.

Runoff efficiencies measured on the Snap Point catchment are relatively low; yet this water-harvesting system is supplying the required amount of drinking water for the livestock and wildlife using the area (Cooley et al. 1978).

The low runoff efficiency measured on the Temple catchment in August, 1976, may have been expected in retrospect. The recommended procedure for wax treatments is to construct catchments with less than 8% slope so that the velocity of the water flowing over the catchment surface is low enough to minimize possible soil erosion. This catchment had an average slope of over 10%, and in some areas the slopes were approximately 20%. Also, the original was application rate was less than what now is recommended for soils of this type. This catchment surface was severely damaged from an unusually intense thunderstorm in September 1976. The damaged areas were repaired and retreated with wax in July, 1977. Sprinkler tests since then indicate good runoff efficiencies (over 80%). The catchment still has an excess slope, and can potentially be damaged by high intensity precipitation events.

Tests on the Westwind catchment in August, 1976, showed an average runoff efficiency of 88%. It was believed that insufficient wax for the soil type had been applied. In July, 1977, additional wax was applied. Sprinkler tests since re-treatment have not shown a consistent increase in runoff efficiencies. Runoff averaged 90, 84, and 85% when checked in August, 1977, May, 1978, and September, 1978, respectively.

The Burnt Ridge, Toquer, and Gubler catchments were all treated in July, 1977. Sprinkler tests in August, 1977, showed average runoff efficiencies of 92 and 95% from Burnt Ridge and Toquer, respectively, but the Gubler catchment averaged only 59%. Similar runoff efficiencies were measured on these three catchments in May, 1978, and September, 1978. The exact cause of the poor performance on the Gubler catchment is unknown. Some chemicals in the soil may be causing an adverse interaction with the paraffin.

The Corner catchment was hand smoothed and treated with a granulated paraffin wax spread on the soil surface in a uniform layer. The hot soil temperatures during the next 3 days were sufficient to melt the wax into the soil. Sprinkler tests on this catchment in May, 1978, showed essentially 100% runoff. The threshold rainfall was relatively high, partially a result of the rough catchment surface.

The Graham catchment had the best runoff results (100%) of any of the field catchments treated with wax. The soil at this site is a loamy sand formed from decomposed granite. This catchment also has a southwestern exposure, which was an

Table 2. Sprinkler-runoff and rainfall-runoff efficiencies of 11 water harvesting treatments at the Granite Reef Test Site.

			Sprinkler evaluation		Precipitation efficiency	
Treatment	Test year	No. of tests	Threshold rainfall (mm)	Runoff efficiency after threshold (%)	Threshold rainfall (mm)[1]	Runoff efficiency after threshold (%)[1]
Chlorinated polyethylene	1976	1	.6	100	.1	97
Asphalt-polypropylene	1977	1	1.2	100	.4	100
Asphalt-	1976	1	1.0	95	.1	97
fiberglass	1977	1	1.0	96	.1	95
Wax	1976	2	1.2	92 (91-93)[2]	.2	88
	1977	3	1.1 (0.9-1.4)[3]	86 (79-99)	.1	81
Aluminum foil	1976	1	1.3	88	.3	82
Sprayed asphalt	1976	1	1.1	84	.3	77
Concrete	1977	1	1.1	75	.9	75
Gravel-covered roofing	1977	2	2.8 (2.6-2.9)	77 (74-80)	1.8	74
Silicone (1)	1976	2	2.9 (1.7-1.3)	90 (81-99)	1.8	76
	1977	3	2.9 (1.7-4.4)	81 (74-91)	2.3	67
Silicone (2)	1977	3	1.4 (1.1-1.9)	79 (66-91)	1.1	71
Silicone (3)	1977	3	1.6 (1.1-2.0)	72 (66-77)	1.8	66

[1] Determined by linear regresson as described by Fink and Frasier, 1977. Does not include storms with no runoff.
[2] Range of runoff efficiency.
[3] Range of threshold rainfall.

Table 3. Threshold runoff and runoff efficiency after threshold as determined by sprinkler testing on 14 operational water harvesting catchments.

