The Use of Wax-Fiberglass as a Catchment Surface for Water Harvesting in Hawaii

Circular C 79

United States Department of Agriculture
Science and Education Administration
in cooperation with
Division of Water and Land Development
DEPARTMENT OF LAND AND NATURAL RESOURCES
State of Hawaii

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By Gary W. Frasier

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Honolulu, Hawaii
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Trade and company names are included for the benefit of the reader, and do not imply any endorsement or preferential treatment of the products listed by the United States Department of Agriculture or the State of Hawaii.

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THE USE OF WAX-FIBERGLASS AS A CATCHMENT SURFACE FOR WATER-HARVESTING IN HAWAII

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ABSTRACT

Domestic water development in the rural areas of Hawaii is difficult because of extreme temporal and spatial variations in the rainfall distribution, salt water intrusion into groundwater supplies, relatively porous soils, and a mountainous topography lacking suitable impounding reservoir sites. Water-harvesting is a means of water supply which may be used in these areas. A newly developed wax-fiberglass membrane catchment apron was installed on an operational water-harvesting system to determine the feasibility of the treatment for a water supply compared to standard water-harvesting methods used in the state. Studies indicated that the runoff water, with proper chlorination, would be acceptable as a potable water supply. The wax-fiberglass catchment was one-third to one-half the cost of comparable sheet metal or artificial rubber coverings.

INTRODUCTION

Purpose and Scope:

This report presents the preliminary results of a study to determine the feasibility of using a newly developed wax-fiberglass membrane catchment apron for water-harvesting to supply domestic water in Hawaii. Detailed analysis or discussion of the application of the data is beyond the scope of the report.

Background:

The basic water resource in Hawaii is precipitation. Hawaii's water supply problems are not from a general shortage of precipitation, but result from temporal and spatial variabilities in the rainfall distribution, coupled with an insufficient number of water-storage facilities. Some parts of the Islands are classified as desert, with rainfall less than 200 mm (8 inches) per year, whereas the other nearby areas are among the wettest areas in the world, with precipitation in excess of 10,000 mm (400 inches) per year. The rainfall distribution, combined with mountainous topography and insufficient suitable impounding resrvoir sites, makes the development of Hawaii's water resources both difficult and costly.

Except for the urban population centers on the outlying islands, rural populations are scattered in sparse settlements in fairly remote areas. Many of these settlements do not have an adequate source of potable surface or groundwater. One method of supplying water in these areas is collecting and storing precipitation runoff from the roofs of buildings, a form of water-harvesting. A few butyl rubber and sheet metal catchments have been constructed specifically for collecting rainwater, but these are primarily used for livestock drinking water, and have not been used to supply potable water. The State of Hawaii, Department of Land and Natural Resources (DLNR), through its

Division of Water and Land Development (DOWALD), in cooperation with the United States Department of Agriculture (USDA), Science and Education Administration (SEA), initiated a study to investigate the feasibility of specifically installed water-harvesting systems to supply domestic water to these remote areas. The study also included tests to determine if the runoff water from a catchment surface would meet the drinking water quality standards set by the U.S. Public Health Service.

DESCRIPTION OF TEST INSTALLATION

Location:

The study site was at an anthurium farm on the southernmost island of Hawaii, near the town of Mountain View (Fig. 1), at an elevation of 480 m (1590 ft) (latitude 19° 31'41", and longitude 155° 6'33"). This test site is located in the 5000-mm (200-inch) median rainfall zone on the northeastern flank of the active volcano Kilauea. Sugarcane is the primary agriculture in this region, with scattered homesteads of truck-farming crops and anthurium flower growers.

Treatment:

SEA personnel used knowledge gained in constructing water-harvesting systems in Arizona as guidelines to determine the type of treatment and installation techniques for the study. The "soils" at the test site were limited, derived from unweathered lava flows with very little fine material. To provide a suitable catchment surface, some type of additional fine soil covering was required. A volcanic ash obtained from a cinder cone at the Puna area was selected for the covering material. A sample of the cinders was sent to the U.S. Water Conservation Laboratory (SEA) in Phoenix, Arizona to determine the type of catchment treatment suitable for the study. A membrane composed of chopped fiberglass matting saturated with a two-phase treatment of molten wax was selected as a potential treatment. The wax provided the necessary water-proofing, and the fiberglass membrane the necessary reinforcement to prevent cracking of the surface.

In June, 1977 a bulldozer was used to construct a 23- x 23-meter (75-ft) pad for the catchment apron. This pad was covered with a 5-cm (2-inch) layer of the Puna cinders to fill the large voids between the rocks to provide a smooth base for the catchment treatment (Photos 1a through 1d). A misunderstanding with the contractor resulted in an average catchment slope of less than 2% instead of the required 5-8% slope. This problem was not noticed until just prior to installation of the membrane. The outlet from the catchment drained into a 1.9 million-liter (500,000-gallon) butyl-lined reservoir (Fig. 2). The wax was melted in a 750-liter (200-gal) roofing tar kettle equipped with two 10,000 BUT per hr propane burners and a gasoline-powered gear pump sprayer (Photo 2). Starting at the lower edge of the catchment, a strip about 150-cm (5-ft) wide was sprayed with the molten slack wax (Chevron Slack Wax 140) at a rate of 1-kg per sq m (2 lb per sq yd) (photo 3). A strip of chopped fiberglass matting (Owens-Corning M-700, 1-1/2 oz/ft^2) was unrolled over the area and saturated with the slack wax at a rate of 1-kg per sq m (2 lb per sq yd) (Photo 4a). This process was continued with lap joints of 5 to 10 cm (2 to 4 in) over the entire area (Photo 4b). The hot wax softened the starch sizing in the matting, allowing it to conform to the minor surface irregularities, and provided a good bond at the lap joints. A berm of the cinders was placed around the edges of the catchment to seal the membrane to the soil to prevent wind damage. The membrane was given a final sealcoat of refined paraffin wax 70^{C} (160) AMP (average melting point) sprayed on at a rate of 2 lbs/yd^2. In September, 1977 a second coating of the refined paraffin wax was applied at a rate of 0.8 kg per sq m (1.5 lbs per sq yd).

Instrumentation:

In September, 1977 a critical depth flume with a capacity of 43 liters per sec (675 gal/min) was installed to measure the rate and quantity of runoff from the catchment. A tipping bucket raingage, 0.25 mm per tip (.01 inch/tip) was used to measure the amount and intensity of the rainfall events (Photo 5). The data were recorded on a dual trace 30-day stripchart recorder.

Water Analysis:

Beginning in November, 1977 water samples were collected at 10-day intervals from the water stored in the butyl-lined reservoir below the catchment for total- and fecal-coliform analyses. Starting in January, 1978 an integrated sample of runoff water from the wax-fiberglass catchment surface was collected in 1-liter (1-quart) bottles mounted at the flume outlet. In February, 1978 water samples were collected from a corrugated fiberglass-roofed greenhouse. Starting in April, 1978 water samples were collected from a household tap fed by a rooftop catchment on a residential house about 3 miles from the test site. All water sampling and analysis was done by the State of Hawaii, Department of Health, Hilo Laboratory, in accordance with approved U.S. Public Health Service drinking water procedures. Both multiple-tube fermentation and membrane filter techniques were used to determine bacterial density.

On 10 October and 26 December, 1978 water samples were collected from the wax catchment's butyl-lined reservoir, the greenhouse roof reservoir, a residential galvanized rooftop catchment, and a standard municipal well in the Hawaii County water system. These samples were sent to the Honolulu office of the Department of Health for analysis of heavy trace metals and various inorganic anions and cations.

Data Processing:

Flume and raingage recorder charts were removed at a 4-week interval and sent to the U.S. Water Conservation Laboratory, Phoenix, Arizona for processing. An analog-to-digital chart reader was used to tabulate the rainfall-runoff data by individual storm events.

RESULTS AND DISCUSSION

Water Quality:

The results of the multiple-tube fermentation and membrane filter analysis of the collected water samples are presented in Tables 1 through 4 for the butyl-lined reservoir at the test site, direct runoff from the wax-fiberglass catchment, runoff from a greenhouse roof stored in a butyl-lined reservoir, and a residential rooftop catchment, respectively. Some of the samples collected from the butyl-lined reservoir at the test site and from the water collected from the catchment at the flume outlet were found to contain fecal coliforms. Water from the adjacent greenhouse rooftop reservoir also contained fecal coliforms during a brief interval in August, 1978. The source of these coliforms is unknown. These results indicated that the water would have to be chemically treated to be certified for potable use. The water from the residence rooftop catchment did not show any coliform during the test period. The results of the analyses for heavy metals and inorganic elements from the two samplings are presented in Table 5. The measured quantities of the elements, except zinc, were all less than the maximum allowed by the Public Health Standards. The relatively high quantity of zinc in the water from the residential galvanized rooftop catchment is from the galvanized coating of the sheet metal.

Runoff Efficiency and Catchment Performance:

Tables 6 and 7 show the rainfall and runoff quantities from the wax-fiberglass catchment by individual storm events. Data for periods during which the raingage and/or water stage recorder malfunctioned are omitted from the table. The relatively low runoff efficiency measured during the larger precipitation events resulted from the insufficient catchment slope. For many storms, the collected water overflowed the catchment sides instead of draining into the reservoir. This would have been prevented if the catchment had been properly sloped toward the outlet. Figure 3 presents the results of linear regression analysis of the rainfall-runoff data. The analysis showed an average runoff efficiency of about 50%. Inspection of the individual storm rainfall-runoff data indicated that, for events with precipitation quantities greater than 5 mm (0.2 in), runoff from only about 60% of the catchment area reached the pond. Comparison of the runoff data by 4-month intervals showed no decrease in catchment performance during the test period.

The catchment surface weathered satisfactorily and showed no visible signs of deterioration of the wax surface or damage from high winds. Stray cattle walked over the surface without visibly damaging the membrane, except for track marks. Plant growth was not a problem even though the site was in a high rainfall zone conducive to good vegetation growth. Observations made during rainfall events showed no discoloration of the runoff water.

Costs:

A total of 3.5 kg of wax was applied per square meter (7.5 lb per sq yd) of catchment area at a cost of $1.40 per sq m ($1.65 per sq yd). The fiberglass matting costs another 58 cents per sq m (70 cents per sq yd), for a total materials cost of $1.98 per sq m ($2.35 per sq yd). Other materials presently in use as water-harvesting catchments in Hawaii, such as galvanized sheet metal and butyl rubber sheeting, cost $3-5 per sq m ($4-6 per sq yd). The total cost of any system must also include the cost of site preparation. The landowner cleared the site, prepared the catchment pad, and hauled the cinders. The catchment apron was prepared by a bulldozer in 8 hours. The cinders were spread and the membrane installed by 3 people in 3 days (72 manhours). Costs for these items are estimated to be $1.70-2.60 per sq m ($2-3 per sq yd). Most types of catchment treatments would require the same costs. These costs are highly variable, depending upon the type and amount of soil available, land topography, available equipment, and site accessibility.

SUMMARY

A cooperative study between the State of Hawaii Department of Land and Natural Resources, Division of Water and Land Development, and the U.S. Department of Agriculture, Science and Education Administration, was initiated to develop water-harvesting methods that would be suitable for furnishing potable water supplies for remote homesites and villages. A test installation using a newly developed membrane of wax-fiberglass was installed in June, 1977. Measurements of precipitation runoff from the membrane indicated the treatment was capable of collecting large quantities of water. Water quality analyses indicate that the water, with proper chlorination, would be acceptable as a potable water supply. The treatment cost was 1/3 to 1/2 the cost of comparable treatments of galvanized sheet metal and artificial rubber sheeting.

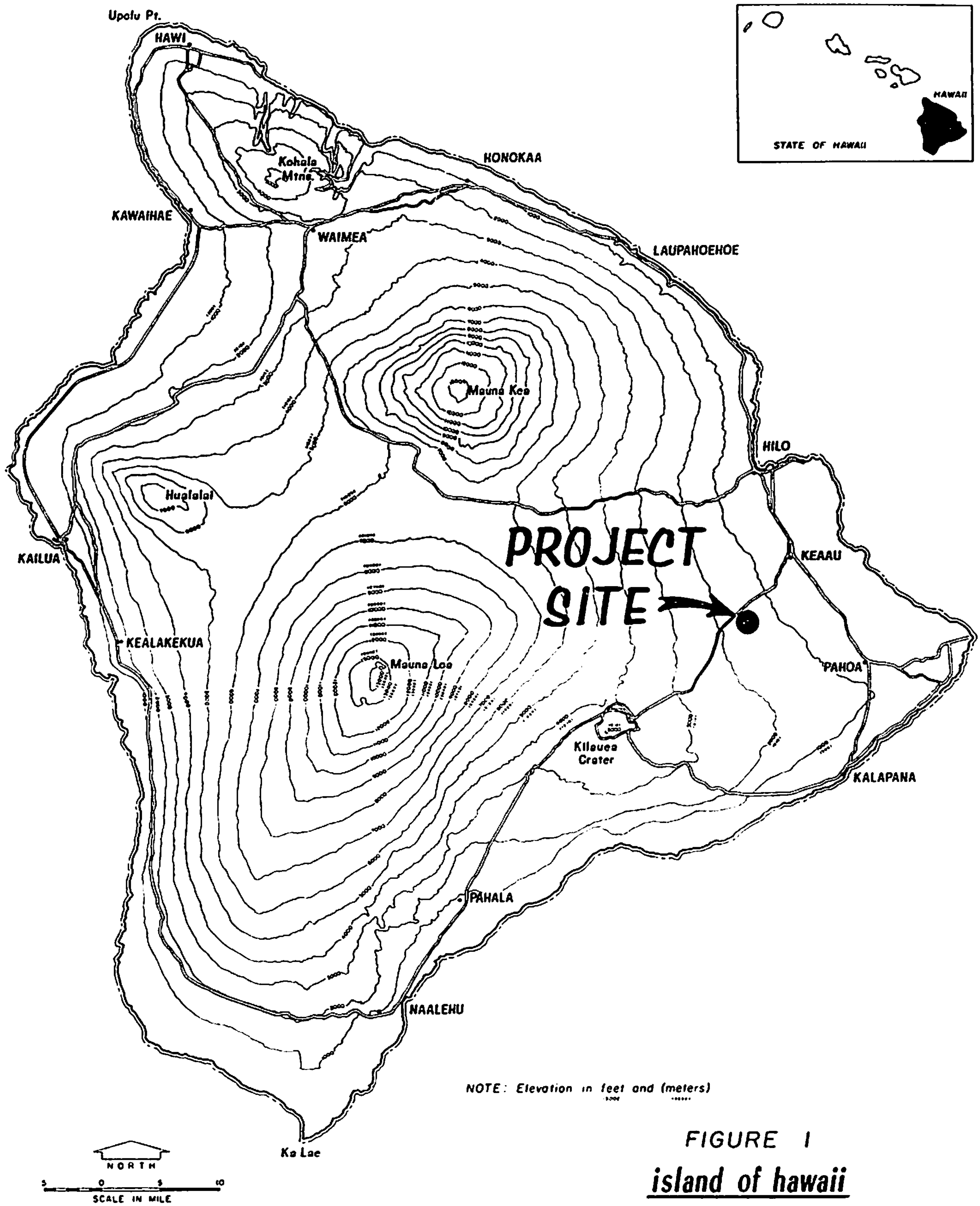
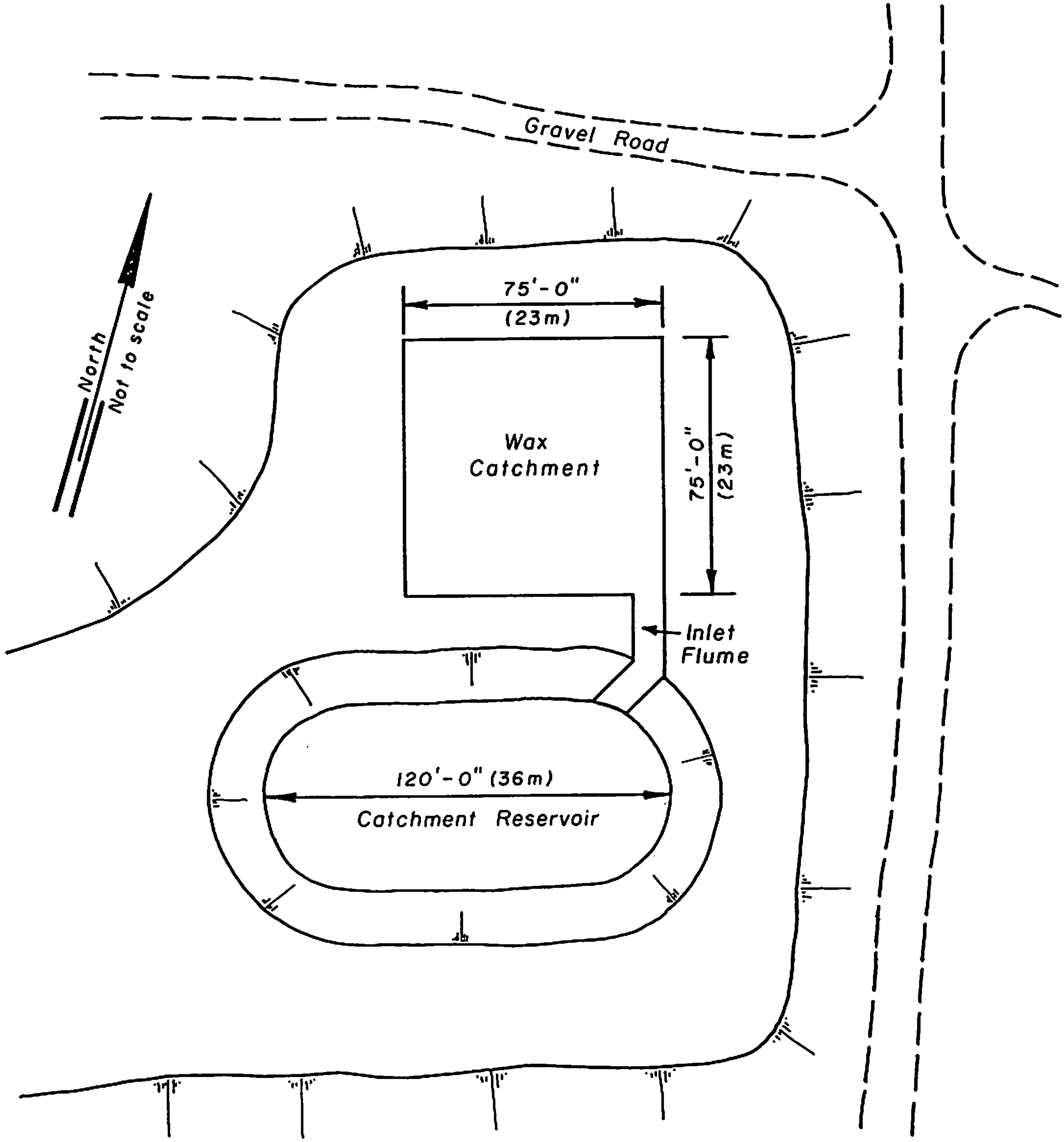