Catchment name	Treatment	Date Installation	Date test	Threshold rainfall No. of tests	Threshold rainfall Avg (mm)	Threshold rainfall Range (mm)	Runoff efficiency Avg (%)	Runoff efficiency Range (%)
Boggs Ridge	Gravel-covered polyethylene	70	Apr. 76	2	4.4	(4.2-4.6)	57	(44-70)
Van Gusic	Asphalt-fiberglass	Oct. 70	Apr. 76	3	0.6	(0.5-0.8)	96	(92-100)
Montijo	Asphalt-fiberglass	Aug. 71	Apr. 76	4	0.7	(0.4-0.8)	94	(88-100)
Cowhide	Resin-fiberglass	67	May 76	1	0.5	–	97	–
Seegmuller	Butyl rubber sheeting	[1]	Aug. 76	1	1.3	–	100	–
Slope	Paraffin wax (0.9 kg/m²)	Sept. 74	May 76	3	0.9	(0.9-1.0)	78	(61-91)
			Aug. 76	3	1.4	(1.2-1.6)	96	(93-100)
			Aug. 77	3	1.2	(0.9-1.6)	84	(69-84)
			May 78	3	1.0	(0.6-1.2)	79	(73-87)
			Sep 78	3	1.6	(1.4-1.8)	96	(93-100)
Snap Point	Paraffin wax (0.9 kg/m²)	Sept. 74	May 76	3	1.1	(0.8-1.5)	67	(57-79)
			Aug. 77	3	1.0	(1.0-1.1)	70	(48-88)
Westwind	Paraffin wax (0.9 kg/m²)	June 76	Aug. 76	3	1.1	(0.8-1.6)	88	(74-99)
	Additional wax (0.9 kg/m²)	July 77	Aug. 77	3	1.3	(1.3-1.3)	90	(83-96)
			May 78	3	1.1	(0.9-1.6)	84	(84-85)
			Sept. 78	3	2.2	(1.8-2.7)	88	(76-94)
Temple	Paraffin wax (0.9 kg/m²)		Aug. 77	2	1.3	(1.3-1.3)	81	(65-90)
	Re-treated (1.5 kg/m²)		May 78	3	1.1	(0.8-1.4)	94	(90-100)
			Sept. 78	3	1.9	(1.7-2.1)	87	(82-93)
Burnt Ridge	Paraffin wax (1.5 kg/m²)	July 77	Aug. 77	3	1.6	(1.2-2.1)	92	(81-100)
			May 78	3	1.3	(1.1-1.4)	84	(69-94)
			Sept. 78	3	2.5	(2.2-2.8)	93	(83-99)
Toquer	Paraffin wax (1.5 kg/m²)	July 77	Aug. 77	3	1.3	(1.2-1.4)	95	(92-98)
			May 78	3	1.5	(1.2-1.9	89	(86-92)
			Sept. 78	3	1.8	(1.5-2.1)	91	(74-100)
Gubler	Paraffin wax (1.5 kg/m²)	July 77	Aug. 77	2	1.5	(1.4-1.5)	59	(28-29)
			May 78	2	3.2	(2.6-3.7)	48	(36-59)
			Sept. 78	3	6.2	(5.2-7.7)	48	(37-56)
Corner	Paraffin wax (0.9 kg/m²)	Aug. 77	May 78	4	1.7	(1.4-2.3)	99	(96-100)
Graham	Paraffin wax (0.9 kg/m²)	Aug. 76	May 78	3	1.2	(1.2-1.2)	100	(100-100)

[1] Prior to 1975.

advantage in maintaining high soil temperature which aided in remelting the wax and resealing the catchment surface.

Summary and Conclusions

The performance of a water harvesting system depended upon the effectiveness of the catchment apron treatment to inhibit infiltration. Water yield estimates of operational water-harvesting catchments are usually based on the average runoff obtained from small instrumented similarly treated plots. A small portable sprinkler was developed to estimate the runoff efficiency of operational water harvesting catchments. The sprinkler method, which evaluates 1-meter-square portions of the catchment, was validated by comparing the results with actual precipitation-runoff measurements from various catchment treatments at the Granite Reef Test Site. This sprinkler method permitted the evaluation of the performance of operational water-harvesting catchments, without the labor and expense of standard runoff instrumentation.

The sprinkler was used to estimate the runoff efficiency from various type treatments on 14 operational catchments. The results indicated that membrane treatments, like asphalt fiberglass or butyl, yield 90 to 100% precipitation runoff. A gravel-covered polyethylene treatment required a high threshold rainfall quantity to overcome the water retention within the gravel layer. Small holes in the plastic sheeting contributed to the low runoff efficiency.

The sprinkler results from the wax-treated catchments showed that this treatment can be effective treatment for water harvesting catchments. One wax catchment had a very poor runoff efficiency. Further studies are needed to explain why the wax treatment was not effective on this catchment.

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