FIGURE I

island of hawaii

LOCATION MAP



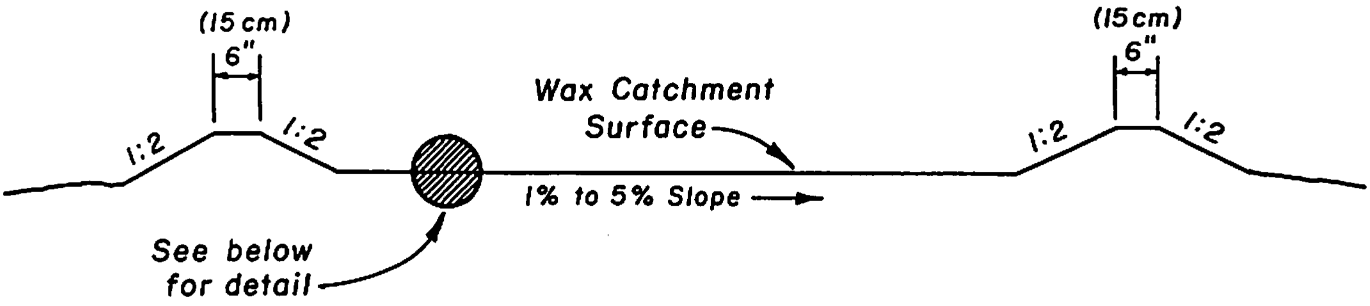
PLOT PLAN

NOT TO SCALE

FIGURE 2

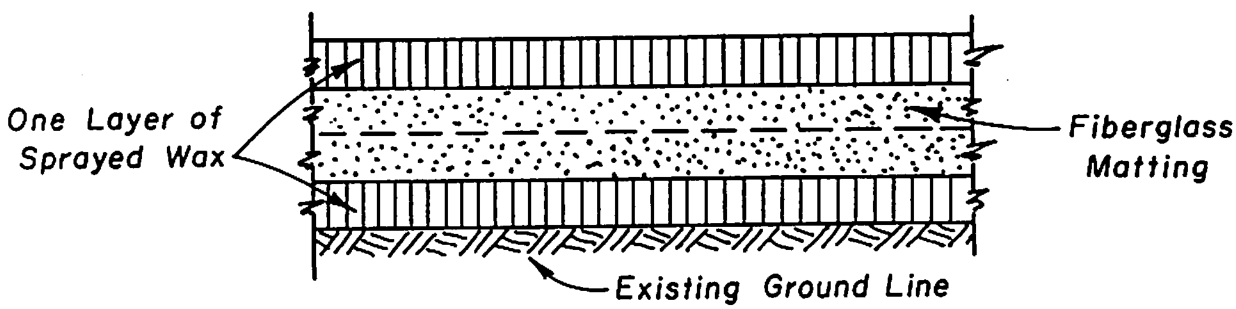
Test Installation Details

SHT. 1 OF 2



WAX CATCHMENT PROFILE

NOT TO SCALE



WAX CATCHMENT DETAIL

NOT TO SCALE

FIGURE 3

Test Installation Details

SHT. 2 OF 2

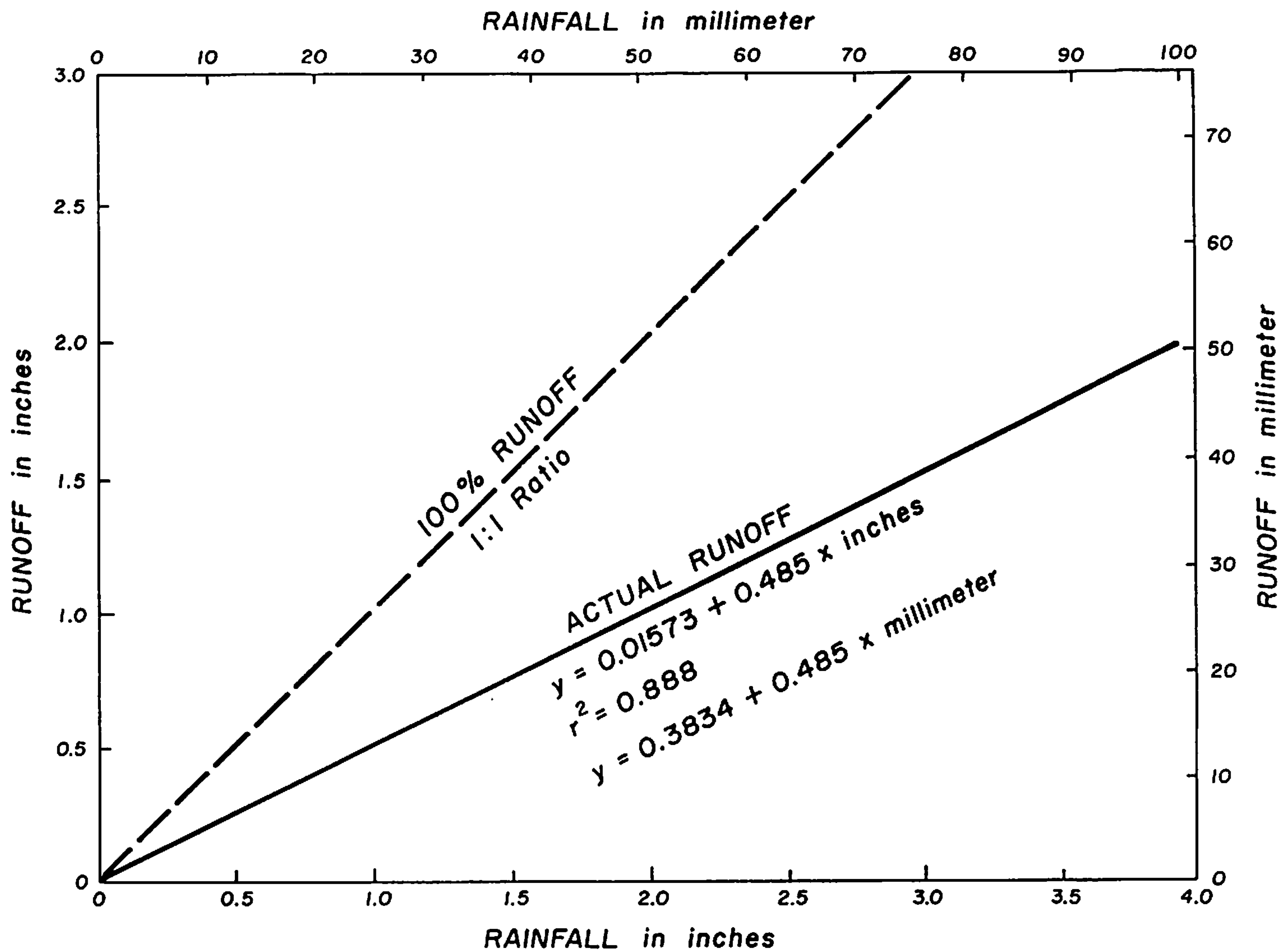
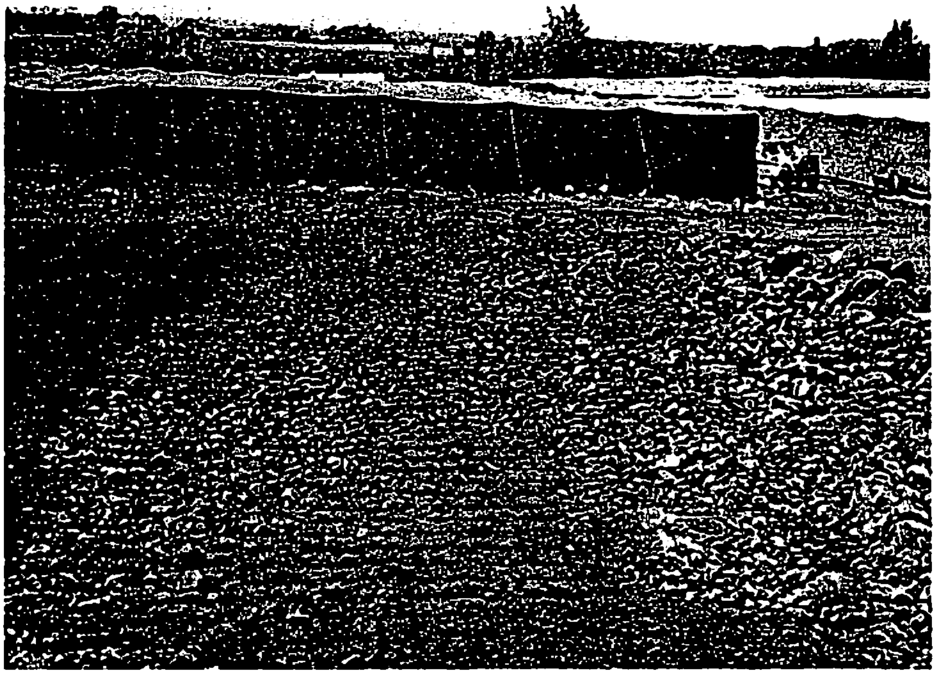
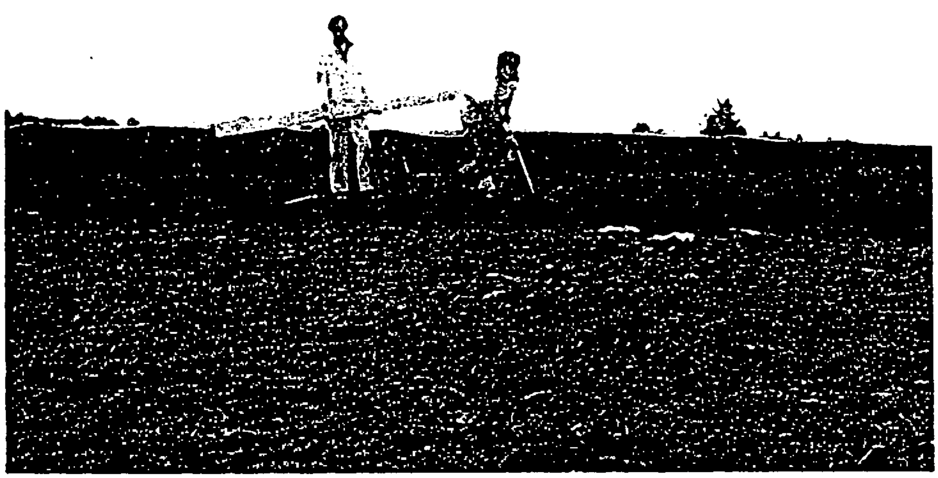


FIGURE 4

Rainfall - Runoff Relationship

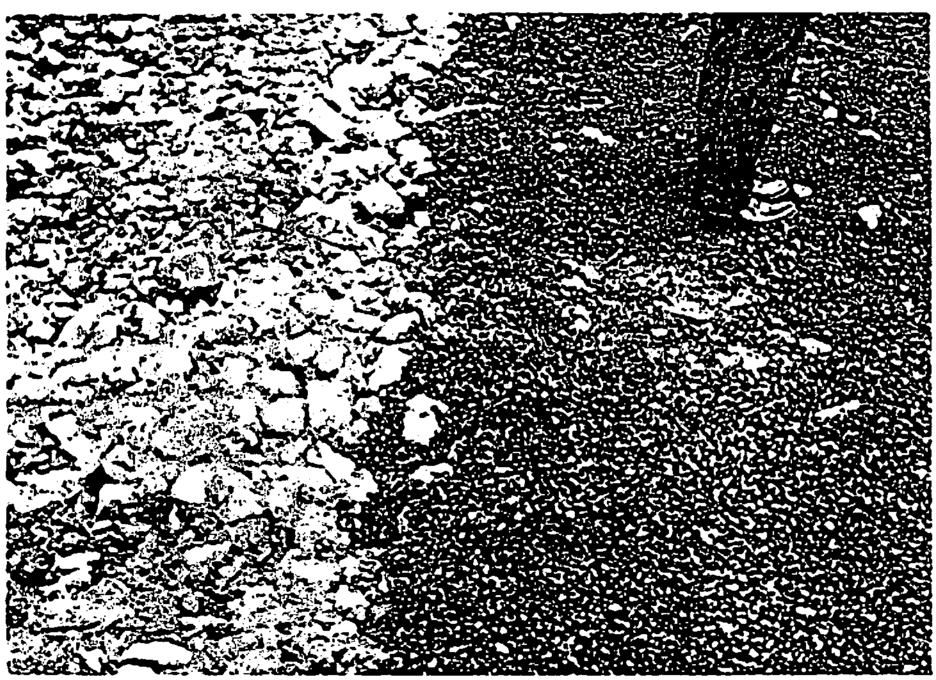


1a. Catchment pad before covering.

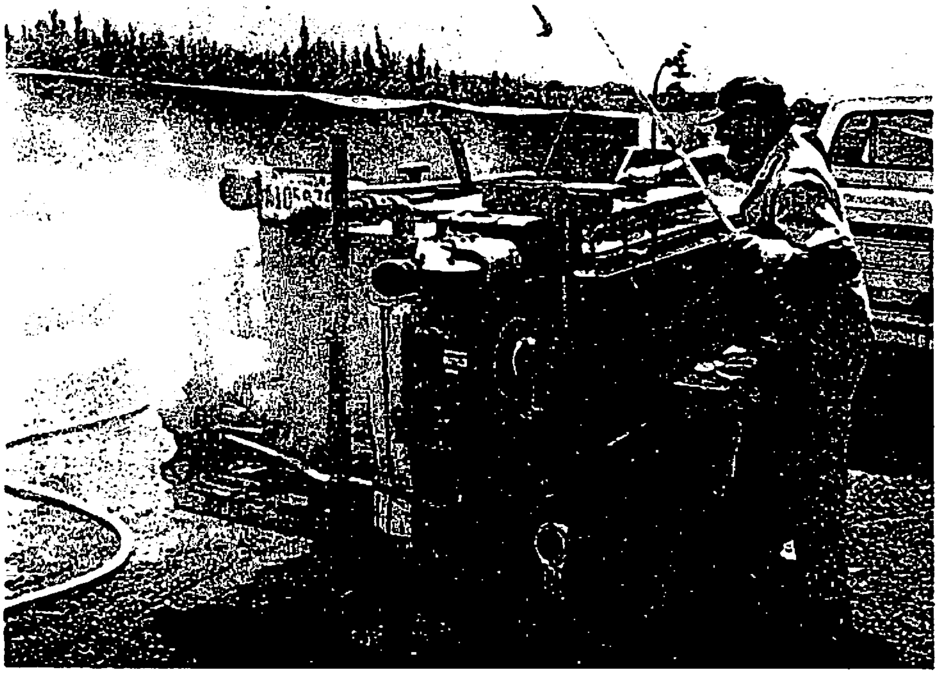


1b. Spreading cinder base.

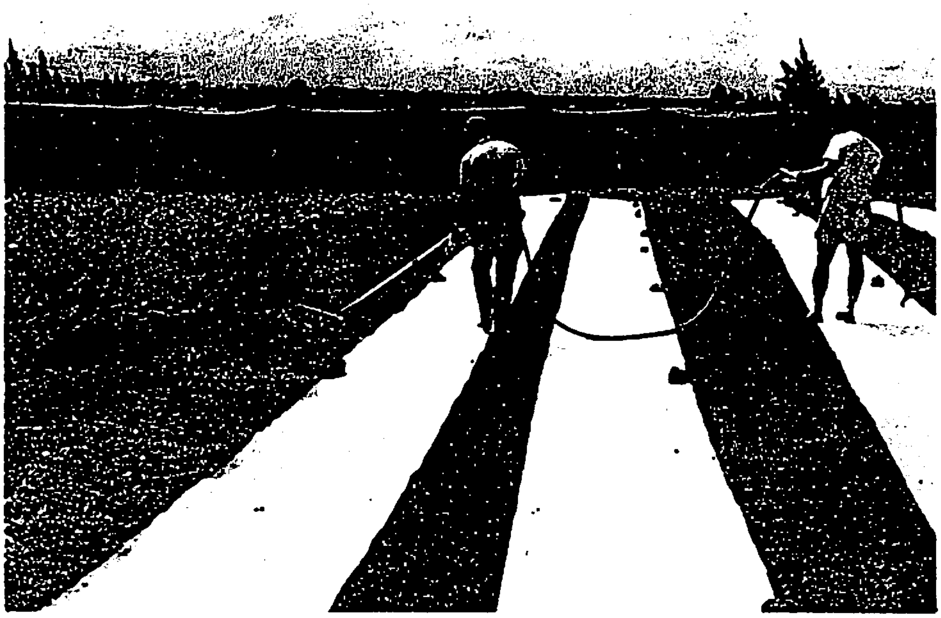
1c. Smoothing and leveling of cinder base.



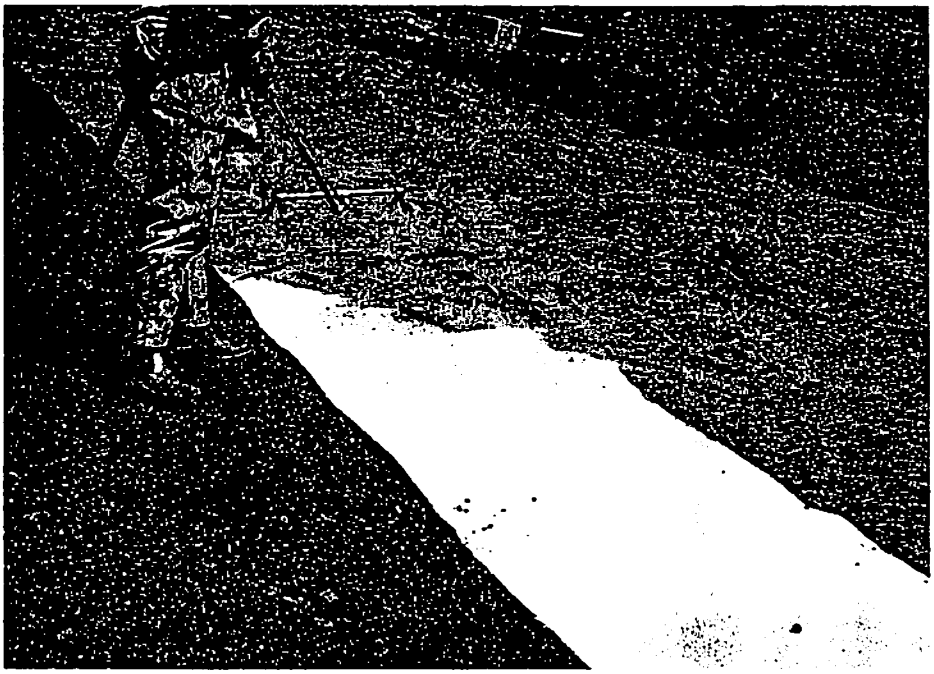
1d. Finished cinder base.



2. Heating and spraying equipment.

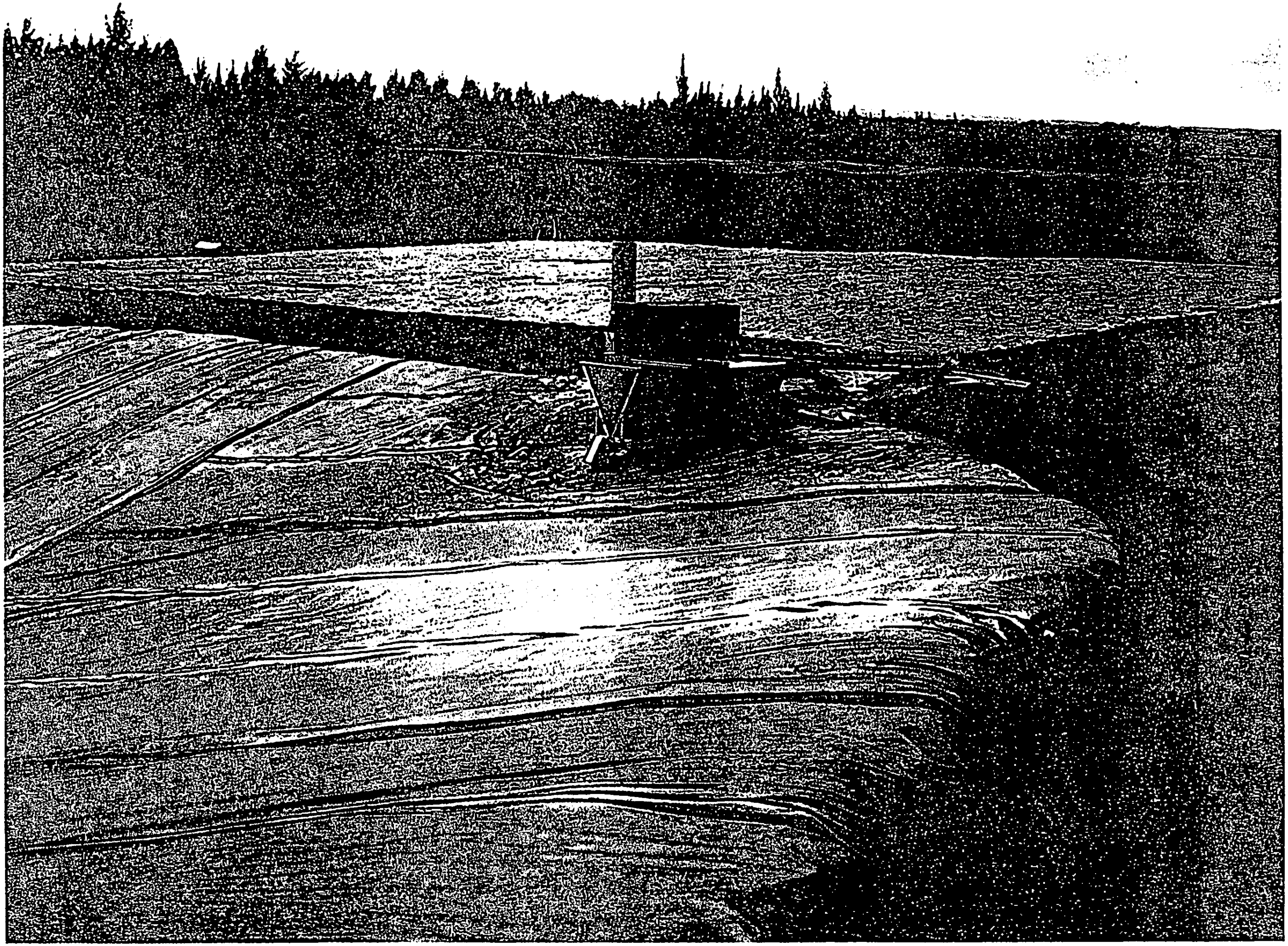


3. Spraying first layer of melted wax before laying fiberglass matting.



4a. Spraying second layer of melted wax on fiberglass.

4b. Finished catchment surface.



5. Finished catchment and water measuring flume at storage reservoir inlet.

Table 1. Results of the total and fecal coliform analysis of water from the butyl-lined reservoir at the test site.

	Multiple-tube Fermentation			Membrane Filter	
Sample Date	Sample Size	Tubes with positive reactions	Total Coliform	Total Coliform	Fecal Coliform
	(ml)	(No.)	(MPN/100 ml)[a]	(Colonies/100 ml)	(MPN)
7 Nov 77	10	2/5	5	<1	<1
14 Nov 77	10	2/5-3/5	5-9	<1	<1
21 Nov 77	10	4/5-5/5	>16	37-22	<1
5 Dec 77	10	1/5-3/5	2-9	<1	<1
12 Dec 77	10	4/5-5/5	>16	12-10	<1
19 Dec 77	10	4/5-5/5	>16	20-11	<1
9 Jan 78	10	1/5-2/5	2-5	<1	0/5
16 Jan 78	10,1,.1		49-13	TNTC[b] w/Coliform	2
23 Jan 78	10	0/5	<2	<1	0/5
6 Feb 78	10	0/5-2/5	<2-5	7-6	0/5
13 Feb 78	10,1,.1		13	1	<2
27 Feb 78	10,1,.1		22	28	<2
6 Mar 78	10,1,.1		17	<1	<2
13 Mar 78	10,1,.1		49	21	<2
20 Mar 78	10,1,.1		11	<1	<2
3 Apr 78	10,1,.1		2	1	<2
10 Apr 78	10,1,.1		17	4	<2
24 Apr 78	10,1,.1		8	13	2
1 May 78	10,1,.1		33	TNTC w/Coliform	<2
8 May 77	10,1,.1		22	TNTC w/Coliform	2
22 May 77	10,1,.1		5	TNTC w/Coliform	2

[a]Most Probable Number (MPN) per 100 ml.

[b]Too numerous to count.

Table 1. (Continued)

	Multiple-tube Fermentation			Membrane Filter	
Sample Date	Sample Size (ml)	Tubes with positive reactions (No.)	Total Coliform (MPN/100 ml)	Total Coliform (Colonies/100 ml)	Fecal Coliform (MPN)
5 Jun 77	10,1,.1		5	TNTC w/Coliform	<2
19 Jun 77	10		46	TNTC w/Coliform	8
26 Jun 77	10		31	TNTC w/Coliform	<2
10 Jul 77	10,1,.1		49	TNTC w/Coliform	2
17 Jul 77	10,1,.1		11	5	2
24 Jul 77	10,1,.1		33	5	<2
7 Aug 77	10,1,.1		140	21	5
14 Aug 77	10,1,.1		350	TNTC w/Coliform	17
24 Aug 77	10,1,.1		280	32	23
11 Sep 77	10,1,.1		7	<1	<2
18 Sep 777	10,1,.1		45	TNTC w/Coliform	<2

Table 2. Results of the total and recal coliform analysis of runoff water from the wax-fiberglass catchment.

	Multiple-tube Fermentation			Membrane Filter	
Sample Date	Sample Size (ml)	Tubes with positive reactions (No.)	Total Coliform (MPN/100 ml)	Total Coliform (Colonies/100 ml)	Fecal Coliform (MPN)
9 Jan 78	10	5/5	>16	Confluent w/Coliform	2/5
16 Jan 78	No Sample				
23 Jan 78	No Sample				
6 Feb 78	No Sample				
13 Feb 78			2	<1	<1
27 Feb 78	No Sample				
6 Mar 78	No Sample				
13 Mar 78	10,1,.1		220	76	<2
20 Mar 78	10,1,.1		350	TNTC w/Coliform	49
3 Apr 78	10,1,.1		49	TNTC w/Coliform	<4
10 Apr 78	10,1,.1		110	30	<2
24 Apr 78	10,1,.1		1600	TNTC w/Coliform	1600
1 May 78	10,1,.1		793	TNTC w/Coliform	<2
8 May 77	10,1,.1,.01		280	TNTC w/Coliform	2
22 May 77	10,1,.1		7	TNTC w/Coliform	<2
5 Jun 77	10,1,.1,01		11	Confluent w/o Coliform	<2
19 Jun 77	10		140	TNTC w/Coliform	<2
26 Jun 77	10		920	Confluent w/Coliform	<2

Table 2. (Continued)

	Multiple-tube Fermentation			Membrane Filter	
Sample Date	Sample Size (ml)	Tubes with positive reactions (No.)	Total Coliform (MPN/100 ml)	Total Coliform (Colonies/100 ml)	Fecal Coliform (MPN)
10 Jul 77	10,1,.1,.01		1700	TNTC w/Coliform	8
17 Jul 77	10,1,.1,.01		330	Confluent w/Coliform	2
24 Jul 77	10,1,.1,.01		180	Confluent w/Coliform	5
7 Aug 77	10,1,.1,.01		1400	Confluent w/Coliform	79
14 Aug 77	10,1,.1,01		790	Confluent w/Coliform	79
11 Sep 77	10,1,.1,.01		170	TNTC w/Coliform	11
18 Sep 77	10,1,.1,.01		16	TNTC w/Coliform	49

Table 3. Results of the total and fecal coliform analysis of runoff water from a greenhouse rooftop and stored in a butyl-lined reservoir.

	Multiple-tube Fermentation			Membrane Filter	
Sample Date	Sample Size (ml)	Tubes with positive reactions (No.)	Total Coliform (MPN/100 ml)	Total Coliform (Colonies/100 ml)	Fecal Coliform (MPN)
27 Feb 78	10,1,.1		17	29	2
6 Mar 78	10,1,.1		280	80	<2
13 Mar 78	10,1,.1		140	Confluent w/Coliform	<2
20 Mar 78	10,1,.1		170	TNTC w/Coliform	<2
3 Apr 78	10,1,.1		49	TNTC w/Coliform	2
3 Apr 78	10,1,.1		49	TNTC w/Coliform	2
10 Apr 78	10,1,.1		2400	Confluent w/Coliform	<2
24 Apr 78	10,1,.1		2400	Confluent w/Coliform	<2
1 May 78	10,1,.1,.01		110	Confluent w/Coliform	<2
8 May 78	10,1,.1,.01		170	Confluent w/Coliform	<2
22 May 78	10,1,.1		79	TNTC w/Coloform	<2
5 Jun 78	10,1,.1,.01		1700	Confluent w/Coliform	2
19 Jun 78	10		540	Confluent w/Coliform	<2
26 Jun 78	10		240	TNTC w/Coliform	<2
10 Jul 78	10,1,.1,.01		34	TNTC w/Coliform	<2
17 Jul 78			170	TNTC w/Coliform	<2

Table 3. (Continued)

	Multiple-tube Fermentation			Membrane Filter	
Sample Date	Sample Size (ml)	Tubes with positive reactions (No.)	Total Coliform (MPN/100 ml)	Total Coliform (Colonies/100 ml)	Fecal Coliform (MPN)
24 Jul 78	10,1,.1		2400	TNTC w/Coliform	<2
7 Aug 78	10,1,.1,.01		700	TNTC w/Coliform	130
14 Aug 78	10,1,.1,.01		1100	TNTC w/Coliform	5
24 Aug 78	10,1,.1,.01		350	Confluent w/Coliform	<2
11 Sep 78	10,1,.1,.01		180	TNTC w/Coliform	<2
18 Sep 78	10,1,.1,.01		220	Confluent w/Coliform	<2

Table 4. Results of the total and fecal coliform analysis of water from a residential rooftop catchment.

	Multiple-tube Fermentation			Membrane Filter	
Sample Date	Sample Size (ml)	Tubes with positive reactions (No.)	Total Coliform (MPN/100 ml)	Total Coliform (Colonies/100 ml)	Fecal Coliform (MPN)
3 Apr 78	10,1,.1		<2	<1	<2
10 Apr 78	10,1,.1		4	1	<2
24 Apr 78	10,1,.1		2	Conflutent w/Coliform	<2
1 May 78	10,1,.1		5	Confluent w/Coliform	<2
8 May 78	10,1,.1		7	TNTC w/Coliform	<2
22 May 78	10,1,.1		<2	<1	<2
5 Jun 78	10,1,.1		13	6	<2
19 Jun 78	10		49	41	<2
26 Jun 78	10		95	<1	<2
10 Jul 78	10,1,.1		4	4	<2
17 Jul 78	10,1,.1		2	1	<2
24 Jul 78	10,1,.1		17	5	<2
7 Aug 78			2	4	<2
14 Aug 78	10,1,.1		2	<1	<2
24 Aug 78	10,1,.1		2	<1	<2
11 Sep 78	10,1,.1		8	3	<2
18 Sep 78	10,1,.1		2	Confluent w/Coliform	<2

Table 5. Results of the inorganic elements analysis of water samples collected from the butyl-lined reservoir at the test site, butyl-lined reservoir from a greenhouse roof, a residential galvanized rooftop, and a well in the Hawaii County water system.

PARAMETERS	U.S. P.H.S. DRINKING WATER STANDARDS (mg/liter)	BUTYL-LINED RESERVPOR AT TEST SITE		GREENHOUSE ROOF RESERVOIR		GALV. ROOF CATCHMENT		MUNICIPAL WATER SUPPLY WELL	
		(10/10/78) (mg/liter)	(12/26/78) (mg/liter)	(10/10/78) (mg/liter)	(12/26/78) (mg/liter)	(10/10/78) (mg/liter)	(12/26/78) (mg/liter)	(10/10/78) (mg/liter)	(12/26/78) (mg/liter)
Arsenic	.05	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02
Barium	1.00	<.8	<.8	<.8	<.8	<.8	<.8	<.8	<.8
Cadium	.01	<.008	<.005	<.008	<.005	<.008	<.005	<.008	<.005
Chromium	.05	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Lead	.05	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Mercury	.002	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005
Nitrates	10.00	<.05	<.05	<.05	<.05	.07	<.05	.34	.49
Selenium	.01	<.008	<.01	<.008	<.01	<.008	<.01	<.008	<.01
Silver	.05	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03
Iron	.3	<.005	<.5	.010	<.5	.010	<.5	.073	<.5
Magnesium	.05	N.D.[1]	<.3	N.D.	.3	N.D.	.3	2.2	2.3
Zinc	.15	.13	<.5	.11	<.5	.20	1.0	.05	<.5
Calcium		N.D.	<.5	N.D.	<.5	N.D.	<.5	5.8	4.9
Potassium		N.D.	<.3	N.D.	<.3	N.D.	<.3	N.D.	1.8
Sodium		3.0	2.2	3.3	2.8	3.0	3.0	6.1	6.4

1/ Not detected.

Table 6. Rainfall/runoff from the wax-fiberglass catchment for 1977.

Date	Rainfall		Runoff	
(1977)	(in)	(mm)	(in)	(mm)
23 Sep	.22	5.6	.20	5.1
24 Sep	.08	2.0	.06	1.5
25 Sep	.04	1.0	.05	1.3
28 Sep	.51	13.0	.22	5.6
1 Oct	.44	11.2	.19	4.8
1-2 Oct	1.38	35.1	.62	15.7
3 Oct	.07	1.8	.05	1.3
3 Oct	.38	9.7	.16	4.1
4 Oct	.05	1.3	.06	1.5
4 Oct	.27	6.9	.16	4.1
5 Oct	.07	1.8	.08	2.0
27-28 Oct	.46	11.7	.26	6.6
28-29 Oct	.37	9.4	.28	7.1
29 Oct	.35	8.9	.31	7.9
30 Oct	.78	19.8	.39	9.9
31 Oct	.25	6.4	.12	3.0
1 Nov	.06	1.5	.05	1.3
1-2 Nov	.82	20.8	.54	13.7
2-4 Nov	1.57	39.9	1.02	25.9
5 Nov	.09	2.3	.07	1.8
12 Nov	.15	3.8	.08	2.0
12 Nov	.23	5.8	.16	4.1
13 Nov	.15	3.8	.08	2.0
13 Nov	.27	6.9	.16	4.1
13-14 Nov	.35	8.9	.14	3.6
14-15 Nov	.37	9.4	.31	7.9
15.16 Nov	.59	15.0	.36	9.1
16 Nov	1.68	42.7	.79	20.1
17 Nov	.42	10.7	.21	5.3
29 Nov	.17	4.3	.13	3.3
16 Dec	.14	3.6	.06	1.5
16-17 Dec	.92	23.4	.55	14.0
17 Dec	.14	3.6	.08	2.0
18 Dec	.93	23.6	.49	12.4
18-19 Dec	.81	20.6	.52	13.2
22 Dec	.12	3.0	.16	4.1
28 Dec	.39	9.9	.40	10.2
28 Dec	.08	2.0	.09	2.3

Table 7. Rainfall/runoff from the wax-fiberglass catchment for 1977.

Date	Rainfall		Runoff		Date	Rainfall		Runoff	
(1977)	(in)	(mm)	(in)	(mm)	(1977)	(in)	(mm)	(in)	(mm)
1 Jan	.29	7.4	.18	4.6	9 Jun	.15	3.8	.06	1.5
3 Jan	.17	4.3	.20	5.1	12 Jun	.42	10.7	.18	4.6
26 Jan	.95	24.3	.54	13.7	13 Jun	.21	5.3	.22	5.6
28 Jan	.12	3.0	.11	2.8	14 Jun	.45	11.4	.19	4.8
9 Feb	.30	7.6	.22	5.6	15 Jun	.19	4.8	.16	4.1
14 Feb	.76	19.3	.46	11.7	16 Jun	.60	15.2	.21	5.3
15 Feb	.34	8.6	.17	14.3	17 Jun	.55	14.0	.16	4.1
16 Feb	.06	1.5	.02	0.5	18 Jun	.44	11.2	.19	4.8
20 Feb	.08	2.0	.03	0.8	19 Jun	3.37	85.6	1.32	33.5
23 Feb	.55	14.0	.30	7.6	19 Jun	.14	3.6	.08	2.0
27 Feb	.21	5.3	.08	2.0	22 Jun	.56	14.2	.24	6.1
24 Mar	.23	5.8	.10	2.5	23 Jun	1.89	48.0	1.38	35.1
26 Mar	.21	5.3	.18	4.6	30 Jun	.23	5.8	.18	4.6
7 Apr	3.07	78.0	1.17	29.7	1 Jul	.05	1.3	.02	0.5
7 Apr	.14	3.6	.07	1.8	2 Jul	.22	5.6	.15	3.8
9 Apr	.33	8.4	.12	3.0	2 Jul	.21	5.3	.09	2.3
14 Apr	.18	4.6	.18	4.6	4 Jul	1.76	44.7	.65	16.5
15 Apr	.15	3.8	.04	1.0	4 Jul	.16	4.1	.10	2.4
15 Apr	.49	12.4	.19	4.8	6 Jul	3.77	95.8	2.32	58.9
16 Apr	.35	8.9	.15	3.8	8 Jul	.81	20.6	.31	7.0
21 Apr	.57	14.5	.22	15.6	9 Jul	.59	15.0	.16	4.1
26 Apr	.38	9.7	.10	2,4	11 Jul	.60	15.2	.25	6.4
30 Apr	.25	6.4	.17	4.3	12 Jul	.56	14.2	.50	12.7
1 May	.51	13.0	.19	4.8	16 Jul	.07	1.8	.06	1.5
2 May	.54	13.7	.29	7.4	22 Jul	.30	7.6	.09	2.3
3 May	.26	6.6	.16	4.1	25 Jul	.26	6.6	.16	4.1
11 May	.41	10.4	.17	4.3	26 Jul	.25	6.4	.12	3.0
11 May	.07	1.8	.05	1.3	28 Jul	.44	11.2	.23	5.8
13 May	.28	7.1	.20	5.1	30 Jul	1.39	35.3	.52	13.2
14 May	.32	8.1	.15	3.8	30 Jul	.80	20.3	.22	5.6
16 May	.86	21.8	.51	13.0	31 Jul	.50	12.7	.18	4.6
17 May	.26	6.6	.20	5.1	1 Aug	.09	2.3	.05	1.3
19 May	.25	6.4	.08	2.0	4 Aug	.35	8.9	.15	3.8
24 May	.57	14.5	.27	6.0	5 Aug	.29	7.4	.10	2.4
26 May	.67	17.0	.32	8.1	5 Aug	.22	5.6	.11	2.8
28 May	1.41	35.8	.64	16.3	7 Aug	.36	9.1	.10	2.4
30 May	.69	17.5	.29	7.4	7 Aug	1.22	31.0	.65	16.5
30 May	.31	7.9	.12	3.0	11 Aug	.46	11.7	.33	8.4
7 Jun	.38	9.7	.13	3.3	11 Aug	.11	2.8	.10	2.4
7 Jun	.25	6.4	.08	2.0	12 Aug	.39	9.9	.13	3.3
					14 Aug	.17	4.3	.06	1.5
					15 Aug	.40	10.2	.19	4.8

HISTORY OF THE DEVELOPMENT OF WATER HARVESTING IN THE HAWAIIAN ISLANDS

by

Gary Frasier and Wayne Williamson[1]

APPENDIX

Introduction

Water resources in the State of Hawaii are primarily derived from precipitation. However, unlike many parts of the world, Hawaii's water supply problems are not caused by a general shortage of precipitation. Instead, they result from temporal and spatial variabilities in the rainfall distribution and insufficient numbers of water storage facilities. Some parts of the islands are classified as desert with less than 200-mm annual rainfall, while other nearby areas a few miles distant receive some of the largest quantities of precipitation in the world, often exceeding 10,000-mm per year. The rainfall distribution, combined with the mountainous topography and relatively porous soils, makes development of Hawaii's water resources both difficult and costly.

The early Hawaiians started the development of the water resources by constructing simple ditches to bring runoff water from the wetter areas of the islands to irrigate small patches of land for growing taro. With the arrival of the "haole" settlers, more extensive collection and conveyance ditches were constructed to increase the water supplies for a more diversified agriculture. This system supplies sufficient water to meet the needs of several years.

In the early 1880's, the farmers realized that seepage losses were significant from the unlined ditches and small holding reservoirs. To meet the water

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demands of the expanding population, industry, and agriculture, it became necessary to efficiently utilize the existing water supplies and to develop new water sources.

About 1900, various methods of reducing seepage losses from the unlined ditches and reservoirs were tried in an attempt to conserve the existing water supplies. Some of the initial methods consisted of spraying the soil with an "oil" coating or using a pressed "mud" lining. Other membrane linings consisted of materials such as asphalt-impregnated felt planking, asphaltic concrete, sand plaster with poultry wire reinforcement, and exposed or buried asphaltic barriers. These water conservation methods sufficiently extended the existing water supplies to meet the needs for several more years. By 1940, a new water supply method, "water-harvesting," began to receive considerable interest for supplying water to livestock.

Water-Harvesting and Seepage Control

Water-harvesting is the process of collecting and storing natural precipitation from prepared watersheds for beneficial use. Harvesting precipitation from prepared areas, such as collecting water from the roofs of buildings for household use, had been used for many years in other parts of the world. The concepts of water-harvesting were especially attractive and feasible for the Hawaiian Islands because of the many areas which receive high annual precipitation. Large quantities of good quality water could be obtained by covering or treating small areas of land to produce essentially 100% runoff efficiency. Water-harvesting basically consists of two operations -- collecting precipitation runoff, and storing the collected water until time of need.

Initially, water-harvesting systems if Hawaii were developed to supply drinking water for various types of livestock, and consisted of sloping sheet-metal roof catchments and wooden or metal water storage tanks located directly underneath. The roofs shaded the water surface and reduced evaporation losses. Later, similar sheet-metal roof-type catchments were constructed on the ground, and the water was carried downslope in pipes or channels to the water storage tank. Another early-type catchment consisted of spreading fine cinders on the soil surface and spraying them with an asphalt emulsion. A second similar layer was applied and rolled into a compact, dense covering. These catchments were relatively expensive, but were successful for livestock water. In 1959, the potential of this type of catchment for water-harvesting was evaluated near Holualoa Kona. The rainfall runoff from an experimental catchment, made by spraying hot mix asphalt directly onto the soil, was measured for three years. Even with the limited guidelines for design and construction, the results indicated that catchments did offer a solution to the problem of obtaining water supplies in areas where there were no perennial streams and where groundwater sources were too expensive to develop.

By the early 1950's, lightweight and relatively inexpensive thin plastic films or sheetings had become available, and showed considerable promise for water-harvesting and seepage control. Special care was required during preparation of the subgrade to remove any sharp objects, such as sticks or stones, which might tear or puncture the film during lining installation. Some of the plastics also had poor resistance to deterioration by sunlight. To reduce further mechanical damage and chemical deterioration in reservoir linings, a graded or screened soil cover was placed over the linings. This limited the shapes of ponds and reservoirs suitable for treatment to ones with relatively flat sideslopes; otherwise, the soil cover would gradually slide to the bottom. Other problems, such as plant growth on the soil cover, difficulty in placing the soil cover without damaging the plactic, and making water-tight seams, all

all tended to limit the use of plastic sheetings for seepage control. For water-harvesting, the plastic sheetings were placed directly on the soil surface. To reduce potential wind damage, woven wire fencing was placed on top of the plastic and held in place with sandbag weights. Even when weighted, wind would cause the sheeting to vibrate and cause small holes to wear through the plastic. On several catchments, wind penetrated under the sheeting and completely lifted the plastic, wire, and weights from the soil surface, destroying the catchment.

In the 1960's, synthetic rubber sheetings (butyl) became available for water-storage liners. The rubber sheetings were considerably stronger and more durable than the plastic films, and were sufficiently light-weight, weather resistant, and easily installed with adhesive-sealed water-tight seams. Many reservoirs were successfullfy lined with butyl in Hawaii for a variety of uses, including irrigation, stock water, industrial, and household. The most impressive lined reservoir, covering 42 hectares (104 acres) on the island of Molokai, has a storage capacity of over 5.3 billion liters of water. Water from this reservoir has permitted several industries and businesses to develop which would not have been possible without an adequate water supply.

With the introduction of artificial rubber membranes for reservoir linings, users soon found that a simple catchment could be constructed by extending the lining upslope for a water-collection area. During the past 15 years, this type of combination catchment and storage has been successfully used in many places in Hawaii.

Problems were encountered with wind uplift, materials sliding downslope, and poor quality butyl sheeting. Cooperative studies in Hawaii and on the mainland between federal research agencies, industry, and users led to the incorporation of a reinforcing fabric within the butyl sheeting for added strength to control sheeting elongation, and to improve the weathering performance of the rubber compounds.

Research by state and federal agencies is continuing in cooperation with local industries to develop other lower-cost methods of controlling or stopping seepage losses from ponds and reservoirs. These methods include new types of laid-in-place asphalt fiberglass or asphalt polypropylene-reinforced linings and various types of chemical agents which can be applied directly to the soil. Hopefully, these methods will expand the locations where seepage control methods can be used effectively.

Water-harvesting research is also continuing in an attempt to develop additional methods and materials which can be used to treat Hawaii's volcanic cinders and soils to provide water which will meet the current Environmental Protection Agency's requirement for potable water. The goals of these studies are to insure that Hawaii will always have a dependable supply of good quality water for all future needs.

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